An investigation into the effectiveness of core muscle strengthening on cycling performance in asymptomatic cyclists

By

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I, Kate Wiseman, do declare that this dissertation is representative of my own work in both conception and execution.

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DEDICATION

It is with immense pleasure that I dedicate this dissertation to my parents, Dave and Sally. Thank you for your endless encouragement, love and support. Your positivity and understanding during my studies kept me motivated and gave me confidence when I needed it most.

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ABSTRACT

Background:

Core strengthening may improve athletic ability by providing stability to the trunk, and as a result, stabilising the pelvis. The leverage from which cyclists generate power may be enhanced as a result of a stable pelvis, thereby improving the cyclist's performance. In the popular, highly competitive sport of cycling, performance enhancement is much sought after. Despite its widespread use, research involving core strengthening in sporting situations is lacking, with studies investigating the effect of a core strengthening programme on cycling performance yet to be investigated.

Objectives:

To determine the participants' cycling speed, power, cadence and completion time, and core strength in terms of objective findings, pre- and post- core strengthening intervention, in the whole sample and within the two age strata. To determine the participants' heart rate in terms of objective findings, and the rate of perceived exertion in terms of subjective findings, pre- and post- core strengthening intervention, in the whole sample and within the two age strata. To determine the participants' perception of change in speed, power and cadence post- intervention, in the whole sample and within the two age strata.

Method:

Forty-two asymptomatic cyclists performed two 1.5 km time trials, pre- and post- core strengthening intervention. Core strength assessments were performed pre- and post- intervention, using the Pressure Biofeedback Unit, and the maximum and average speed (km/hr), power (w) and cadence (rpm), and completion time (s) were recorded pre- and post- intervention, using the Computerised Electromagnetic Roller resistance Ergometer (Tacx Trainer). Heart rate and rate of perceived exertion (RPE) were recorded pre- and post- intervention, as well as the participant's perception of change in speed, power, and cadence post- intervention. SPSS version 20 (SPSS Inc) was used to analyse the data, in the whole sample and stratified into two age strata.

Results:

All cycling performance indicators, speed, power, cadence and completion time showed a significant improvement post- intervention, in the whole sample, and within the two age strata. Core strength indicators showed a significant improvement post- intervention, in the whole sample and within the two age strata. A significant decrease in rate of perceived exertion and corresponding heart rate measurements post- intervention was observed in the whole sample. Similarly, the younger age strata reflected a significant decrease in rate of perceived exertion, however heart rate measurements were not significant. In contrast, the older age strata showed significant changes in heart rate measurements, with no significance in rate of perceived exertion measurements. The majority of participants experienced an increased perception in all outcomes post- intervention.

Conclusions:

The results of this study found that core strengthening had a statistically significant effect (p < 0.001) on cycling performance, both in terms of objective and subjective findings. Future studies could address the effect of core strengthening in an endurance setting.

Keywords:

Core muscle strengthening, cycling performance, Pressure Biofeedback Unit (PBU), computerised electromagnetic roller resistance ergometer (Tacx Trainer).

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LIST OF ABBREVIATIONS

Ave:	average
BDC:	bottom dead centre
BMI:	body mass index
bpm:	beats per minute
cm:	centimetres
HR:	heart rate
kg:	kilograms
km:	kilometres
km/h:	kilometres per hour
m:	metres
Max:	maximum
min:	minutes
MTB:	mountain bicycle
***n*:**	sample number
***p*:**	probability
PBU:	Pressure Biofeedback Unit
%:	Percentage
RPE:	Rate of Perceived Exertion
rpm:	revolutions per minute
s:	seconds
SD:	standard deviation
TA:	transversus abdominis
Tacx:	Tacx Fortius Virtual Reality Trainer
TDC:	top dead centre
TT1:	time trial one
TT2:	time trial two
VO_2:	oxygen uptake
w:	watts

GLOSSARY OF TERMS

Aerodynamics:

The science of air in motion, and the body's reaction to movement in air (Beneke, Beneke, Noakes and Reynolds, 1989).

Amateur cyclist:

One who rides a bicycle as a recreational or competitive activity, rather than as a profession (http://www.merriam-webster.com/dictionary/amateur).

Asymptomatic:

Without symptoms, or presenting with no symptoms of disease (http://www.merriam-webster.com/medical/asymptomatic).

Biarticular:

Relating to two joints ((http://www.merriam-webster.com/medical/biarticular).

Bottom bracket:

The main bearing unit at the bottom of the frame, responsible for supporting the crankset (Liggett, 1992).

Bicycle setup:

Adjustments made to the bicycle to provide the most efficient and comfortable position for the cyclist on the bicycle, specific to each individual (Burke, 2003).

Cadence:

The speed at which the pedals are turned, measured in revolutions per minute (rpm) (Beneke *et al*., 1989).

Chain:

A series of joined links, connecting the chain ring and cogs, allowing pedalling to propel the bicycle forward (Downs, 2010).

Cassette:

Also referred to as the cluster, is an assembly of gears attached to the rear hub (Liggett, 1992).

Core Strength:

The muscular control around the lumbar spine that is required to maintain functional stability (Akuthota and Nadler, 2004).

Cycling efficiency:

Efficiency is a ratio of energy expenditure to work accomplished (Burke, 2003). The ratio of energy expenditure to work done, as determined by the power produced for the energy expended and oxygen consumed (Faria, Parker and Faria, 2005b; Burke, 2003).

Derailleur:

Mechanism working in conjunction with the gear levers, allowing for the selection of gears through movement of the chain from one cog to another (Downs, 2010).

Drive train:

Also referred to as the transmission system, consists of the pedals, chain, cassette, and derailleurs. The drive train functions in translating human power into forward movement (Downs, 2010; Beneke *et al*., 1989)

Dynamic load:

The forces that change or move depending on the structure acted upon (Parker, 2003).

Elite cyclist:

Elite cyclists are defined as those cyclists that are in the best of their class (http://www.merriam-webster.com/dictionary/elite). For the purposes of this study, this included cyclists regularly finishing in the top ten percent of the race finishers.

Frame geometry:

Determined by the angles and lengths of the tubes of the frame, dependent on the type of bicycle specific to a cycling discipline (Downs, 2010; Beneke *et al*., 1989).

Hub:

Located in the centre of the wheel, the hub houses the axle and bearings on which the wheels turn. The hub also provides the foundation of the wheelset, anchoring the spokes that attach to the rims (Downs, 2010).

Kinematic chain:

The kinematic chain is defined as a complex unit comprised of numerous successfully arranged joints (Bergmann and Peterson, 2002). The core musculature is considered to be the centre of the functional kinematic chain (Akuthota and Nadler, 2004).

Mountain bicycle:

Bicycle designed for off road riding, with upright handlebars, wide knobbly tyres and a wide selection of gears (Downs, 2010; Burke 2003).

Pedal stroke:

A complete circular movement of the pedals around the bottom bracket (Asplund and St Pierre, 2004).

Power:

The rate at which work is performed, or work performed per unit of time. Measured in watts (w) (Powers and Howley, 1997).

Professional cyclist:

A cyclist who receives monetary compensation for participation in cycling events, and often trains under a coaching and management team (Liggett, 1992; LeMond and Gordis, 1990).

Road bicycle:

A lightweight, slim frame bicycle, with smooth thin tyres, and drop handlebars (Downs, 2010; Beneke *et al*., 1989).

Rolling resistance:

Resistance of the wheels, directly dependent on the area of contact between the tyre and the road, and proportional to the weight supported by the wheel (Burke, 2003; Beneke *et al.*, 1989).

Rotary bias:

Lack of rotary control and stability of the pelvis (Richardson, Jull, Hodges and Hides, 1999).

Seat tube:

Frame tube that extends from the seat to the bottom bracket (Downs, 2010; Beneke *et al*., 1989).

Speed:

Distance travelled per unit of time. Measure in kilometres per hour (km/h) (Faria, Parker and Faria, 2005b; Powers and Howley, 1997)

Spoke:

A solid wire attaching the hub to the rim, of varying number dependent on the type of bike and wheel (Beneke *et al*., 1989)

Static load:

Also referred to as a dead or non-varying load, static load is the effect of gravity on an object at rest (Parker, 2003).

Time Trial:

An individual race against the clock, where the cyclist completes a course in the fastest possible time (Beneke *et al*., 1989).

Track bicycle:

Containing no brakes and only a single fixed gear, track bicycles are rigid and short, maximising the acceleration capabilities for sprinting (Beneke *et al*., 1989).

Wheelset:

The assembly of the tyre, rim, spokes, and hub (Beneke *et al*., 1989).

CHAPTER ONE

INTRODUCTION

1.1 Introduction to the Study

As well as being a global method of transportation, cycling has become a popular recreational sport and fitness activity, with the competitive nature of cycling as a sport continuing to grow increasingly popular (Faria, Parker, and Faria, 2005a). Cycling South Africa membership statistics (Duncan 2012) are represented in Table 1.1 below:

Table 1.1 Cycling Statistics for South Africa and Kwa-Zulu Natal

	South Africa	**Kwa-Zulu Natal**
Road Cycling	16 132	2 321
Mountain Biking	13 909	3 160
Track Cycling	750	105
Total	31 191	5 705

It should, however, be noted that many cyclists actively participate in more than one discipline (Duncan, 2012). In South Africa, 3 831 of the members are licensed competitive cyclists, and in Kwa-Zulu Natal, the competitive cyclists total 587, a small portion of the total number of cyclists. Of the competitive cyclists in South Africa, 1 402 participated in road events, 1 994 in mountain bike events, 301 in track events. Kwa-Zulu Natal competitive cyclists are more evenly distributed between road and mountain biking, with 265 competing in mountain bike events and 247 in road events, and 42 in track events (Duncan, 2012). In addition, the Kwa-Zulu Natal members showed a bias toward the male population, with 79 percent (Duncan, 2012). These statistics support the literature in terms of the increasing participation in cycling at a recreational and competitive level, with notable growth in the popularity of mountain biking over in recent years (Faria, Parker, and Faria, 2005a).

Although a cyclists legs provide the pedalling motion and power during cycling, a stable core could prevent energy being lost to twisting the trunk, and instead, transfer that power to the lower extremities (Asplund and Ross, 2010; Abt, Smoliga, Brick, Jolly, Lephart and Fu, 2007). The stability may also provide balance, which would help to maintain an aerodynamic position and thus, a more efficient cycling output (Asplund and Ross, 2010). Cycling requires repetitive hip flexion, and in turn pelvic stability to act as an anchor (Asplund and Ross, 2010). Core strength and stability would be required to ensure cycling efficiency, in addition to contributing to the enhancement of the leverage from which cyclists generate power to the pedals (Asplund and Ross, 2010; Abt *et al*., 2007).

Core strengthening has become a global fitness trend that has filtered into world of sports medicine due to its numerous benefits, including improving athletic ability and preventing injury (Akuthota, Ferreiro, Moore and Fredericson, 2008). Improved core stability allows for highly coordinated muscle activation patterns to change continually, depending on the demands of the task at hand (McGill, Grenier, Kavcic and Cholewicki, 2003). Abt *et al*., (2007) found that a stable core allows for greater stability in the saddle, and as such, lower extremity alignment, which allows for greater transmission of forces from the torso to the lower extremity. Abt *et al.,* (2007) utilised an exhaustive cycling protocol based on set gear ratios, and a core fatigue workout, to determine whether diminished core stability would result in altered cycling mechanics and pedal force (Abt *et al.,* 2007). However, the authors noted numerous limitations. The study revealed that core fatigue altered cycling biomechanics; however, no significant differences in pedalling forces or work variables were noted. Abt *et al.,* (2007) attributed this to compensatory kinematic adaption that took place to maintain a fixed power output, due to the fixed speed and gear ratio settings of the trials, forcing the participants to pedal in a set manner for pre- and post- experimental trials. However, their study identified the need for further research with alterations to methodology, specifically using self-pacing cycling to better simulate outdoor riding. This study aims to address this, with the use of the Tacx Trainer, which will allow the participants in this study to ride an unrestricted, self-paced time trial, to more accurately simulate outdoor riding (Abt *et al*., 2007).

The findings of Abt *et al*., (2007) are supported by Asplund and Ross (2010), who also indicated that the strength of the abdominal muscles is vital in maintaining a stable pelvic position. It was suggested that strengthening of these muscles could lead to improved pedalling efficiency (Asplund and Ross, 2010). It was noted however, that studies investigating core strengthening in sporting activities are limited, as most studies investigating the effectiveness of core strengthening are based in a rehabilitation setting. In addition, Allen (2002) suggested that muscles of the extremities may require less force in contractions to produce power when the core is stable. Abt *et al.,* (2007) also suggested that the leverage from which cyclists generate power may be enhanced as a result of improved core stability. These studies support the hypothesis that a strong core will improve pelvic stability, thereby decreasing the loss of force through twisting of the trunk, and improving the force distribution to the lower extremities, which would in turn lead to improved pedalling efficiency. In addition, Faries and Greenwood (2007) suggested that further research in core strengthening should examine the effects on performance and sport-specific training.

According to Panjabi (1992), the stabilising system (viz. the core musculature) is responsible for providing sufficient stability to match varying demands that arise as a result of changes in posture, as well as changes in static and dynamic loads. Core strengthening consists of activating trunk musculature which in turn should allow for improved performance of the axial and appendicular skeleton (Asplund and Ross, 2010; Akuthota *et al.,* 2008; Hibbs, Thompson, French, Wrigley and Spears, 2008; Abt *et al.,* 2007; Akuthota and Nadler, 2004; McGill *et al*., 2003; Hedrick, 2000).

The core musculature includes an abdominal, lumbar, hip girdle and iliopsoas component (Moore and Dalley, 2006; Akuthota and Nadler, 2004; Hedrick, 2000). For the purpose of this study, the abdominal component consists of: rectus abdominis, external oblique, internal oblique and transversus abdominis (TA); the lumbar component consist of: multifidus, quadratus lumborum, superficial and deep erector spinae, intertransversarii and interspinales; the hip girdle component consists of: gluteus maximus and gluteus medius, and the iliopsoas component consists of: psoas major, psoas minor and iliacus (Moore and Dalley, 2006; Akuthota and Nadler, 2004; Hedrick, 2000). Activation of these muscles provides stabilization of the spine and efficient movement of the extremities, allowing transfer of power with minimal dissipation of energy (Hedrick, 2000). Thus, Hedrick (2000) suggested that a lack of adequate core strength may result in an inability of the athlete to generate extremity strength, resulting in decreased power and endurance.

In this study, participants will take part in a core muscle strengthening programme, as this is expected to improve pelvic stability, thereby decreasing the loss of force through twisting of the trunk, and improving the force distribution to the lower extremities, which should in turn lead to improved pedalling efficiency (Asplund and Ross, 2010).

1.2 Aims

The aim of this study was to determine whether core muscle strengthening would have a statistically significant effect on cycling performance in asymptomatic cyclists.

1.3 Objectives

The objectives of the study were:

Objective One:

To determine the participants' core strength (mmHg), pre- and post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

Objective Two:

To determine the participants' power output (w), cycling speed (km/h), cadence (rpm) and completion time (seconds), pre- and post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

Objective Three:

To determine the participants' rate of perceived exertion (RPE), and corresponding heart rate (bpm), pre- and post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

Objective Four:

To determine the participants' perception of a change in power output (w), cycling speed (km/h) and cadence (rpm) post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

Objective Five:

To compare outcomes of the pre- and post- intervention measures, in the whole sample and within the two age strata.

1.4 Hypotheses of the Study

The following null hypotheses were set to address the objectives outlined:

Null Hypothesis One:

The null hypothesis was that the core muscle strengthening intervention would result in no significant difference in core strength (mmHg), in the whole sample and within the two age strata.

Null Hypothesis Two:

The null hypothesis was that the core muscle strengthening intervention would result in no significant difference in the participants' cycling speed (km/h), power (w), cadence (rpm) and completion time (s), in the whole sample and within the two age strata.

Null Hypothesis Three:

The null hypothesis was that the core muscle strengthening intervention would result in no significant change in heart rate (bpm) and rate of perceived exertion, in the whole sample and within the two age strata.

Null Hypothesis Four:

The null hypothesis was that the core muscle strengthening intervention would result in no difference in the participants' perception of change in speed, power and cadence, in the whole sample and within the two age strata.

1.5 Rationale and Benefits of the Study

Abt *et al*., (2007) found that a stable core allows for greater stability in the saddle, and as such, lower extremity alignment which allows for greater transmission of forces from the torso to the lower extremity. This is supported by Asplund and Ross (2010), who found that the strength of the abdominal muscles is vital for stabilising pelvic posture. It was suggested that strengthening of these muscles would lead to improved pedalling efficiency. These studies support the hypothesis that a strong core will improve pelvic stability, thereby improving the force distribution to the lower limbs and improving pedalling efficiency. However, most studies investigating the effectiveness of core strengthening are conducted in a rehabilitation setting, or on untrained athletes (Akuthota *et al*., 2008; Hibbs *et al*., 2008; Faries and Greenwood, 2007; Willardson, 2007; Abt *et al*., 2007; Akuthota and Nadler, 2004).

The paucity in the literature regarding the effects of core strengthening in cycling has been highlighted, with suggestions for further research on the effects of core strengthening on performance and sport-specific training (Akuthota *et al*., 2008; Hibbs *et al*., 2008; Faries and Greenwood, 2007; Abt *et al*., 2007).

Despite the widespread use of core strengthening programmes by athletes, including cyclists, there is paucity in the literature as to the effects of core strengthening on sporting performance. The benefits of this study were therefore to gain a formally tested conclusion on the effects of core muscle strengthening on cycling performance in asymptomatic cyclists.

1.6 Limitations

All participants were required to complete all components of this study honestly (Mouton, 1996). If the participants elected to be dishonest, it would be impossible for the researcher to determine, and therefore, such data would still be included in the outcomes of this study. The small sample size of this study is a limitation, as it is not exhaustive of the entire population of cyclists in Kwa-Zulu Natal. In addition, participants included in this study did not cover all disciplines of cycling, and it is therefore not exhaustive of the entire cycling population in Kwa-Zulu Natal.

1.7 Conclusion

The aim of this study was to determine whether core muscle strengthening would have a statistically significant effect on cycling performance in asymptomatic cyclists.

In the following chapters, the researcher will review the literature on the core musculature, and the literature on cycling (Chapter Two); describe in detail the methodology of this study (Chapter Three); and present the statistics (Chapter Four); the results and discussion (Chapter Five); and the subsequent conclusions and recommendations (Chapter Six).

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter provides a review of all the recent literature and aims to inform the reader of the anatomy of the core musculature, as well as cycling biomechanics and the significant outcome measures of cycling. It also describes the relationship between the core musculature, cycling biomechanics and cycling performance.

2.2 Anatomy of the Core Muscles

The core muscles work together as a unit to stabilize the body and spine, serving as a corseted centre of the kinematic chain (Akuthota and Nadler, 2004).

For the purpose of this study, the core musculature included an abdominal, lumbar, hip girdle and iliopsoas component (Moore and Dalley, 2006; Akuthota and Nadler, 2004; Hedrick, 2000).

Table 2.1 The Core Musculature Components

Core Musculature Component	Muscles
Abdominal Component	Rectus abdominis External oblique Internal oblique Transversus abdominis
Lumbar Component	Multifidus Quadratus lumborum Rotatores Superficial and deep erector spinae Intertransversarii Interspinales
Hip Girdle Component	Gluteus maximus Gluteus minimus
Iliopsoas Component	Iliacus Psoas Major Psoas Minor

The core musculature is categorised into global and local systems, dependent on the muscles mechanical role in stabilisation (Richardson, Jull, Hodges and Hides, 1999).

The global stabilising system includes the internal oblique, external oblique, rectus abdominis, gluteus maximus, lateral fibres of quadratus lumborum and portions of erector spinae. These are the larger, more superficial, torque producing muscles that enable an upright position. They are responsible for movement, as well as balancing and controlling external loads applied to the trunk, by reducing the resultant forces on the spine. [Richardson, Jull, Hodges and Hides, 1999]

The local stabilising system includes the deep muscles, and some deep portions of muscles, with insertions on the lumbar vertebrae. These muscles are responsible for maintaining lumbar posture, and stability between the spinal segments (Richardson *et al*., 1999). The multifidus muscle is considered to be part of the local system as it assists in segmental stabilisation as a result of its vertebrae to vertebrae attachments. Similarly, the transversus abdominis is considered a key muscle in the local stabilising system, due to its direct attachment to the lumbar vertebrae via the thoraco-lumbar fascia, and decussations with its opposite muscle in the midline (Richardson *et al*., 1999).

2.2.1 Abdominal Component

The abdominal component of the core muscles consists of:

- Rectus abdominis
- External oblique
- Internal oblique
- Transversus abdominis

The rectus abdominis is a long flat strap-like muscle that extends the length of the anterior abdominal wall. This paired muscle, separated by linea alba in the midline, is broad and thin superiorly, and narrow and thick inferiorly. The rectus abdominis is anchored to the anterior layer of the rectus sheath, through its attachment to three or more transverse fibrous bands. This is visible in muscular, athletic, people when the muscle is strained or tensed, and the muscle between the fibrous bands bulges outwards. [Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005]

The external oblique is the largest and most superficial of the anterolateral group of abdominal wall muscles. The laterally placed fibres of the external oblique pass inferomedially, and the aponeurosis component of the muscle covers the anterior part of the abdominal wall, where it entwines in the midline to form the linea alba. [Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005]

The internal oblique, a smaller and thinner muscle, lies deep to the external oblique, with fibres passing superomedially. Similarly, to the external oblique, its fibres end in an aponeurosis, which participates in the formation of the rectus sheath. As a result of the attachments and continuous fibres of the external and internal oblique muscles anteriorly, the contralateral external oblique and internal oblique form a functional working unit. [Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005]

The transversus abdominis, the deepest of the flat anterolateral abdominal wall muscles, has all but its most inferior fibres running in a transverse direction, aiding in the compression and support of abdominal contents and increasing the intra-abdominal pressure. The fibres of the transversus abdominis also end in an aponeurosis, contributing to the formation of the rectus sheath. [Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005]

The attachments, innervations and main actions of the muscles forming the abdominal component of the core musculature are summarised in Table 2.2

Table 2.2 Attachments, Innervation and Action of Abdominal Component

Muscle	Proximal Attachment	Distal Attachment	Innervation	Action
Rectus abdominis	Pubic Symphysis and the pubic crest.	Xiphoid processes and the coastal cartilages 5 to 7.	Thoracolumbar nerves, (the anterior rami of the inferior 6 thoracic nerves.	Flexion of the trunk and compression of the abdominal viscera. Also, stabilisation of the pelvis.
Transversus abdominis	Internal surfaces of costal cartilages 7 to 12, the thoracolumbar fascia, iliac crest, and the lateral third of the inguinal ligament.	Linea alba, with aponeurosis of internal oblique, the pubic crest, and pecten pubis.	Thoracoabdominal nerves, (the anterior rami of inferior 6 thoracic nerves) and the first lumbar nerves.	Compression and support of the abdominal viscera.
Internal oblique	Thoracolumbar fascia, the anterior two-thirds of the iliac crest, and the lateral half of inguinal ligament.	Inferior borders of ribs 10 to 12, linea alba, and pectin pubis.	Thoracoabdominal nerves, (the anterior rami of inferior 6 thoracic nerves) and the first lumbar nerves.	Flexion and rotation of the trunk. Compression and support of the abdominal viscera.
External oblique	External surfaces of ribs 5 to 12.	Linea alba, the pubic tubercle, and the anterior half of the iliac crest.	Thoracolumbar nerves (inferior 5 thoracic nerves) and the subcostal nerve.	Flexion and rotation of the trunk. Compression and support of the abdominal viscera.

(Table adapted from Moore and Dalley, 2006)

2.2.2 Lumbar Component

The lumbar component of the core muscles consists of:

- Multifidus
- Quadratus lumborum
- Rotatores
- Superficial and deep erector spinae
- Intertransversarii
- Interspinales

Multifidus, with its intervertebral attachments between the lumbar and sacral vertebrae, is another key muscle in the local stabilising system. The most medial of the lumbar muscles, multifidus consists of short triangular muscular bundles, which become thickest in the lumbar region. This muscle consists of five separate bands, with fascicles stemming from the spinous processes and laminae of the lumbar vertebrae. Multifidus functions to maintain stabilisation of the vertebrae during movements of the vertebral column. [Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005]

Quadratus lumborum is a thick muscle of the posterior abdominal wall, adjacent to the lumbar transverse processes. Acting unilaterally, the muscle depresses and stabilises the 12th rib, and with the pelvis fixed, contributes to lateral flexion of the spine on the ipsilateral side. With the spine in a fixed position, the muscle acts unilaterally to lift the ipsilateral hip. Acting bilaterally, quadratus lumborum extends the spine. [Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005]

The rotatores muscle, also referred to as the rotator muscles are best developed in the thoracic region and assist in rotary movements of the vertebral column, as well as stabilising the vertebrae and assisting in extension of the spine (Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005).

The erector spinae muscle is the largest group of intrinsic back muscles. It is comprised of three components, spanning the cervical, thoracic and lumbar regions. These components include the iliocostalis lumborum, thoracis and cervicis; longissimus thoracic, cervicis and capitis; and spinalis thoracic, cervicis and capitis. For the purpose of this study, the portion of the erector spinae that will be described is the iliocostalis lumborum. The erector spinae lies posterolaterally to the vertebral column, between the spinous processes medially and the angle of the ribs laterally. Iliocostalis is the most lateral component of the erector spinae muscle. Bilaterally this muscle assists in extension of the lumbar spine, whilst unilaterally, it assists in lateral flexion of the lumbar spine. [Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005]

The interspinales and intertransversarii form a group of postural segmental muscles, functioning to stabilise adjacent vertebrae during movement of the vertebral column. The attachments of the interspinales and intertransversarii, between adjacent spinous processes and transverse processes respectively, allows for this stabilisation to occur, whilst allowing for effective movements of the larger lumbar muscles. [Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005]

The attachments, innervations and main actions of the muscles forming the lumbar component of the core musculature are summarised in Table 2.3

Table 2.3 Attachments, Innervation and Action of Lumbar Component

Muscle	Proximal Attachment	Distal Attachment	Innervation	Action
Multifidus	Posterior sacrum, posterior superior iliac spine of the ilium, aponeurosis of erector spinae, the sacroiliac ligaments, mammillary processes of T1 to T3, and articular processes of C4 to C7.	Thickest in lumbar region; fibres pass obliquely superomedially to entire length of spinous processes of vertebrae, located 2 to 4 segments superior to origin.	Posterior rami of the spinal nerves.	Stabilisation of the vertebrae during local movements of the vertebral column.
Quadratus Lumborum	Medial half of the inferior border of the 12th ribs, and the tips of the lumbar transverse processes.	Iliolumbar ligament and internal lip of the iliac crest.	Anterior branches of nerves T12, and L1 to L4.	Extension and lateral flexion of the vertebral column. Stabilises the 12th rib during inspiration.
Rotatores	Arise from transverse processes of vertebrae, best developed in thoracic region.	Fibres pass superomedially to attach to junction of lamina and transverse process, or spinous process of vertebra immediately (brevis) or 2 segments (longus) superior to vertebra of origin.	Posterior rami of the spinal nerves.	Stabilise the vertebrae and assist with local extension and rotary movements of the vertebral column.
Erector Spinae – Iliocostalis lumborum	Posterior part of the iliac crest and the posterior surface of the sacrum, sacroiliac ligaments, sacral and inferior lumbar spinous processes and supraspinous ligament.	Superiorly, to the angles of the lower ribs.	Posterior rami of the spinal nerves.	Bilateral Action: Extension of the vertebral column and head Unilateral Action: Lateral flexion of the vertebral column.
Intertransversarii	Transverse processes of the cervical and the lumbar vertebrae.	Transverse processes of the adjacent vertebrae.	Posterior and anterior rami of the spinal nerves.	Assists in lateral flexion of the vertebral column; Bilateral Action: stabilisation of the vertebral column.
Interspinales	Superior surfaces of the spinous processes of the cervical and lumbar vertebrae.	Inferior surfaces of the spinous processes of vertebra superior to vertebra of origin.	Posterior rami of the spinal nerves.	Assists in extension and rotation of the vertebral column.

(Table adapted from Moore and Dalley, 2006)

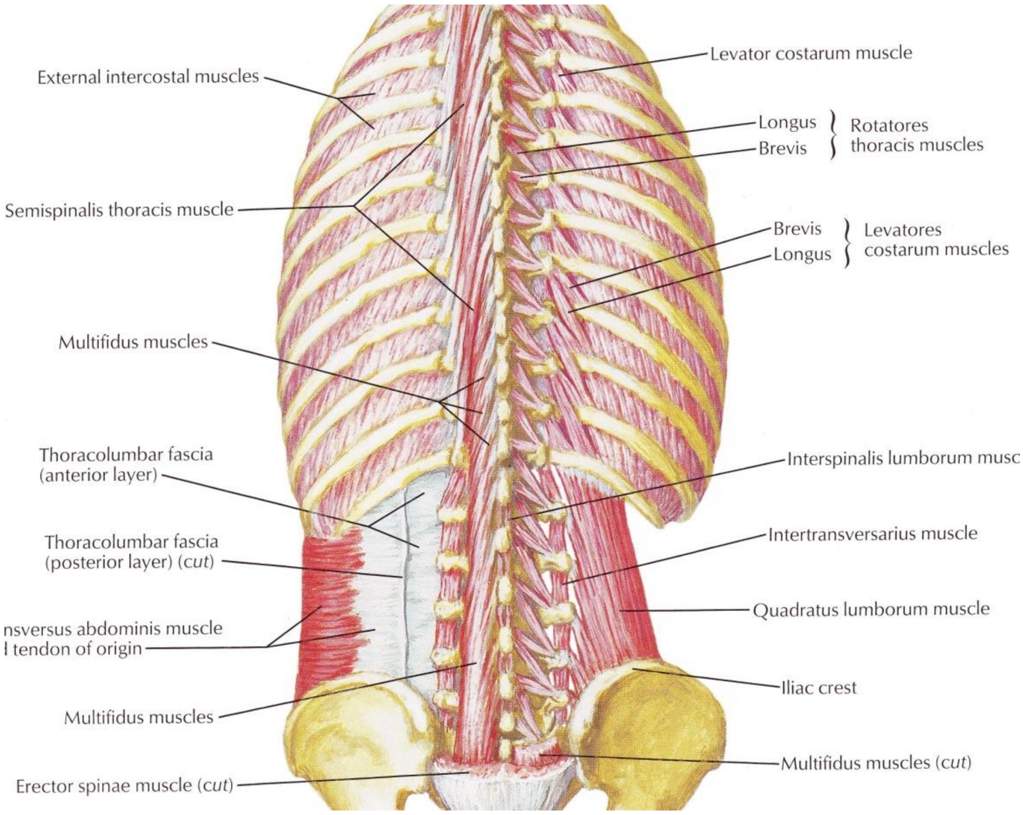

Figure 2.1 The Core Musculature – Lumbar Component
(Source: Netters)

2.2.3 Hip Girdle Component

The hip girdle component of the core muscles consists of:

- Gluteus maximus
- Gluteus medius

The hip girdle component plays an important part in the kinematic chain through its contribution to stabilising the pelvis and trunk, and its role in transfer of forces between the trunk and the lower limbs (Akuthota and Nadler, 2004). The gluteal muscles share a common compartment, but are organised into superficial and deep layers. Gluteus maximus and medius, as well as gluteus minimus and the tensor fascia lata comprise the superficial layer of the gluteal muscles (Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005). Gluteus maximus is the largest muscle in the gluteal region, covering all of the other gluteal muscles, except for one-third of the gluteus medius. Its main actions include extension and lateral rotation of the hip, however it functions primarily between the seated and standing posture of the thigh (Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005). Gluteus medius abducts and medially rotates the thigh, as well as providing stabilisation to the pelvis (Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005). The stabilisation of the pelvis provided by the gluteal muscles is instrumental in the efficient pedal stroke of the cyclist, due to the important role they play in the crank cycle (Lopes and McCormack, 2005). This relationship to cycling biomechanics will be discussed further in this chapter.

The attachments, innervations and main actions of the muscles forming the hip girdle component of the core musculature are summarised in Table 2.4

Table 2.4 Attachments, Innervation and Action of Hip Girdle Component

Muscle	Proximal Attachment	Distal Attachment	Innervation	Action
Gluteus maximus	Ilium, posterior to the posterior gluteal line; the dorsal surface of sacrum and coccyx; and the sacrotuberous ligament.	Portion of fibres end in iliotibial tract and its insertion into the lateral condyle of tibia; the remaining fibres insert into the gluteal tuberosity.	Inferior gluteal nerve (L5, S1, S2).	Extension of the thigh, particularly from a flexed position, as well as lateral rotation. Assists in rising from a seated position.
Gluteus medius	External surface of ilium between anterior and posterior gluteal lines.	Lateral surface of greater trochanter of femur.	Superior gluteal nerve (L5, S1).	Abduction and medial rotation of the thigh. Stabilisation of the pelvis when the ipsilateral limb is weight bearing.

(Table adapted from Moore and Dalley, 2006)

2.2.4 Iliopsoas Component

The iliopsoas component of the core musculature consists of:

- Psoas Major
- Psoas Minor
- Iliacus

The iliopsoas is the most powerful of the hip flexors, with the longest range. The iliopsoas muscle is formed by the iliacus, on its broad lateral part, and the psoas major on its long medial part. This muscle is unique in its attachments to the vertebral column, pelvis and femur, allowing it to both provide stability and movement. [Moore and Dalley, 2006]

The attachments, innervations and main actions of the muscles forming the iliopsoas component of the core musculature are summarised in Table 2.5

Table 2.5 Attachments, Innervation and Action of Iliopsoas Component

Muscle	Proximal Attachment	Distal Attachment	Innervation	Action
Psoas Major	Sides of T12-L1 vertebrae and discs, transverse processes of L1-L5.	Lesser trochanter of femur.	Anterior rami of lumbar nerves (L1, L2, L3).	Act conjointly in flexion of the thigh at the hip joint, and in stabilisation of the hip joint.
Psoas Minor	Sides of T12-L1 vertebrae and intervertebral discs.	Pectineal line, iliopectineal eminence, via iliopectineal arch.	Anterior rami of lumbar nerves (L1, L2).	
Iliacus	Iliac crest, iliac fossa, ala of sacrum, and anterior sacroiliac ligaments.	Tendon of psoas major, lesser trochanter, and femur distal to it.	Femoral nerve (L2, L3).	

(Table adapted from Moore and Dalley, 2006)

2.2.5 Thoracolumbar Fascia

Akuthota and Nadler (2004) described the thoracolumbar fascia as a “retinacular strap” of the lumbar spine musculature. It attaches to the vertebral column medially, and is thin and transparent over the thoracic portions of the deep muscles, and thick and strong over the lumbar portions (Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005). In essence, the thoracolumbar fascia connects the upper body to the lower limbs (Kibler, Press and Sciascia, 2006).

In the lumbar region, the thoracolumbar fascia is made up of an anterior, middle and posterior layers (Drake, Vogl and Mitchell, 2005). The posterior layer is considered the most significant due to its function in supporting the lumbar spine and abdominal musculature (Akuthota and Nadler, 2004). The middle and posterior layers of the thoracolumbar fascia merge at the lateral margin of the erector spinae, and join the anterior layer at the lateral border of the quadratus lumborum, where together they form the aponeurotic attachment for the transversus abdominis. (Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005).

The thoracolumbar fascia provides functional stability by creating a hoop structure for the transversus abdominis, internal oblique and external oblique to collectively increase intra-abdominal pressure, as well as functioning to supply proprioception with respect to trunk position, during contraction of the surrounding musculature (Moore and Dalley, 2006; Drake, Vogl and Mitchell, 2005; Akuthota and Nadler, 2004). The link provided by the thoracolumbar fascia may assist in the force distribution from the trunk to the lower limbs, thus enhancing the cyclists' efficiency (Asplund and Ross 2008; Akuthota and Nadler, 2004).

2.3 Core Strengthening

Spinal stability has been identified as consisting of three subsystems, namely the passive components of the spinal column, the active control of the spinal muscles, and the neuromuscular coordination (Panjabi, 1992). Coordination of these subsystems results in improved core stability, which in turn improves the control of the trunk over the pelvis, allowing for maximal production and transfer of forces to the extremities for highly coordinated athletic activities (Kibler, Press and Sciascia, 2006). Although the transversus abdominis and the multifidus muscles have been identified as the most important, all of the core musculature is required for optimal stabilisation and performance of the cyclist, as a result of the improved force distribution to the lower limbs that this may provide (Akuthota and Nadler, 2004).

Core strengthening consists of activating trunk musculature, which in turn should allow for improved performance of the axial and appendicular skeleton in various sporting situations (Asplund and Ross, 2010; Akuthota *et al*., 2008; Hibbs *et al*., 2008; Abt *et al.,* 2007; Akuthota and Nadler, 2004; McGill *et al*., 2003; Hedrick, 2000). A comprehensive strengthening programme aimed at these muscles has been advocated as a means of performance enhancement, however, further research linking a core strengthening programme and measurable improvements in performance is required (Asplund and Ross, 2010; Akuthota *et al*., 2008; Hibbs *et al*., 2008; Abt *et al.,* 2007; Akuthota and Nadler, 2004; McGill *et al*., 2003; Hedrick, 2000). Raymond, Joseph and Gabriel (2005) identified the need to evaluate the extent of upper body and the trunk musculature activity in cycling, to accurately prescribe an optimal strength training programme to aid cycling performance.

The core exercises selected for the purpose of this study, as illustrated in **Appendix H**, are specifically designed to develop isolated and co-contraction muscle patterns to stabilise the lumbar spine, thereby improving the stability of the pelvis (Liebenson, 2007. Richardson *et al.*, 1999). Each exercise was held for a period of 10 seconds, for 10 repetitions (Liebenson, 2007). The power bridge is indicated for gluteal insufficiency, and is suggested to strengthen the link between the lower back and the gluteal muscles (Liebenson, 2007; http://www.bicycling.co.za/training-nutrition/workouts/core-muscles). The plank is designed to build strength and endurance, by activating the TA and multifidus, which is suggested to assist in positioning on the bicycle, particularly in the drop handle bar position (Liebenson, 2007; http://www.bicycling.co.za/training-nutrition/workouts/core-muscles). The transverse plank is indicated to improve abdominal endurance, with activation of the TA and internal and external obliques thought to improve the control and stability of the cyclist in the saddle, particularly when hill climbing (Liebenson, 2007; http://www.bicycling.co.za/training-nutrition/workouts/core-muscles). The quadruped reach is indicated to improve trunk extensor endurance. The quadruped reach improves balance, primarily as a result of a strengthened corset effect of the core musculature (Liebenson, 2007; Richardson *et al*., 1999; http://www.bicycling.co.za/training-nutrition/workouts/core-muscles).

Scientific studies have demonstrated molecular, biological, physiological and measurable improvements in skeletal muscle tissue after four weeks of a structured exercise programme. In addition, statistically significant results have been recorded after four weeks of core strengthening exercise. [Defreitas *et al*., 2011; Camera, Anderson, Hawley and Carey, 2010; Clarke, 2009; Kendall, Smith, Graef, Fukuda, Moon, Beck, Cramer and Stout, 2009; Kuszewski *et al*., 2009; Smit, 2009; Spangenburg, 2009; Campbell, 2007; Ludmila *et al*., 2003; Piegaro, 2003; Boden, 2002; Staron *et al*., 1994]

Exercise involving co-contraction of the abdominal and lumbar component of the core assists in stabilisation. Simultaneous isometric co-contraction of the transversus abdominis and the multifidus muscles, whilst maintaining a neutral position of the spine, can ensure re-education and reinforcement of the stabilisation roles of these muscles (Richardson and Jull, 1995).

2.4 Cycling

Cycling is a sport of growing popularity, particularly in the competitive arena (Faria, Parker and Faria, 2005a). As a result, cyclists continually strive for new ergogenic aids to enhance their performance (Burke, 2003). The low impact, non-weight bearing nature of the sport results in fewer injuries, when compared to other sports, which may play a role in the popularity of cycling at any age (Sheets and Hochschuler, 1990; Beneke, Beneke, Noakes and Reynolds, 1989). Cycling disciplines vary greatly, not only in terms of the type of bicycle used, but also the skills required and the differences in biomechanics (Burke, 2003; Beneke *et al*., 1989). As described in the statistics of Cycling South Africa 2012, both road and mountain biking are especially popular, with road cycling having 2 321 members, and mountain biking having 3 160 members, of the 5 705 members in Kwa-Zulu Natal (Duncan, 2012). A large number of cyclists paricpate in more than one discipline, combining road cycling with track or mountain biking (Duncan, 2012).

Numerous differences exist between road, mountain and track cycling (Downs, 2010, Burke, 2003; Beneke *et al*., 1989). Firstly, the drive train of a mountain bike consists of an extra chain ring, allowing for an increased selection of gears (Downs, 2010; Liggett, 1992). In addition, pedal strokes differ between the different cycling disciplines (Burke, 2003; Beneke *et al*., 1989). Pedal strokes of mountain bike cyclists tend to occur in a more uniform pattern than that of road cyclists, which may be a skill aquired as a result of cycling in conditions with extreme terrains, where a uniform torque generation is necessary (Burke, 2003). Track cycling is a highly specialised discipline of the sport, with tactics, technique and consistently high cadence being vital components (Beneke *et al*., 1989).

2.4.1 Cycling Biomechanics and the Musculature Involved

Pedalling technique has an important role in contributing to the cyclists' performance and optimal muscle recruitment (Wisbey-Roth, 2009). The pedalling cycle, most often referred to as the crank cycle, can be divided into two main phases, the first being the downstroke, occurring from 0º to 180º, and secondly the upstroke, from 181º to 360º (Burke, 2003). The downstroke phase, also known as the power phase, requires a much larger force than that of the upstroke phase, which is also referred to as the recovery phase (Raymond, Joseph and Gabriel, 2005). Certain literature further subdivides the crank cycle to include a third and fourth phase associated with the pushing and pulling phases in which the foot is pushed forward at top dead centre (TDC) and pulled back at bottom dead centre (BDC) (Bertucci, Grappe, Girard, Betik and Rouillon, 2005; Raymond, Joseph and Gabriel, 2005).

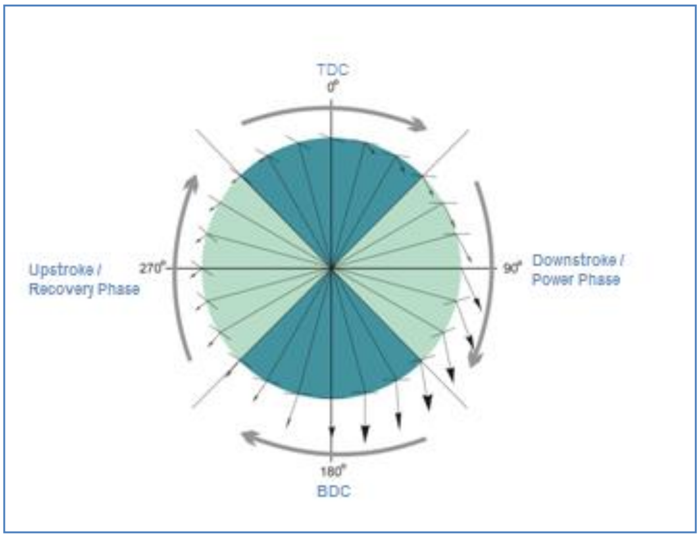

Figure 2.2 The Crank Cycle

(Adapted from Jones, 2008)

Much emphasis is given to the importance of a smooth pedal stroke, with even distribution of power to the pedals during the entire crank cycle (Raymond, Joseph and Gabriel, 2005). During the downstroke phase, muscle power is achieved through activation of the hip, knee and ankle extensors, where the largest amount of energy is transferred to propel the bicycle forward (Lopes and McCormack, 2005; Asplund and St Pierre, 2004; Burke, 2003). During the upstroke phase, muscle power is achieved through the activation of the hip, knee and ankle flexors (Lopes and McCormack, 2005; Asplund and St Pierre, 2004; Burke, 2003).

During the crank cycle, the hip remains in a predominantly flexed position, whilst the knee goes through approximately 75º of motion (Asplund and St Pierre, 2004). The hip undergoes extension until 180º at the BDC, before flexion occurs with lifting of the foot and the pedal, returning hip to the maximal flexed position, whilst initiating the downstroke phase of the opposite leg (Asplund and St Pierre, 2004; Burke, 2003). The knee begins the crank cycle in a maximally flexed position at 110º and extends to 35º at the bottom of the downstroke phase (Asplund and St Pierre, 2004; Burke, 2003). The knee exhibits a small degree of medial translation on the downstroke phase, due to the angulations of the femoral condyles, which then translates laterally on return to flexion in the upstroke phase (Asplund and St Pierre, 2004; Burke, 2003). The movement of the ankle during the crank cycle exhibits plantar flexion on the upstroke phase, until approximately 320º, where it begins to dorsiflex into the downstroke phase (Burke, 2003). Fixed pedals restrain the foot on the pedal, allowing for even transmission of power, through optimal use of all the muscles involved in the crank cycle (Raymond, Joseph and Gabriel, 2005).

The major muscles involved in the crank cycle include the quadriceps muscle, responsible for hip flexion and knee extension, and the hamstrings, responsible for knee flexion and hip extension (Raymond, Joseph and Gabriel, 2005; Asplund and St Pierre, 2004). The majority of the power produced to propel the bicycle forward is a result of activation of the quadriceps, hamstrings, and gluteus maximus (Raymond, Joseph and Gabriel, 2005; Asplund and St Pierre, 2004). The hamstrings may also decrease the load on the quadriceps muscle, preventing the quadriceps from needing to lift the weight of the opposite leg, whilst applying downward force in the downstroke phase of the other leg (Burke, 2003).

Many of the muscles involved in cycling are biarticular, which assist during various phases of the crank cycle (Raymond, Joseph and Gabriel, 2005). The most important of these muscles are the rectus femoris, the hamstrings and the gastrocnemius. These biarticular muscles are responsible for providing the energy to a joint action, whilst simultaneously countering that action at an adjacent joint (Raymond, Joseph and Gabriel, 2005; Burke, 2003). Rectus femoris, a primary knee extensor, exhibits activation during the downstroke phase, between 0º and 150º. The hamstrings exhibit activation at a late stage of the downstroke phase, at the point where hip extension and knee flexion meet, creating a coupling effect of the joint motions. The gastrocnemius muscle exhibits maximum recruitment between 120º and 180º, whilst acting as an accessory muscle between 60º to 190º. [Umberger, Gerritsen and Martin, 2006; Raymond, Joseph and Gabriel, 2005; Burke, 2003]

The uniarticular muscles of main importance are the gluteus maximus, the vastus lateralis and medialis, the soleus and the anterior tibialis (Raymond, Joseph and Gabriel, 2005). These muscles are primarily responsible for producing power, specifically at a similar point in the crank cycle (Raymond, Joseph and Gabriel, 2005). Activation timing for each of these muscles corresponds with the specific joint action that each muscle produces (Raymond, Joseph and Gabriel, 2005; Burke, 2003). Vastus medialis and lateralis exhibit activation between 45º and 90º, corresponding with the dominant knee extensor movement (Burke, 2003). Gluteus maximus, primarily a hip extensor, is active during the downstroke phase, between 70º and 150º, following which, it is relatively inactive for the upstroke phase (Lopes and McCormack, 2005; Asplund and St Pierre, 2004; Burke, 2003).

The iliopsoas muscle provides the completion of the upstroke phase, exhibiting activity between 270º and 0º, whilst the quadriceps muscle of the opposite leg begins the downward force for the next downstroke (Burke, 2003). The anterior tibialis muscle also has a small but significant role in lifting the toes as the pedal moves between 280º and 0º (Burke, 2003).

Figure 2.1 illustrates the involvement of the major muscles discussed during the crank cycle.

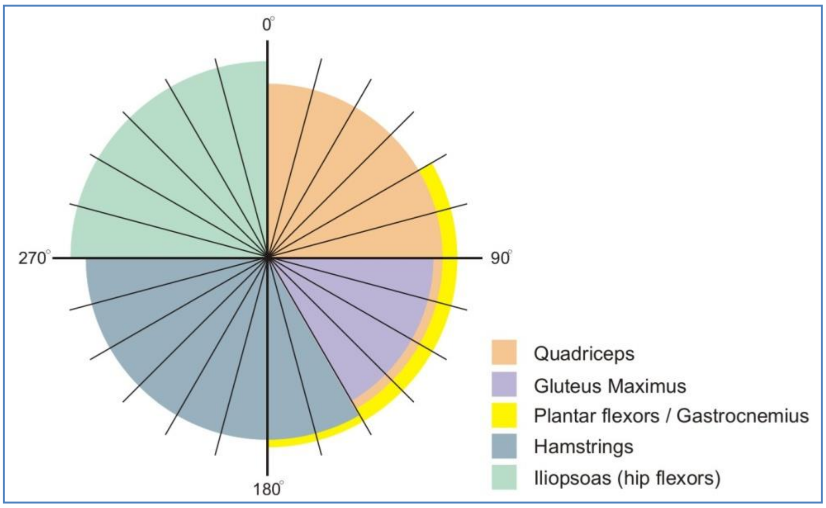

Figure 2.3 Muscle Involvements during the Crank Cycle
(Source: Jones, 2008)

The muscles involved in cycling work in a structured, co-ordinated pattern, to maximise the transfer of energy from the cyclist to the bicycle (Raymond, Joseph and Gabriel, 2005). Muscles of the trunk and upper limbs provide a counter-balanced force to the lower limbs during cycling (Raymond, Joseph and Gabriel, 2005). In addition, muscles of the lower limbs require a vastly smaller amount of force of muscle contractions to produce power when the muscles of the core are strong and stable (Allen, 2002). Improved strength of the muscles of the trunk may assist in stability of the pelvis, and more efficient transfer of power to the lower limbs during cycling (Asplund and Ross, 2010).

2.4.2 The Road Bicycle

The road bicycle has seen major advances in materials and components over the years. The typical road bicycle consists of a double diamond pattern frame, essentially 2 triangles that share a common base in the seat post, and is considered to be the heart of the bicycle. The frame provides the base onto which the components of the bicycle attach. These components include a front and rear wheel, a fork and handlebars, a drive train, a braking system, and a saddle. [Beneke *et al.*, 1989]

Figure 2.4 The Road Bicycle

The geometry of a frame is important in the efficiency and performance of the bicycle, and therefore, of the cyclist (Liggett, 1992). An efficient frame would be compact, making it rigid, and resulting in an improved transfer of the cyclist's energy to the rear wheel for an increased speed (Liggett, 1992; Beneke *et al*., 1989). The most important angle in this geometry is that formed by the seat tube angle and the ground, and is most commonly between 72 to 74 degrees (Burke, 2003). This allows for the knee to be over the pedal of the front foot when the cranks are horizontal (Burke, 2003). This angle also relates to the femur length, as a longer femur would require a smaller angle, allowing the cyclist to be seated further back on the bicycle and allow for the correct positioning of the knee (Burke, 2003).

The components attached to the frame, as mentioned, include the front and rear wheel, the fork and handlebars, the drive train, the braking system and the saddle (Beneke *et al*., 1989). The wheels consist of a hub, spokes, a rim, and a tyre, as shown in Figure 2.2. The wheels may show numerous variations, including hub style; spoke material, shape and thickness, as well as configuration of the spokes and spoke lacing pattern; rim recess; wheel construction and tyre types. These factors all play a role in determining the weight of the wheels and their quality and impact of efficiency (Burke, 2003; Liggett, 1992; Beneke *et al*., 1989). The braking system is another component that may vary between bicycles (Beneke *et al*., 1989). The most widely used system is the calliper system; however, drum brakes are also commonly used, and disc brakes are becoming increasingly popular, despite the disadvantage of a heavier mechanism (Beneke *et al*., 1989). As mentioned, the quality of the bicycle is impacted by the weight of the components, and as such, is specific for each cyclist, dependent of their level of expertise and experience (Liggett, 1992).

The drive train, also known as the transmission system, comprises of the pedals, chainset and cassette, chain and derailleurs (Downs, 2010; Beneke *et al.,* 1989). The drive train functions in translating human power into forward movement, by transferring power produced by the cyclist at the pedals to the chain, and as a result, the rear wheel, resulting in movement or turning of the wheel (Downs, 2010; Beneke *et al.,* 1989). This requires the drive train to meet certain criteria, including, a light weight, wide range of gear selections, low maintenance, reliability and smooth operation (Burke, 2003). In addition, the drive train needs to be mechanically efficient, minimising the energy lost to internal friction to less than five percent, and biomechanically efficient, ensuring that the caloric efficiency of the cyclists' power production is not impaired by the pedalling motion (Burke, 2003).

The quality of the bicycle is specific to each cyclist, and is dependent on numerous factors, including the level of expertise and experience of the cyclist, and their level of competition (Liggett, 1992). This in turn has an effect on the efficiency of the cyclist, most importantly when assessing the weight of the bicycle (Liggett, 1992; Beneke *et al*., 1989). In addition, correct positioning on the bicycle is paramount for the cyclist's efficiency, power and comfort, as well as minimising the risk for overuse injuries (Ettema and Loras, 2009; Wisbey-Roth, 2009; Burke, 2003; Beneke *et al*., 1989). Riding position has a direct impact on the efficiency of the cyclist, and optimum positioning is therefore vital in maximising the performance of the cyclist (Wisbey-Roth, 2009; Burke, 2003)

2.4.3 Cycling Performance and Efficiency

Gross efficiency is an estimate of the whole body efficiency, and is defined as a ratio of energy expenditure to work accomplished (Burke, 2003). Efficiency is greatly affected by the volume of training of the cyclist, which allows the cyclist to sustain an intense work load for an extended period of time, with a greater resistance to fatigue (Ettema and Loras, 2009; Wilmore, Costill and Kenney, 2008; Faria, Parker and Faria, 2005b; Burke, 2003). An experienced, well-trained cyclist may show biomechanical adaptations that may cause the resultant improved efficiency (Ettema and Loras, 2009).

One of these adaptations may include muscle fibre type that predominates (Faria, Parker and Faria, 2005b). Muscle fibres are classified according to the speed at which they contract in response to a stimulus (Baker, 1998). Type 1 fibres are slow twitch, and are therefore most commonly associated with endurance events, whilst Type II fibres are fast twitch, and are most commonly associated with sprint distances (Faria, Parker and Faria, 2005b; Burke, 2003; Baker, 1998). Type II fibres may be further subdivided into type IIA, which produce energy aerobically and anaerobically, and type IIB, which produce energy anaerobically (Baker, 1998). The percentage of type I muscle fibres in the trained cyclist will have a positive effect on efficiency due to the association of an increased percentage of type I fibres with a lower sub-maximal oxygen expense (Faria, Parker and Faria, 2005b; Burke, 2003). In addition to the changes in muscle fibre ratios as a result of the fitness levels in cyclists, age may also play a role in the muscle fibre ratios and resultant efficiency of the cyclist, with a decrease in type II muscle fibres associated with aging (Williams, Higgins and Lewek, 2002; Baker, 1998). This, along with the insufficient quality and quantity of training, may influence the relationship between age and cycling performance (Baker, 1998).

An efficient cyclist will direct their energy into driving the bicycle forward by pedalling effectively and powerfully, gaining maximal distance in the shortest time possible, without loss of energy and wasted effort (Burke, 2003; Beneke *et al*., 1989). This may be influenced by a number of external factors, including positioning on the bicycle. An efficient position on the bicycle allows the cyclist to pedal effectively and powerfully, without loss of energy due to poor pedalling mechanics (Burke, 2003; Beneke *et al*., 1989). This positioning may be influenced by the anthropometric measurements, the cyclists' strength and flexibility, and muscle recruitment patterns (Wisbey-Roth, 2009).

Cyclists positioning on the bicycle may also be impacted directly by a weak core (Asplund and Ross, 2010). If the cyclists back is flattened, weakness of the core is suspected. Similarly, the positioning of the shoulders whilst climbing should be square, however a weak core may predispose to excessive movement of the shoulders. Furthermore, poor core strength may result in various injuries and overuse syndromes, as a result of the compensatory mechanisms for a fatigued core (Asplund and Ross, 2010; Mills, 2006).

Other factors directly influencing the cyclists efficiency include friction between surfaces of the components of the bicycle, particularly the drive train, bottom bracket, and chain elements. In addition, the type of bearings and lubricants used will directly impact the amount of friction between components and can cause dissipation of between 5 to 15 percent of the cyclists' energy. [Burke, 2003; Beneke *et al*., 1989]

The rolling resistance of wheels also directly impacts the cyclists' efficiency, dependent on what portion of its surface is in contact with the road (Beneke *et al*., 1989). The narrower the tyre, the less surface area it has in contact with the road, and therefore, the less rolling resistance it possesses (Beneke *et al*., 1989). Rolling resistance plays a further role in efficiency, based on the body mass of the cyclist (Burke, 2003). Mass is a force working against the cyclist, as gravity increases the bearing loads and deformation of the tyres, resulting in an increased contact area with the road, and a higher rolling resistance (Burke, 2003; Beneke *et al*., 1989). A higher body mass index (BMI) will require an increased power output to resist gravity, and therefore, a resultant loss of efficiency (Beneke *et al*., 1989). An efficient cyclist will therefore opt for the lightest possible bicycle, requiring less leg power to resist gravity, particularly on an uphill (Burke, 2003). According to Beneke *et al*., (1989), a lighter cyclist on a lighter bicycle will have a clear advantage over the heavier cyclist or the heavier bicycle.

2.4.4 Factors Affecting Cycling Efficiency

2.4.4.1 Speed

The speed at which a cyclist can propel a bicycle is dependent on the amount of power the cyclist applies to the pedals (Burke, 2003). The potential for speed is influenced by the level of fitness and training status of the cyclist, as well as external factors in the natural environment, including wind speed and direction (Burke, 2003). As previously mentioned, the type of muscle fibres that predominate will also affect the cyclists' potential for speed (Faria, Parker and Faria, 2005b; Burke, 2003). Over shorter distances, fast-twitch, type II muscle fibres would be recruited, as these are more efficient at the higher cadences associated with a faster speed over a short distance (Baker, 1998). However, over an endurance distance, slow-twitch, type I muscle fibres are better suited for recruitment, as they process oxygen more efficiently and are therefore more applicable to slower cadences (Faria, Parker and Faria, 2005b; Burke, 2003). Cycling speed, power and cadence are therefore largely inter-dependent, and of utmost importance to the efficiency of the cyclist.

2.4.4.2 Power

Power, measured in watts (W), is used to describe the rate at which work is performed or work performed per unit of time (Powers and Howley, 1997). Power can therefore be used to describe the intensity of an exercise. When measured at the cranks, power represents the amount of energy the cyclist delivers to the pedals per unit of time. As a result, cyclists, coaches and scientists perceive that power is one of the most significant measures of cycling performance (Burke, 2003).

Maximum power output is considered to be highly correlated with cycling success (Faria, Parker and Faria, 2005b). Maximum power output may be influenced by a number of variables, including body positioning on the bicycle, geometry of the bicycle and the cyclists pedalling rate (De Groot, Welbergen, Clijsen, Clarijs, Cabri and Antonis, 1994). Riding position is influenced by various factors including anthropometric measurements of the cyclist, as well as the strength and flexibility, lengths of the lower limb muscles, and muscle recruitment patterns (Wisbey-Roth, 2009). This in turn directly influences the amount of power that the cyclist is able to produce. In addition, the cyclists' position on the bicycle places the core muscles in a strained position, therefore the cyclist positioning may be impacted directly by a weak core (Asplund and Ross, 2010). Flattening of the back, and excessive movement of the shoulders, particularly during hill climbing, are indicative of a weak core. Poor core strength may also result in injuries and overuse syndromes, as a result of the compensatory mechanisms of a fatigued core (Asplund and Ross, 2010; Mills, 2006).

Energy is delivered from the chain ring to the rear wheel, through the chain and transmission, however power losses may occur as a result of friction in the bottom bracket bearings, chain elements, and rear transmission (Burke, 2003). As previously mentioned, rolling resistance may affect the efficiency of the cyclist. Rolling resistance may affect power output due to the deformation, and energy consumption associated with it (Burke, 2003). Lastly, aerodynamic forces on the cyclist may account for a large portion of resistance to forward propulsion of the bicycle, hence the extensive attention to factors such as cyclist position, bicycle frame and component elements, and cycling techniques, to reduce the aerodynamic drag of the cyclist (Burke, 2003; Beneke *et al*., 1989).

2.4.4.3 Cadence

Cadence, measured in revolutions per minute (rpm), refers to the speed at which the pedals are turned (Beneke *et al*., 1989). Numerous factors may influence the cyclists' cadence, including power output, the duration of the exercise, the testing mode such as a cycle ergometer, the conditioning and training status of the cyclist. There is a high inter-individual variability in optimal cadence, even with comparison between well trained cyclists with similar fitness levels (Burke, 2003). This may be due to the fact that a cyclist will pedal at a rate at which they feel works best for them (Burke, 2003; Armstrong, Carmichael and Nye, 2003; Liggett, 1992). Factors such as bicycle set up and components, muscle fibre types, and the individual cyclist's perception of their exertion may affect their preference for cadence (Burke, 2003). The level of experience of the cyclist affects the chosen cadence, with the development of higher cadence utilisation in well-trained, experienced cyclists (Ansley and Cangley, 2009). This choice of higher cadence in trained athletes may also be influenced by the minimisation of the perceived exertion, regardless of the higher economy of the type I muscle fibres associated with the higher cadence (Burke, 2003). However, regardless of fibre type predominance, cadences, on either end of the scale, at less than 40 rpm and more than 120 rpm have been found to be significantly less efficient than cadences that fall between 60 to 100 rpm (Umberger, Gerritsen and Martin, 2006).

The influence of blood flow to the muscles on optimal cadence is important to note. During the first third of the crank cycle, when maximum muscle contraction occurs, blood flow and oxygenation to the contracting muscles is significantly restricted (Burke, 2003). This has been recognised as a result of an increase in intramuscular pressure during muscle contraction (Burke, 2003). Therefore, higher cadences may have an advantage over slower cadences, as there is a higher frequency of contraction and relaxation of the muscle, resulting in a shorter period of restricted blood flow to the muscles (Burke, 2003). In addition, the higher cadences tend to minimise the force required per pedal stroke, thereby reducing both the force required by muscle contractions and the recruitment of type II muscle fibres (Atkinson, Davison, Jeukendrup and Passfield, 2003; Burke, 2003).

2.4.4.4 Time

Cycling races may be won by a matter of seconds, across all disciplines of the sport. Whilst track cyclists may battle over the mere split seconds that separate a gold from a silver medal at the Olympic Games, tour stage races may find the top positions separated by less than 10 seconds after 21 days of racing. American cyclist Greg LeMond gained a margin of just 8 seconds over his second place rival Laurent Fignon on the final stage of the 1989 Tour De France, making it the closest finish in the tour's history (LeMond and Gordis, 1990). Tour De France 2007 then saw the closest top 3 finishers in the Tour De France history, with a mere 23 seconds separating the first place Alberto Contador and second place Cadel Evans, and only an 8 second margin to the third place Levi Leipheimer (http://www.cyclingweekly.co.uk/news/latest/346450/the-closest-tours-in-history). Completion time is therefore a vital component of assessment in this study, and would be considered a valuable gain should this study show an improvement as a result of the core strengthening intervention.

2.4.5 Cycle Ergometer versus Outdoor Cycling

Numerous studies designed to investigate the factors affecting cycling efficiency, utilising a cycle ergometer, are limited by the laboratory setting under which the participants are tested (Burke, 2003). It has, however, been noted that the best case studies have been designed with the participants riding their own bicycle on an ergometer (Burke, 2003; Powers and Howley, 1997).

Self-pacing cycling in laboratory testing situations has been suggested to provide a better simulation of outdoor riding (Abt *et al*., 2007). This is attributed to the compensatory kinematic adaptations that take place to maintain a fixed power output in studies utilising fixed speed and gear ratio settings (Abt *et al*., 2007).

The cycle ergometer, one of the most popular ergometers used in exercise physiology studies, imposes the mean cycling velocity in a laboratory setting (Burke, 2003; Powers and Howley, 1997). However, in actual road cycling conditions, external factors are not easily controlled, and as a result, the mean cycling velocity oscillates more than in that of the laboratory testing situation (Burke, 2003).

2.4.6 The Effects of Exercise on Heart Rate

During exercise, the amount of oxygen required by the active muscle tissues increases instantly, resulting in an increased supply to these active muscle tissues, and a decrease to the more inactive muscle tissues, whilst still maintaining enough supply to these tissues to maintain normal functioning (Beneke *et al.*, 1989). The increased heart rate and stroke volume match the increased metabolic demands of the active muscles (Wilmore, Costill and Kenney, 2008). The change in distribution of blood supply to tissues is as a result of metabolic breakdown products that are released during muscle contractions, resulting in an increase in oxygen to the muscles involved in exercising, and an increase in breakdown products and heat being removed (Wilmore, Costill and Kenney, 2008).

Resting heart rate in the average individual ranges between 60 and 80 beats per minute (bpm), however in trained athletes, resting heart rates of 28 to 40 bpm are common (Wilmore, Costill and Kenney, 2008). With improved training status, the increased stroke volume generated at any specific power output reduces the rate at which the heart rate increases, as well as increases the rate at which the heart rate returns to normal post exercise (Carter, Banister and Blaber, 2003). The maximum heart rate is the point at which the highest heart rate value is reached at a maximal exertion, and is often calculated using the formula 220 minus age, due to the age related decrease of about one beat per year, giving an approximate maximum heart rate value (Wilmore, Costill and Kenney, 2008). For example, a 25-year-old individual would have an approximate maximum heart rate of 195, using the formula 200 minus 25. Endurance training does however have an effect on this age related decrease in maximum heart rate, and as a result, the formula may not be applicable in a well conditioned athlete (Wilmore, Costill and Kenney, 2008; Carter, Banister and Blaber, 2003).

There is, however, paucity in the literature on the effects of a core strengthening programme on heart rate measurements. This study aims to investigate these effects in a formal setting, and provide recommendations for future research, as outlined in Chapter Six.

2.5 Measurement Tools

2.5.1 Pressure Biofeedback Unit (PBU)

The Pressure Biofeedback Unit (PBU) is an inelastic, three-section air filled bag, inflated to fill the space between the examination surface and the body, and connected to a pressure dial, used for monitoring the pressure within the bag, providing feedback on the movement of the abdominal wall (Richardson *et al.,* 1999).

Figure 2.5 The Pressure Biofeedback Unit

Although the device has been used for stabilisation exercises for all parts of the body, it has most importantly met the need to quantify the abdominal draw in action. The specific design of the device is advantageous for this purpose. The shape of the bag, when positioned correctly, allows for an evaluation of the movement of the abdomen to be made, in addition to the three-section partitions, allowing for distribution of air within the bag, and the inelastic properties of the bag preventing distortion whilst reflecting abdominal wall movement. [Richardson *et al.,* 1999]

As the fibres of the transversus abdominis muscle are horizontal, they may produce concavity of the abdominal wall without causing movement of the spine. As a result, the transversus abdominis causes narrowing of the abdominal wall, producing a measurable amount of movement of the abdomen, thereby providing a method of identifying the participant's ability to perform the contraction. [Richardson *et al.,* 1999]

2.5.2 Computerised Electromagnetic Roller Resistance Ergometer (Tacx Trainer)

The computerised electromagnetic roller resistance ergometer is a popular device used to provide an accurate measure of performance, including power output, speed and cadence (Powers and Howley, 1997). The computerised electromagnetic roller resistance ergometer used in this study was the Tacx Fortius Virtual Reality Trainer (Tacx Trainer). The Tacx Trainer, consisting of a power unit connected to the rear wheel of a bicycle, uses an electromagnetic brake in addition to the tyre friction to provide resistance to the pedal power, and create a sensation of change in terrain (Jones, 2008). The Tacx Trainer software then records all cycling performance parameters automatically for the purpose of analysis. The Tacx Trainer allows the cyclist to select their preference of gear selection and well as cadence, allowing for self paced cycling and improved simulation of outdoor riding (Tacx I-Magic Manual, 2000).

Figure 2.6 The Tacx Trainer

2.5.3 Rate of Perceived Exertion

The rate of perceived exertion (RPE) scale provides a measure in which athletes are able to rate their perceptions of sensory input and work performed. Gunnar Borg established these scales in 1962, on the principle of psychophysics, which identifies that perception differs from sensation, in that sensation identifies a stimulus, whereas perception interprets the external stimulus. [Scherer and Cassady, 1999]

Borg (1998) developed a 15-point scale, which has a range from six to 20, with each number designed to correlate with an exercising heart rate of 10 times that number. A high correlation between the actual heart rate and rate of perceived exertion was identified. Although this formula is not exact, a high correlation between heart rate and rate of perceived exertion has been identified, particularly supporting the reliability at exercise intensities of over 70% of maximum heart rate in the last minute of each stage of exercise. [Scherer and Cassady, 1999]

The numerous stimuli produced by exercise are all factors that affect an athlete’s perception of their exertion (Sellers, 2007; Borg and Kaijser, 2006; Scherer and Cassady, 1999). These stimuli can be categorised into physiological, psychological, external, and symptoms. Physiological stimuli include respiratory and metabolic reactions such as increased respiratory rates and ventilation at a central level, and at a peripheral level, changes in glucose levels, pH levels of blood, and lactate production. Psychological stimuli include mood, motivation, and the experience of the exercise. External factors are directly related to the testing environment, and focus mainly on the competitive settings of the environment (Scherer and Cassady, 1999). The symptoms that may influence an athlete's perception may include sweating, heavy breathing and muscular fatigue (Sellers, 2007).

Although various RPE scales have been developed, the most popular and most commonly used is the 15-point scale (Scherer and Cassady, 1999). When used in conjunction with actual heart rate readings, the scale can identify the individual's ability to tolerate the strain of the test exercise (Sellers, 2007). Interestingly, most individuals rated between 17 and 19 most commonly, with very few rating a maximum of 20 (Scherer and Cassady, 1999). Heart rate measurements have been found to respond well to variations in cycling power, and as such, have been used to estimate physical exertion during cycling for many years (Wilmore, Costill and Kenney, 2008; Burke, 2003). However, it should be noted that heart rate is affected by environmental factors such as temperature and humidity, and as such, may reflect the physiological stress on the individual during exercise (Wilmore, Costill and Kenney, 2008; Burke, 2003). The relationship between heart rate and perceived exertion has shown a high correlation, particularly in young to middle aged adults, regardless of varying fitness levels (Scherer and Cassady, 1999).

2.6 The Hawthorne Effect

It is important to consider the Hawthorne effect when conducting clinical research, as the performance or behaviour of an individual may be altered simply by the awareness that the individual is being observed (De Amici, Klersy, Ramajoli, Brustia and Politi, 2000).

The Hawthorne effect, which takes its name from the Hawthorne Works factory, part of Western Electrical Company, where studies were first conducted in the 1920's has become the topic of numerous organisational behavioural studies (Porter, 2012). Early studies revealed that regardless of the inclusion or exclusion of various environmental factors, productivity continued to increase as a result of the awareness that the individuals were under supervision (Porter, 2012).

The Hawthorne effect will therefore be considered when analysing results, although it should not affect the assessment of the difference between pre- and post- experimental readings (McCarney, Warner, Iliffe, Haselen, Griffin and Fisher, 2007; De Amici *et al*., 2000).

2.7 Conclusion

Despite the growing popularity of core strengthening as a performance enhancement tool in the sporting environment, the research regarding its effects on performance, especially in the field of cycling, is limited. This study, therefore, aims to investigate the effects of core strengthening on cycling performance in asymptomatic cyclists.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

This chapter provides an outline of how the study was conducted. The study design, sample and recruitment, inclusion and exclusion criteria, study procedure and measurement tools, as well as statistical analysis procedures will be described. This study was granted full approval and ethical clearance through the Durban University of Technology's Institutional Research Ethics Committee – IREC 024/12 (**Appendix L**). This approval satisfied the standards set by the Helsinki Declaration of 1975 (Johnson, 2005).

The following flow chart outlines a summary of the research procedure:

Cyclists responded to advertisement.

↓

Inclusion or exclusion of respondent and appointment scheduled.

↓

Participant arrived with their own road bicycle.

↓

Research procedure was explained to the participant.

↓

Letter of Information and Informed Consent was read and signed by participant.

↓

Case history and relevant physical examinations were completed.

↓

Training style and riding status questionnaire were completed.

↓

Participant was taught how to perform a core contraction correctly for the purposes of the assessment, using the four point kneeling position.

↓

Core strength assessments were performed using the Pressure Biofeedback Unit (PBU) for the abdominal draw in test (prone) and the test for lumbopelvic posture (supine).

↓

Participant's road bicycle was mounted on the cycle ergometer (Tacx Trainer).

↓

Participant completed a warm up of 10 minutes.

↓

Participant completed a time trial of 1.5 km, during which, at each change in terrain, the researcher completed a rate of perceived exertion scale (RPE) and recorded the actual heart rate.

↓

Measurements of maximum and average speed, power and cadence, and completion time were recorded on data collection sheet.

↓

Participant was taught the core strengthening exercise programme from the handout and asked to demonstrate the exercises to the researcher to ensure correct technique.

↓

Participant was issued with a training diary and core strengthening programme handout.

↓

Participant was instructed to continue with their standard cycling training and supplementation for the duration of the intervention. Participants were also required to avoid participation in cycling races for the duration of the intervention.

↓

Researcher contacted the participant on a weekly basis during intervention to monitor progress and compliance and address any concerns.

↓

After the intervention period, participant returned to the Chiropractic Day Clinic with their road bicycles.

↓

Participant demonstrated the core exercises to confirm that correct technique was used.

↓

Participant performed the core assessment and cycling performance tests once again.

↓

Results were recorded on the data collection sheet, the training diary was handed in and participant completed a participant feedback form.

Figure 3.1 Flowchart Illustrating Overview of Research Procedure

3.2 Study Design

This study was designed as a quantitative, pre- and post- experimental trial.

3.3 Sample and Recruitment

A sample size of 40 participants was recruited to participate in the study (Esterhuizen, 2012; Cunninghame 2009; Martin, 2006).

Participant recruitment occurred via convenience sampling (Ferber, 2010), utilising advertisements (**Appendix A**), and word of mouth. Permission was obtained to place advertisements at the Durban University of Technology, local sports clubs and cycling shops. Respondents to the advertisement were contacted telephonically, and asked if they were happy to answer study related questions.

The following questions were asked of the respondents to ensure that they satisfied the study criteria:

Table 3.1 Questions and Answers from Respondents for them to Qualify to Participate in the Research Study

Questions asked of respondents	Answers from respondents to qualify to participate in research study
Are you between the age of 20 and 50?	Yes
Have you been cycling regularly for the past one year?	Yes
Do you cycle for a minimum of 6 hours per week?	Yes
Are you currently pain free in the lower back and lower limb regions, including the hip, knee and ankle?	Yes
Do you agree to not participate in any competitive events for the duration of the study?	Yes

If the respondent fulfilled the criteria, an appointment was made at the Durban University of Technology Chiropractic Day Clinic.

3.4 Inclusion and Exclusion Criteria

3.4.1 Inclusion Criteria

1. All participants agreed to sign a Letter of Information and Informed Consent (**Appendix B**).
2. All participants were between the ages of 20 and 50. All participants completed the same assessments and intervention. Participants were stratified into two groups according to age, 20 to 35 years of age and 36 to 50 years of age, for the purpose of analysis. This allowed for analysis of the whole sample, as well as further analysis into the effect of age on core strength improvements and cycling performance. These ages also excluded the need for parental consent and the risk of degenerative changes (Beers, Porter, Jones, Kaplan and Berkwits, 2006)
3. All participants were asymptomatic in regions from the lumbar spine to the lower extremity, including the hip, knee and ankle. This ensured that the effects of the core muscle strengthening were not obscured due to the inhibition of muscles as a result of arthrogenic muscle inhibition (Hopkins and Ingersoll, 2000).
4. Participants agreed to not participate in any competitive events for the duration of the study.
5.

5.1 Participants had actively participated in cycling on a regular basis for a minimum of six hours per week for a period of at least the last one year.

5.2 This training had been consistently on a road bicycle.

3.4.2 Exclusion Criteria

1. Participants with any current injury that impaired the cycling biomechanics were excluded from the research study.
2. Participants that already included a core strengthening programme into their training were excluded from the study.
3. Participants who developed any pain in regions from the lumbar spine to the lower extremity, including the hip, knee and ankle during the intervention period were excluded from the study. In the unlikely event that this would happen, the participant would have been referred to the Chiropractic Day Clinic for a complimentary assessment and treatment.

3.4.3 Participant Informed Consent

At the initial consultation, each participant received a Letter of Information and Informed Consent (**Appendix B**), giving a detailed explanation of what the study entailed, and providing the participant with an opportunity to ask any questions regarding the study. The Letter of Information and Informed Consent also informed participants that they were free to withdraw from the study at any time, and that this would not jeopardise any future treatments at the facility.

All participant details were kept confidential. Participant's names were coded for data collection and analysis, and were accessed only by the researcher and her supervisor. The case history and relevant physical examination at the initial consultation was discussed only with the clinician on duty on the day of the initial consultation.

3.5 Procedure

A sample population size of 40 participants was recruited to participate in the study (Esterhuizen, 2012; Cunninghame, 2009; Martin, 2006). The study took place over a period of 4 weeks (Defreitas, Beck, Stock, Dillon and Kasishke, 2011; Clarke, 2009; Kuszewski, Gnat and Saulicz, 2009; Smit, 2009; Spangenburg, 2009; Campbell, 2007; Ludmila, Cosio-Lima, Reynolds, Paolone and Jones, 2003; Piegaro, 2003; Boden, 2002; Staron, Karapondo, Kraemer, Fry, Gordon, Falkel, Hagerman and Hikida, 1994), involving two consultations, an initial and follow up. Science has demonstrated that there is a molecular, biological, physiological and measurable improvement in skeletal muscle tissue after four weeks of a structured exercise programme, and in addition, studies have also shown statistically significant results after four weeks of core strengthening exercise (Defreitas *et al*., 2011; Camera, Anderson, Hawley and Carey, 2010; Clarke, 2009; Kendall, Smith, Graef, Fukuda, Moon, Beck, Cramer and Stout, 2009; Kuszewski *et al*., 2009; Smit, 2009; Spangenburg, 2009; Campbell, 2007; Ludmila *et al*., 2003; Piegaro, 2003; Boden, 2002; Staron *et al*., 1994). The independent variable assessed was the Core Muscle Strengthening.

Consultations took place at the Durban University of Technology Chiropractic Day Clinic. If the respondent met the inclusion criteria, a Letter of Information and Informed Consent was read and signed (**Appendix B**). Following this, a case history and relevant physical examination was completed (**Appendix C and D**). Participants then completed a Training Status and Riding Style Questionnaire (**Appendix E**). The questionnaire (**Appendix E**) was adapted from a study conducted by Mills (2006). Participants were required to attend both consultations with their own current road bicycle, on which most of the training was done, so as to eliminate variables in gearing, tyres, and riding position, thus allowing musculoskeletal function during cycling to be studied in a laboratory environment (Burke, 2003). No changes were made to the bicycle during the consultation or the intervention period, in order to maintain standard riding setup.

Core strength was measured using a pressure biofeedback unit (PBU). Participants were shown how to perform the required core muscle contraction prior to the tests (**Appendix I**). The four point kneeling procedure was used to demonstrate how to perform a core muscle contraction (Richardson *et al.*, 1999; Richardson and Jull, 1995). The tests entailed an abdominal draw in test in the prone position, and a lumbopelvic posture test in the supine position. All data from these tests was collected and recorded on a Data Collection Sheet (**Appendix J**).

The participant was then seated on their own current road bicycle on an electromagnetic roller resistance ergometer, (Tacx Trainer) (Tacx I-Magic Manual, 2000). The participant was expected to complete a warm up of 10 minutes at their own pace (Hajoglou, Foster, De Koning, Lucia, Kernozek and Porcari. 2005), followed by a standing start 1.5 km time trial (Corbett, 2009), as programmed by the Tacx Trainer, in as fast a time as possible. Results including maximum and average speed (km/h), power (w), and cadence (rpm), and overall completion time (min), as well as heart rate (bpm), were recorded on a data collection sheet (**Appendix J**).

Figure 3.2 The Tacx Trainer Software Programme

Source: K Wiseman

Participants rode an unrestricted, self-paced trial to accurately simulate outdoor riding (Abt *et al.*, 2007); however, they were required to do so in a seated position to maintain pelvic position for the purpose of this study. The course was structured so as to include a 1100 m flat, broken down into a first and second 550 m flat, followed by a 300 m incline and a 100 m decline. A Rate of Perceived Exertion Scale (**Appendix F**) was completed by the researcher at each of these stages during the time trial. This scale, adapted from Borg (1998), incorporates the individual's perception of heart rate, sweating, breathing rate and muscular fatigue as the common denominators (Sellers, 2007). When used in conjunction with measuring actual heart rate, this scale may verify the individual's actual level of intensity (Sellers, 2007). Results were recorded on the data collection sheet (**Appendix J**).

Figure 3.3 The Cycling Performance Assessment Setup
Source: K Wiseman

Participants then had the core exercises demonstrated, and an opportunity to practice them to ensure correct technique. The participants also received an exercise handout sheet detailing the core training exercises (**Appendix H**), as well as a training diary (**Appendix G**).

Participants were instructed to continue with their standard cycling training and supplementation, without alterations, throughout the research process. They were also requested to avoid participation in cycling races for the duration of their participation in the study, in order to prevent variables that may have arisen from such activity, from interfering with the study results.

Participants were contacted telephonically on a weekly basis for the duration of the four week intervention, to monitor progress and compliance, and address any concerns they may have had. A suitable time was established at the initial consultation for these phone calls to take place.

Following the four week intervention period, participants returned to the Durban University of Technology Chiropractic Day Clinic with their same road bicycle that was used at the initial consultation, and training diary. Participants performed the core strengthening exercises to ensure correct technique was maintained throughout the intervention. Should the technique have been incorrect, the participant would have been excluded from the research study. Participants were then assessed again in terms of core strength using the pressure biofeedback unit (PBU), in prone and supine tests (Richardson *et al.*, 1999). The participants then completed the same warm up and 1.5 km time trial as per the initial consultation, and results were recorded on the data collection sheet (**Appendix J**). A rate of perceived exertion scale (**Appendix F**) was again completed by the researcher during the time trial. Participants handed in their training diary, and completed a participant feedback form (**Appendix F**).

3.6 Measurement Tools

3.6.1 Objective Measurement Tools

Objective data was collected during the initial and follow up consultations.

3.6.1.1 Pressure Biofeedback Unit (PBU)

The Pressure Biofeedback Unit (PBU), consisting of an inelastic, three-section air-filled bag and a pressure cell to monitor pressure in the bag for feedback on the movement was utilised in this study. The pressure changes were specific to the movement detected, with movement of the body off the bag resulting in a decrease in pressure, and movement of the body onto the bag resulting in an increase in pressure. [Richardson *et al.*, 1999]

The PBU was utilised once recruitment of the transversus abdominis to elicit a core contraction had been established. Participants were taught to recruit the transversus abdominis (TA) and to elicit a core contraction using the four point kneeling procedure (**Appendix I**). This position was such that the participant's hips were over the knees, the shoulders directly over the hands and the elbows relaxed. Participants were instructed to avoid deep inspiration, in order to minimise movement of the abdominal wall. Participants were then instructed to take a relaxed breath in and out, and without breathing in, draw the abdomen up and in towards the spine, whilst maintaining a neutral steady position of the spine. Participants resumed normal breathing once the contraction had been elicited, and was to be sustained for 10 seconds. The four point kneeling position allowed the participants to gain an increased awareness of the abdominal wall, and as such, the contraction being performed. [Richardson *et al*., 1999]

The abdominal draw in test was performed with the participant in the prone position. Initially, when the unit is placed under the abdomen in the prone test, it conforms to the participants shape, however, as the participant performs a contraction, the stomach is drawn off the bag and the pressure is reduced. The PBU was placed under the abdomen of the participant, with the umbilicus in the centre of the bag, and the inferior distal margins of the bag in line with the right and left anterior superior iliac spines. The pressure bag is inflated to 70 mmHg, and allowed to stabilise. This allows for detection of fluctuations of approximately 2 mmHg for each inhalation and exhalation, as a result of normal breathing. [Richardson *et al*., 1999]

Participants were instructed to perform a contraction as taught in the four point kneeling position. A drop of 6-10 mmHg with contraction is considered normal, indicating that the participant was able to contract the transversus abdominis muscle independently of the global abdominal muscles. Failure to create a sufficient drop in pressure may be due to an inability to activate the transverses abdominis, or recruitment of the global abdominal muscles. Following successful performance of the test, participants were allocated a two minute rest period, followed by a test of endurance. The abdominal draw in test was repeated, and the participant was required to maintain the core contraction, whilst recommencing normal, relaxed breathing. The core contraction was held for as long as possible, whilst the pressure gauge was monitored by the researcher, to identify any compensatory mechanisms being utilised. The contraction time was measured using a stopwatch and the results recorded. The difference in pressure (mmHg) was measured and fluctuations recorded. [Richardson *et al.*, 1999; Richardson and Jull, 1995]

The test for lumbopelvic posture was used to examine the ability of the trunk muscles to stabilise the lumbopelvic region during a sequence of progressive leg loading exercises. This test was performed with the participant in a supine crook lying position, so as to eliminate movements resulting from lack of balance, thereby allowing for accurate monitoring of the lumbopelvic position. The pressure biofeedback unit was placed under the lumbar spine of the participants, allowing for detection of movement in the lumbar spine. Bilateral measurements were assessed in the sagittal plane as well as for rotary bias. If leg loading was directed in the sagittal plane, the bag was placed across the lumbar spine with the base of the bag at the level of S2, whereas if the leg loading indicated a rotary bias, the bag was positioned longitudinally along the lateral aspect of the lumbar spine, on the side that was to be assessed. [Richardson *et al.*, 1999; Richardson and Jull, 1995]

Figure 3.4 The Core Strength Assessment Position

Source: K Wiseman

The PBU was inflated to 40 mmHg and the participant was asked to observe the reading on the gauge for the duration of the testing. The participant then performed a core contraction, during which, a slight increase in pressure was expected. The participant was instructed to maintain this pressure reading throughout testing. When assessing sagittal control, the legs were placed together in an adducted position, and in an abducted position when assessing rotary bias. The participant then performed leg loading movements in this position, whilst maintaining the core contraction. Leg loading movements were performed by sliding the heel along the surface of the examination plinth, and then returning the heel to the starting position. [Richardson *et al.*, 1999]

For the purpose of this study, grade 1a required participants to perform a single leg slide on the examination surface, with contralateral leg support, whilst grade 1b required participants to perform an unsupported single leg slide with the heel of the test leg held 5 cm above the examination surface, with contralateral leg support. If significant pressure changes were observed on leg loading at grade 1a, participants were recorded as displaying poor core control, and at grade 1b, as displaying below average core control. Participants that were able to complete the grade 1 progression, were then required to perform a single leg slide with the contralateral leg unsupported for grade a, and would be recorded as displaying good core control. Finally, participants showing minimal pressure changes were required to perform an unsupported single leg slide with the heel of the test leg held 5 cm above the examination surface, with the contralateral leg unsupported. Significant pressure changes, as well as failure to keep the abdomen drawn in, indicated that the leg load had exceeded the muscle capacity. Participants were graded according to the point at which they could no longer maintain a lumbopelvic posture. [Richardson *et al.*, 1999]

The pressure biofeedback unit was purchased and calibrated prior to the commencement of the research study. The same pressure biofeedback unit was utilised throughout the research study to maintain reliability.

3.6.1.2 Computerised Electromagnetic Roller Resistance Ergometer (Tacx Trainer)

The computerised electromagnetic roller resistance ergometer (Tacx Trainer) consists of a power unit connected to the rear wheel of the bicycle. This transmits data to a linked computer, which then records data including maximum and average speed (km/h), power (w), and cadence (rpm), and overall completion time (min), as well as heart rate (bpm). These readings were used to determine the power and performance capabilities of the cyclist (Tacx I-Magic Manual, 2000).

All time trials took place on the participants own current road bicycle, on which most training is done, mounted on the Tacx Trainer (Burke, 2003; Ettema, Loras and Leirdal, 2009). The importance of the use of the same bicycle for each consultation is due to the elimination of variables including gearing, tyres, and riding position (Burke, 2003). No changes were made to the bicycle during the consultation or the intervention period, in order to maintain standard riding setup.

The Tacx Trainer was automatically calibrated prior to the start of each time trial, as per the Tacx Manual Settings.

3.6.2 Subjective Measurement Tools

Subjective data was collected during the initial and follow up consultations.

3.6.2.1 Training Diary

The training diary (**Appendix G**) was used as a motivational tool, and issued at the initial consultation and collected following the intervention, at the follow up consultation.

3.6.2.2 Rate of Perceived Exertion Scale

The Rate of Perceived Exertion Scale and accompanying actual heart rate readings (**Appendix F**) was completed at the initial and follow up consultation. This scale, adapted from Borg (1998), incorporates the individual's perception of heart rate, sweating, breathing rate and muscular fatigue as the common denominators (Sellers, 2007). When used in conjunction with measuring actual heart rate, this scale may verify the individual's actual level of intensity (Sellers, 2007). This information could be used to determine a clinical significance.

3.6.2.3 Participants' Perception of Change in Speed, Power and Cadence

The participants' perception of change in speed, power and cadence (**Appendix F**), was completed following all assessments at the follow up consultation, as part of the participants feedback form.

3.6.2.4 NRS Discomfort Scale

The NRS Discomfort Scale (**Appendix J**) was utilised in this study as a discomfort scale, as opposed to the conventional use as a pain scale. The scale was completed following the cycling trials pre- and post- intervention, to determine whether the discomfort associated with the exertion during the cycling trial improved post- intervention. This scale relates purely to the exertion, muscle fatigue and breathing rate during the cycling trial, and not to any pain, as all participants will be asymptomatic with regards to pain in the lower kinematic chain. This could provide a clinically significant measure, using a minimum clinically significant difference of 1.39 (Kendrick and Strout, 2005).

3.7 Statistical Analysis

SPSS version 20 (SPSS Inc) was used to analyse the data (**Appendix J**). For the descriptive objectives, the quantitative data was summarised using mean and standard deviation and range. In order to compare pre- and post- measurements, paired *t*-tests were used for each variable separately. Data was further stratified into two age groups for within-groups analysis using the above mentioned statistical methods. A significance level of $p < 0.05$ was used (Esterhuizen, 2012).

3.8 Modifications to Methodology

Due to the nature of this study and the intervention period, the researcher felt it necessary to collect data from additional participants, to account for possible exclusion of participants due to non-compliance or injury. As a result, a total sample size of 52 participants was recruited for this study, with a final sample of 42 participants' data being analysed. The 10 participants that were therefore excluded from the study will be discussed further in Chapter Five.

CHAPTER FOUR

RESULTS

4.1 Introduction

This chapter reveals the results obtained from the statistical analysis of the data collected.

4.2 Data

Data sources utilised in this study were compiled from both primary and secondary sources of information.

4.2.1 Primary Data

Primary data included the information collected by the researcher during the initial and follow up consultations, in the form of the Data Collection Sheet (**Appendix J**), Training Status and Riding Style Questionnaire (**Appendix E**), and Rate of Perceived Exertion Scale (**Appendix F**).

4.2.2 Secondary Data

Secondary data included the data acquired from personal communications with the statistician (Esterhuizen, 2012), as well as literature, journals, books, and internet sources that were used in the construction of the discussions and comparisons of this study.

4.3 Physical Characteristics and Demographic Data

Physical characteristics and demographic data consisting of gender, age, height, mass, body mass index (BMI), training status and riding style were analysed, in the whole sample as well as between the two age strata. The following tables and figures reflect these results. Figures can be found in table format in the Statistical Results (**Appendix M**).

The sample inclusion criteria allowed for both male and female participants. Table 4.1.1 reveals a majority male sample (85.7%).

Table 4.1.1 Gender of Participants

Gender	Frequency	Percent
Male	36	85.7
Female	6	14.3
Total	42	100.0

Table 4.1.2 reflects the gender of participants, stratified into two age groups, 20 to 35, and 36 to 50.

Table 4.1.2 Gender of Participants Stratified by Age Group

	Age Group			
	20-35		36-50	
Gender	**Frequency**	**Percent**	**Frequency**	**Percent**
Male	20	90.9	16	80.0
Female	2	9.1	4	20.0
Total	22	100.0	20	100.0

The physical characteristics of the participants who completed this clinical trial are summarised in Table 4.2.1, and stratified into two age groups in Table 4.2.2. The sample was made up of 42 cyclists, with a mean age of 34.1 ± 9.0 years, and a mean BMI of 24.6 ± 3.7.

Table 4.2.1 Summary Statistics of Physical Characteristics of Participants

	Mean	Standard Deviation	Minimum	Maximum
Age	34.1	9.0	20.0	47.0
Height (m)	1.80	0.1	1.5	2.0
Mass (kg)	76.4	15.0	52.0	122.0
BMI	24.6	3.7	19.4	34.7

Table 4.2.2 Summary Statistics of Physical Characteristics of Participants Stratified by Age Group

	Age Group			
	20-35		36-50	
	Mean	Standard Deviation	Mean	Standard Deviation
Age	26.7	5.2	42.2	3.4
Height (m)	1.80	0.1	1.80	0.1
Mass (kg)	74.4	10.6	78.6	18.7
BMI	24.1	2.6	25.2	4.5

Participants completed a training status and riding style questionnaire, including cycling preference, riding style preference, level of training, level of experience, and level of cycling ability.

Figure 4.1.1 illustrates a strong preference of the whole sample to road cycling, closely followed by mountain biking, and a combination of road and mountain biking. Track cycling had the minority preference, with only two participants in the whole sample, one from each age strata. The combination of road cycling and mountain biking was more popular amongst the 36-50 age strata, than the 20-35 age strata, who were more selective with their preference of either road cycling or mountain biking.

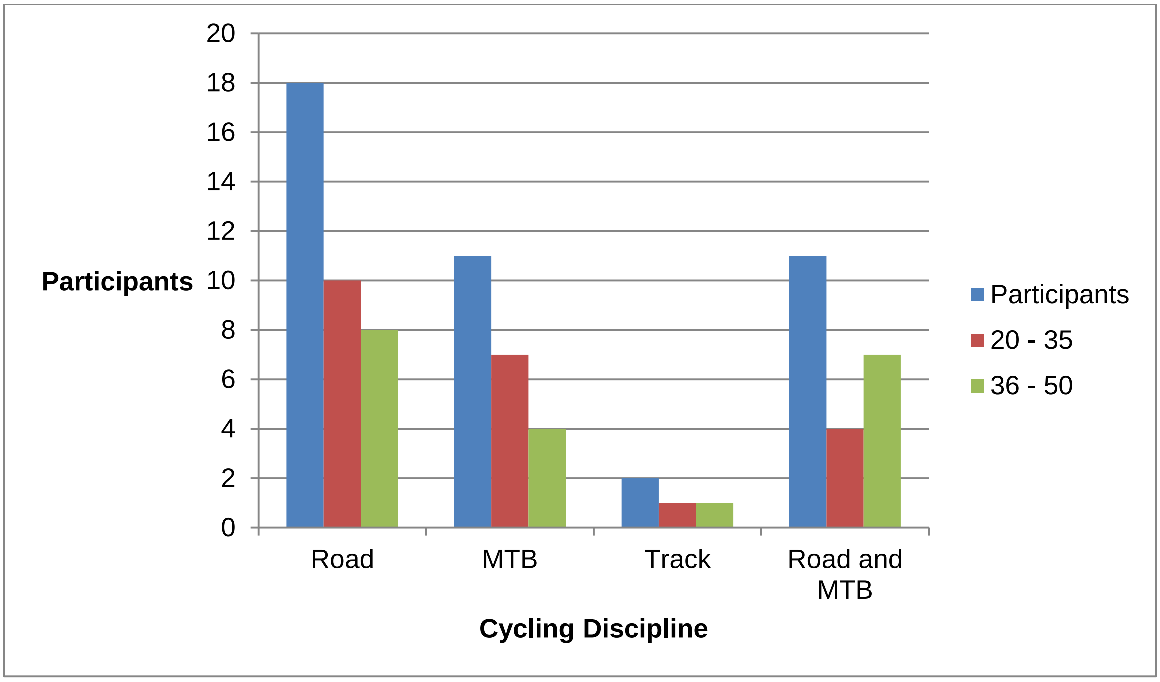

Figure 4.1.1 Participants Preference to Road, MTB or track cycling, or a combination of road and MTB cycling

Figure 4.1.2 represents the preference in riding style of participants. Throughout the sample, hill climbing was the most popular, followed by cadence over 100 rpm. The remaining participants in the younger age strata showed a preference to cadence below 60 rpm, whereas the remaining participants in the older age strata showed a preference to sprinting.

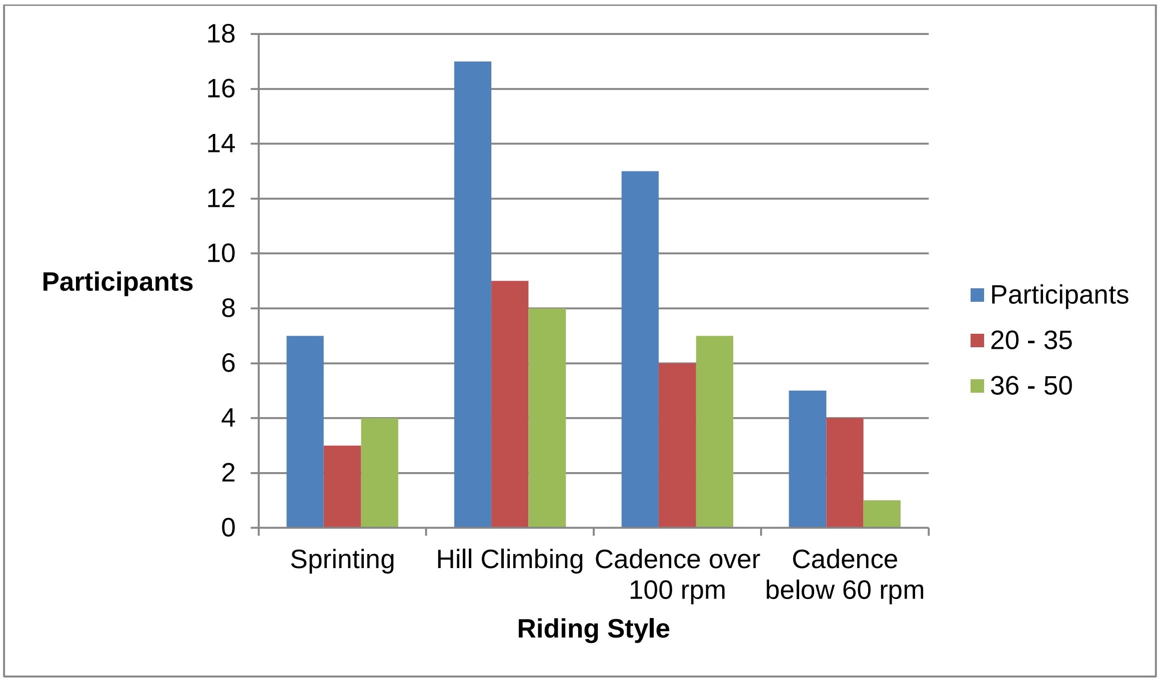

Figure 4.1.2 Participants Riding Style Preference

The participants' average training hours per week is represented in Figure 4.1.3. The vast majority of participants throughout the sample trained for an average of between 6 to 10 hours per week. The 16-20 hours per week category was prevalent for only one participant in the 20-35 age strata, whilst the over 21 hours per week category was populated with two participants from each age strata. The 11 to 15 hours per week category was prevalent for seven participants from the 36-50 age strata, as opposed to five participants from the 20-35 age strata.

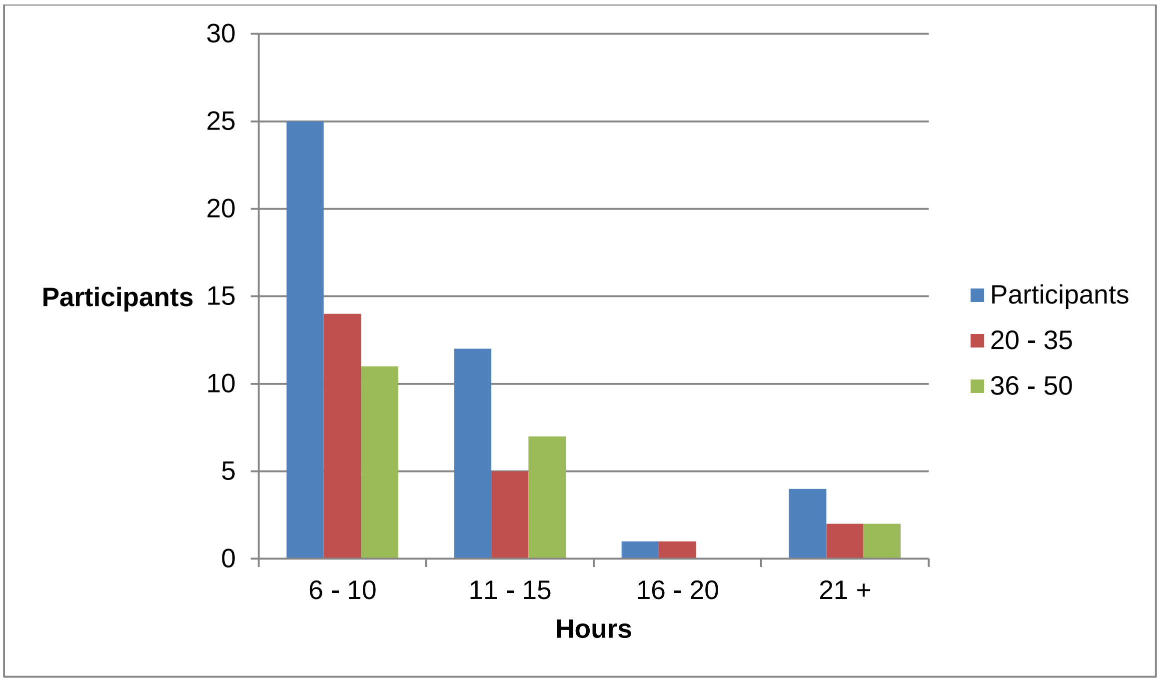

Figure 4.1.3 Participants Average Training Hours per Week

Participants' reported various levels of cycling experience, as represented in Figure 4.1.4. The majority of participants had been actively participating in cycling for between 1 and 5 years. For categories between 6 to 10 years and 10 to 15 years, participants' level of activity was similar. The 15 to 20 years category was visibly the minority, however the over 20 years category was populated by four participants.

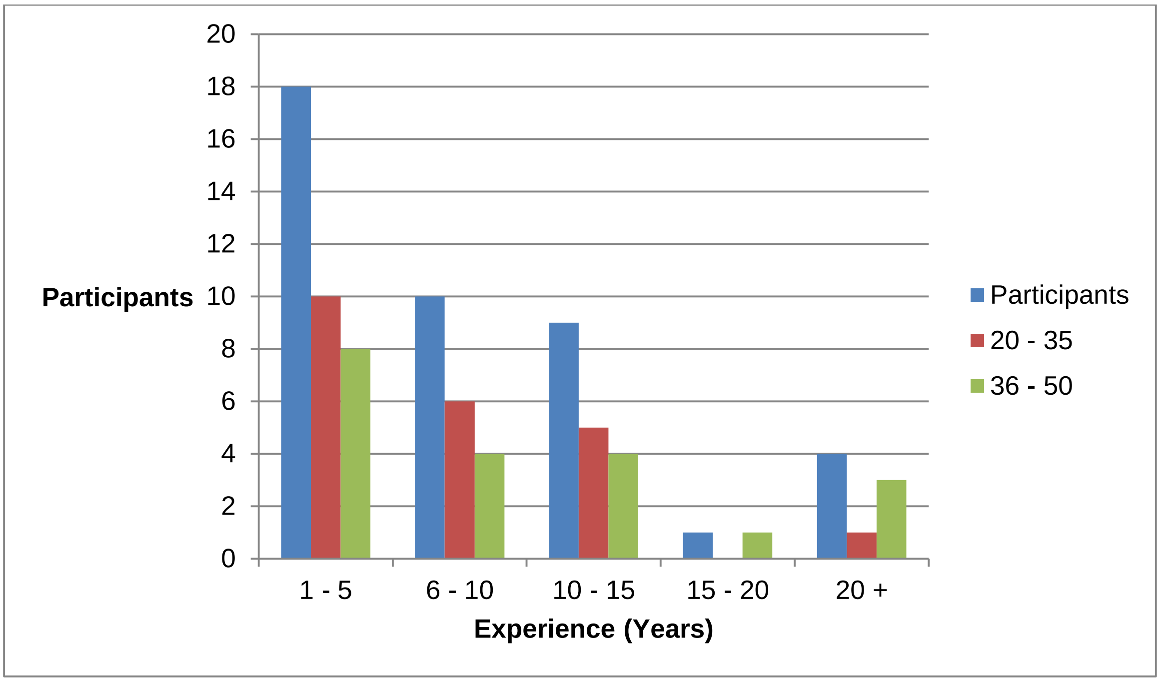

Figure 4.1.4 Participants Level of Cycling Experience

Participants of this study mostly classified themselves as serious amateurs. Only three participants considered themselves to be social cyclists, and a total of eight participants were classified as elite cyclists. Strictly professional cyclists did not participate in this study. The participants level of cycling ability is represented in Figure 4.1.5.

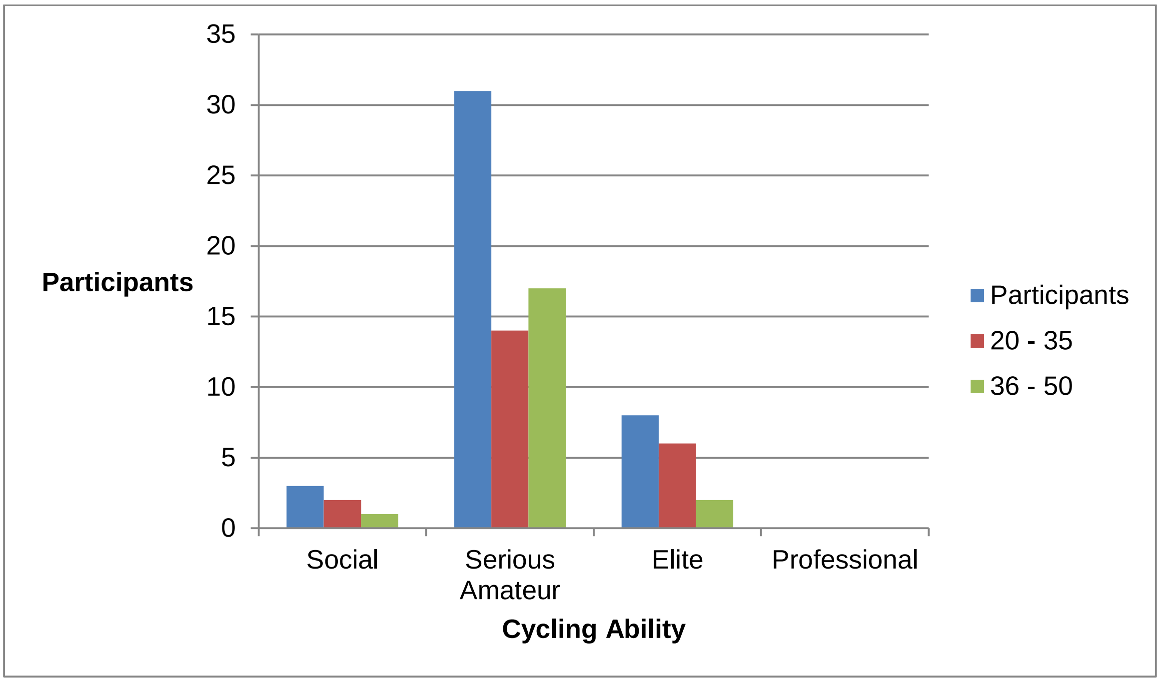

Figure 4.1.5 Participants Level of Cycling Ability

4.4 Core Strength

Paired *t*-tests were used to compare the initial, pre- intervention core strength measurements and the follow up, post- intervention core strength measurements.

Participants completed core strength assessments in the prone position for the abdominal draw in test and in the supine position for the lumbopelvic posture and leg loading tests. Tables 4.3.1 and 4.3.2 represent the measurement results for the core strength assessments.

Table 4.3.1 Mean (± SD) Core Strength Measurements, and Range, for the Initial and Follow Up Consultations

		Initial		**Follow Up**	
		Mean (± SD)	**Range**	**Mean (± SD)**	**Range**
Prone Test	Fluctuation	62.8 (± 1.4)	60.0 – 64.0	61.2 (± 1.4)	60.0 – 64.0
	Difference	-7.2 (± 1.4)	-10.0 - -6.0	-8.8 (± 1.4)	-10.0 - -6.0
	Timing	63.6 (± 43.0)	16.0 – 242.0	147.3 (± 137.8)	24.0 – 644.0
Supine Test	Fluctuation – right	34.6 (± 6.6)	28.0 – 48.0	35.1 (± 4.7)	28.0 – 48.0
	Fluctuation – left	34.3 (± 6.5)	28.0 – 48.0	35.0 (± 5.0)	28.0 – 48.0
	Difference – right	-5.4 (± 6.6)	-12.0 – 8.0	-4.9 (± 4.7)	-12.0 – 8.0
	Difference – left	-5.7 (± 6.5)	-12.0 – 8.0	-5.0 (± 5.0)	-12.0 – 8.0
	Grading – right	2.0 (± 0.6)	1.0 - 3.0	2.9 (± 0.6)	2.0 – 4.0
	Grading – left	1.9 (± 0.6)	1.0 – 3.0	2.9 (± 0.6)	2.0 – 4.0

Units – mmHg

Table 4.3.2 Mean (± SD) Core Strength Measurements for the Initial and Follow Up Consultations in the 20 - 35 and 36 – 50 Age Strata

		20 - 35		**36 - 50**	
		Initial	**Follow Up**	**Initial**	**Follow Up**
		Mean (± SD)	**Mean (± SD)**	**Mean (± SD)**	**Mean (± SD)**
Prone Test	Fluctuation	62.9 (± 1.3)	60.9 (± 1.2)	62.7 (± 1.5)	61.5 (± 1.6)
	Difference	-7.1 (± 1.3)	-9.1 (± 1.2)	-7.3 (± 1.5)	-8.5 (± 1.6)
	Timing	63.6 (± 25.5)	133.3 (± 78.1)	63.5 (± 57.1)	162.8 (± 183.8)
Supine Test	Fluctuation – right	33 (± 6)	35.5 (± 5.0)	36 (± 7)	34.8 (± 4.5)
	Fluctuation – left	34 (± 7)	34.7 (± 5.5)	35 (± 6)	35.3 (± 4.5)
	Difference – right	-7 (± 6)	-4.5 (± 5.0)	-4 (± 7)	-5.2 (± 4.5)
	Difference – left	-6 (± 7)	-5.3 (± 5.5)	-5 (± 6)	-4.7 (± 4.5)
	Grading – right	1.91 (± 0.61)	2.8 (± 0.6)	2.00 (± 0.65)	3.1 (± 0.6)
	Grading – left	1.86 (± 0.56)	2.8 (± 0.6)	1.95 (± 0.60)	3.0 (± 0.6)

Units - mmHg

Paired *t*-tests were used to compare the core strength measurements for the initial and follow up consultations. Tables 4.3.3 and 4.3.4 show that there was a significant change in fluctuation, difference, and timing from pre- to post- intervention (p < 0.001) for the abdominal draw in test. Mean differences were statistically significant for fluctuation and difference, and for timing, indicating a decrease in fluctuation and difference, and an increase in timing. Grading for the test for lumbopelvic posture and leg loading increased significantly on both the left and right side.

Table 4.3.3 Mean (± SD) Core Strength Statistics for Prone Assessments

Initial – Follow Up	Mean (± SD)	*P* value
Fluctuation	1.619 (± 1.413)	0.000
Difference	1.619 (± 1.413)	0.000
Timing	-83.762 (± 107.055)	0.000

p* < 0.001; paired *t*-tests** ***Units - mmHg

Table 4.3.4 Mean (± SD) Core Strength Statistics for Supine Assessments

Initial – Follow Up	Mean (± SD)	*P* value
Fluctuation – right	-0.571 (± 5.306)	0.489
Fluctuation – left	-0.714 (± 4.974)	0.358
Difference – right	-0.571 (± 5.306)	0.489
Difference – left	-0.714 (± 4.974)	0.358
Grading – right	-0.97619 (± 0.34838)	0.000
Grading – left	-1.00000 (± 0.31235	0.000

p* < 0.001; paired *t*-tests** ***Units - mmHg

Significant changes (p < 0.001) were noted in the 20 to 35 age strata, with positive mean differences for fluctuation and difference, and negative for timing, again indicating a decrease in fluctuation and difference, and an increase in timing for the abdominal draw in test. Right fluctuation and difference decreased significantly on the test for lumbopelvic posture, and grading again increased significantly on both the right and left side. Table 4.3.5 and Table 4.3.6 reflect these results.

Table 4.3.5 Mean (± SD) Core Strength Statistics for Prone Assessments for the 20 - 35 Age Strata

Initial – Follow Up	Mean (± SD)	*P* value
Fluctuation	2.000 (± 1.512)	0.000
Difference	2.000 (± 1.512)	0.000
Timing	-69.636 (± 64.908)	0.000

p* < 0.001; paired *t*-tests** ***Units - mmHg

Table 4.3.6 Mean (± SD) Core Strength Statistics for Supine Assessments for the 20 – 35 Age Strata

Initial – Follow Up	Mean (± SD)	*P* value
Fluctuation – right	-2.182 (± 3.487)	0.008
Fluctuation – left	-0.909 (± 3.069)	0.179
Difference – right	-2.182 (± 3.487)	0.008
Difference – left	-0.909 (± 3.069)	0.179
Grading – right	-0.90909 (± 0.29424)	0.000
Grading – left	-0.95455 (± 0.21320)	0.000

p* < 0.001; paired *t*-tests** ***Units - mmHg

Similarly, results for the 36 to 50 age strata showed significant changes, as shown in Tables 4.3.7 and 4.3.8. Fluctuation, difference, and timing again showed significant changes (p < 0.001) from pre- to post- intervention. The average values decreased for fluctuation and difference and increased for timing. Grading changes were similar to that of the 20 to 35 age strata, as was the difference and fluctuation on the right side during lumbopelvic posture and leg loading tests.

Table 4.3.7 Mean (± SD) Core Strength Statistics for Prone Assessments for the 36 – 50 Age Strata

Initial – Follow Up	Mean (± SD)	*P* value
Fluctuation	1.200 (± 1.196)	0.000
Difference	1.200 (± 1.196)	0.000
Timing	-99.300 (± 139.962)	0.005

p* < 0.001; paired *t*-tests** ***Units - mmHg

Table 4.3.8 Mean (± SD) Core Strength Statistics for Supine Assessments for the 36 – 50 Age Strata

Initial – Follow Up	Mean (± SD)	*P* value
Fluctuation – right	1.200 (± 6.404)	0.412
Fluctuation – left	-0.500 (± 6.549)	0.737
Difference – right	1.200 (± 6.404)	0.412
Difference – left	-0.500 (± 6.549)	0.737
Grading – right	-1.05000 (± 0.39403)	0.000
Grading – left	-1.05000 (± 0.39403)	0.000

p* < 0.001; paired *t*-tests** ***Units - mmHg

4.5 Speed, Power, Cadence and Completion Time

The maximum and average speed, power, cadence, and completion time for the participants was recorded during the 1.5 km time trial on the Tacx Trainer, and is shown in the Table 4.4.1 and 4.4.2, and Figure 4.2.1, 4.2.2, 4.2.3, and 4.2.4.

Table 4.4.1 Mean (± SD) Speed, Power, Cadence and Completion Time Measurements, and Range, for TT1 and TT2

	TT1		TT2	
	Mean (± SD)	**Range**	**Mean (± SD)**	**Range**
Max Speed (km/h)	49.8 (± 7.1)	36.0 – 61.0	52.7 (± 5.1)	42.0 – 59.0
Ave Speed (km/h)	37.2 (± 4.6)	27.8 – 46.0	39.4 (± 3.9)	28.0 – 47.0
Max Power (w)	472.7 (± 137.8)	209.0 – 870.0	533.1 (± 146.1)	239.0 – 867.0
Ave Power (w)	279.5 (± 87.3)	128.8 – 512.0	321.1 (± 80.0)	136.0 – 502.0
Max Cadence (rpm)	117.9 (± 12.3)	90.0 – 144.0	127.0 (± 10.7)	106.0 – 149.0
Ave Cadence (rpm)	101.1 (± 11.4)	77.0 – 125.0	105.9 (± 10.7)	88.0 – 133.0
Completion Time (s)	156.6 (± 21.0)	125.0 – 206.0	146.2 (± 15.7)	123.0 – 196.0

Table 4.4.2 Mean (± SD) Speed, Power, Cadence, and Completion Time Measurements for TT1 and TT2 in the 20 – 35 and 36 – 50 Age Strata

	20 - 35		36-50	
	TT1	**TT2**	**TT1**	**TT2**
	Mean (± SD)	**Mean (± SD)**	**Mean (± SD)**	**Mean (± SD)**
Max Speed (km/h)	51.5 (± 7.1)	54.1 (± 4.8)	47.9 (± 6.8)	51.2 (± 5.2)
Ave Speed (km/h)	38.2 (± 5.1)	40.0 (± 4.3)	36.1 (± 3.9)	38.7 (± 3.3)
Max Power (w)	489.9 (± 156.6)	550.7 (± 157.5)	453.8 (± 114.7)	513.7 (± 133.8)
Ave Power (w)	297.4 (± 95.3)	329.0 (± 83.0)	259.8 (± 74.9)	312.5 (± 77.8)
Max Cadence (rpm)	117.1 (± 13.9)	126.2 (± 11.7)	118.7 (± 10.5)	128.0 (± 9.6)
Ave Cadence (rpm)	100.1 (± 13.0)	105.5 (± 11.8)	102.1 (± 9.7)	106.3 (± 9.6)
Completion Time (s)	153.1 (± 23.6)	144.1 (± 17.6)	160.5 (± 17.5)	148.5 (± 13.4)

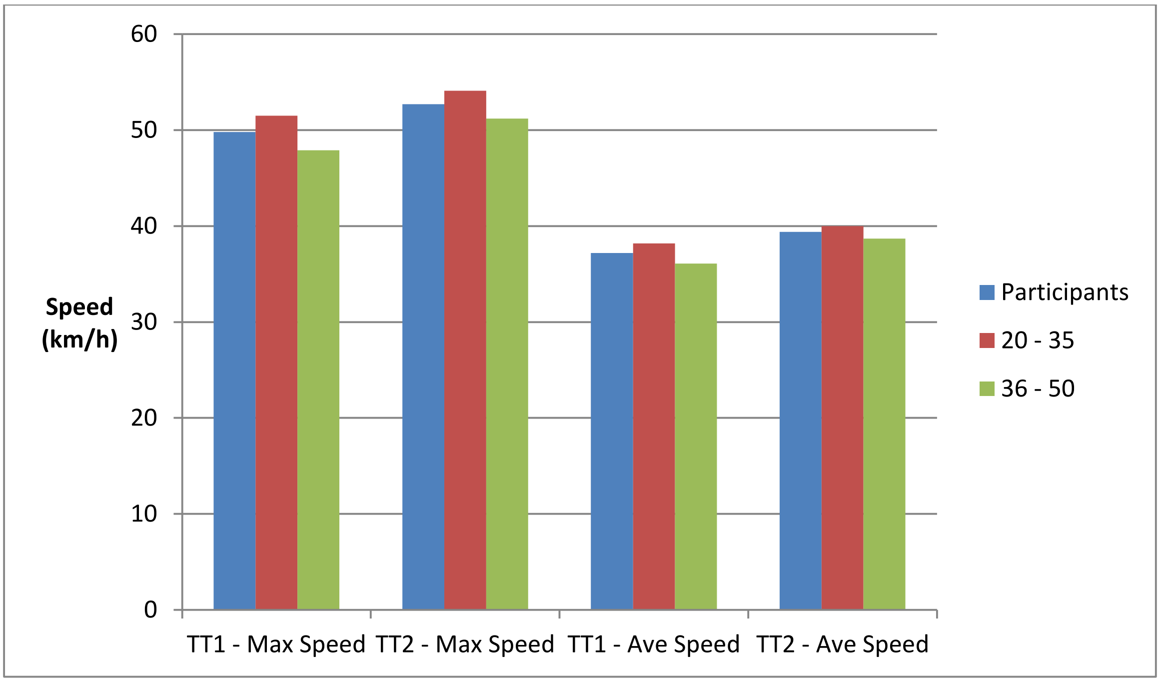

Figure 4.2.1 Mean Maximum and Average Speed Measurements (km/h) for TT1 and TT2

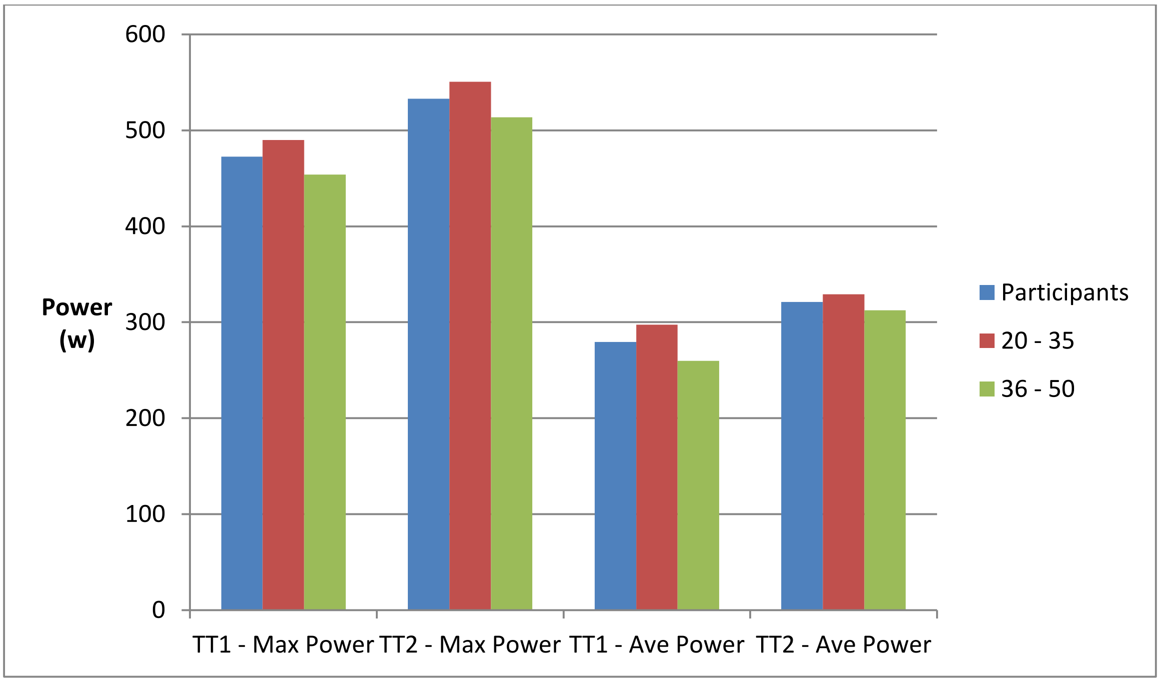

Figure 4.2.2 Mean Maximum and Average Power Measurements (w) for TT1 and TT2

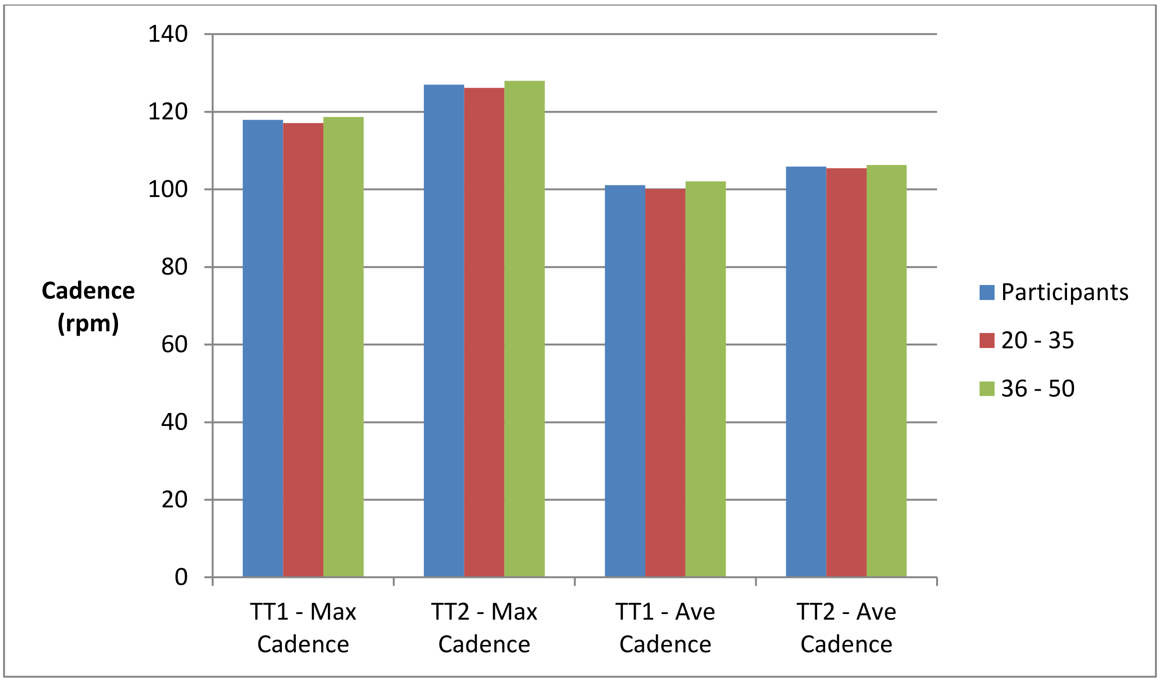

Figure 4.2.3 Mean Maximum and Average Cadence Measurements (rpm) for TT1 and TT2

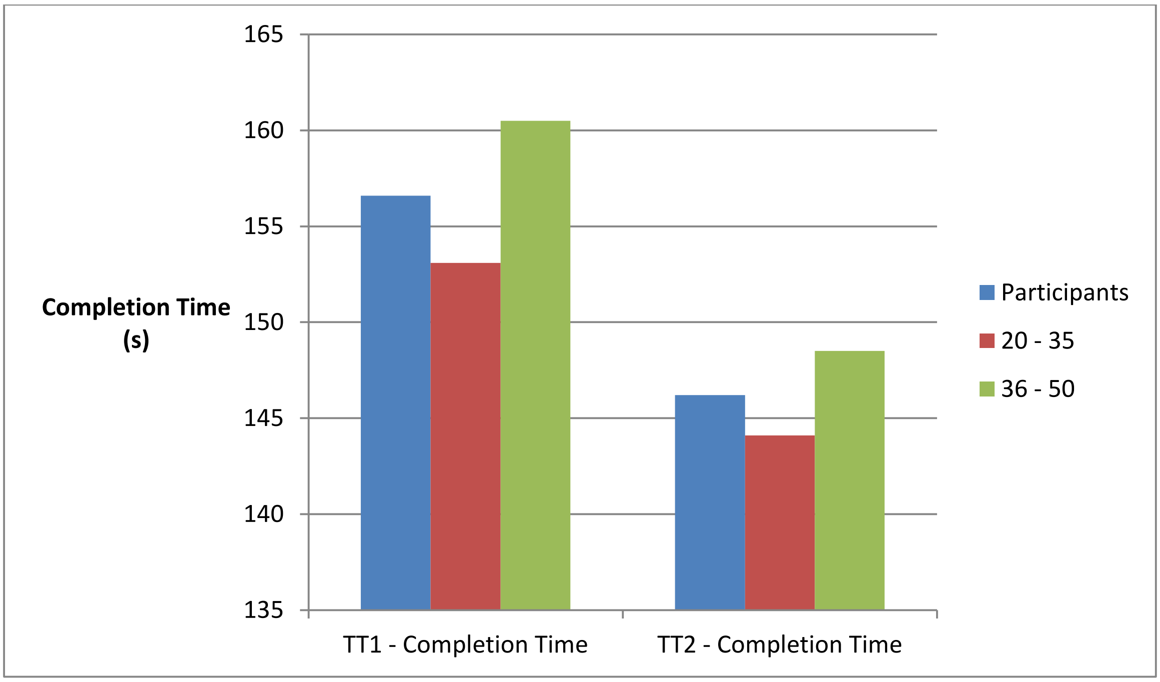

Figure 4.2.4 Mean Completion Time Measurements (s) for TT1 and TT2

All cycling performance assessment indicators showed a statistically significant change from the initial, pre- intervention assessments, to the follow up, post- intervention assessments ($p < 0.001$). For speed, power, and cadence, all the mean differences between initial and follow up values were negative, indicating that the initial values were lower than the follow up values and that the intervention was associated with an increase in speed, power and cadence. For completion time, the mean difference was positive, meaning that the completion time decreased after the intervention. These results are shown in Table 4.4.3

Table 4.4.3 Mean (± SD) Speed, Power, Cadence, and Completion Time Statistics for TT1 and TT2

Initial – Follow Up	Mean (± SD)	*P* value
Maximum Speed (km/h)	-2.9238 (± 4.6514)	0.000
Average Speed (km/h)	-2.1310 (± 2.2512)	0.000
Maximum Power (w)	-60.357 (± 73.165)	0.000
Average Power (w)	-41.667 (± 44.070)	0.000
Maximum Cadence (rpm)	-9.167 (± 8.754)	0.000
Average Cadence (rpm)	-4.833 (± 7.679)	0.000
Completion Time (s)	10.381 (± 10.883)	0.000

***p* < 0.001; paired *t*-tests**

Tables 4.4.4 and 4.4.5 reflect the cycling performance assessment results for the 20 to 35 age strata and the 36 to 50 age strata respectively.

Table 4.4.4 Mean (± SD) Speed, Power, Cadence, and Completion Time Statistics for TT1 and TT2 in the 20 – 35 Age Strata

Initial – Follow Up	Mean (± SD)	*P* value
Maximum Speed (km/h)	-2.5591 (± 4.2121)	0.010
Average Speed (km/h)	-1.7273 (± 2.1366)	0.001
Maximum Power (w)	-60.773 (± 75.196)	0.001
Average Power (w)	-31.545 (± 43.372)	0.003
Maximum Cadence (rpm)	-9.045 (± 9.639)	0.000
Average Cadence (rpm)	-5.409 (± 9.022)	0.010
Completion Time (s)	9.000 (± 9.967)	0.000

***p* < 0.001; paired *t*-tests**

Table 4.4.5 Mean (± SD) Speed, Power, Cadence, and Completion Time Statistics for TT1 and TT2 in the 36 – 50 Age Strata

Initial – Follow Up	Mean (± SD)	*P* value
Maximum Speed (km/h)	-3.3250 (± 5.1725)	0.010
Average Speed (km/h)	-2.5750 (± 2.3441)	0.000
Maximum Power (w)	-59.900 (± 72.810)	0.002
Average Power (w)	-52.800 (± 43.159)	0.000
Maximum Cadence (rpm)	-9.300 (± 7.915)	0.000
Average Cadence (rpm)	-4.200 (± 6.040)	0.006
Completion Time (s)	11.900 (± 11.881)	0.000

***p* < 0.001; paired *t*-tests**

Similar to the whole sample, both the 20 to 35 age strata and the 36 to 50 age strata showed statistically significant changes from pre- to post- intervention. Mean differences for speed, power, and cadence were again negative, indicating an increase in all cycling performance indicators. Completion time showed a positive mean difference, indicating a decrease in completion time post- intervention.

4.6 Rate of Perceived Exertion

The rate of perceived exertion scale was completed during the initial and follow up cycling performance assessments, and compared with actual heart rate measurements during the assessments.

There were statistically significant changes in all rate of perceived exertion measurements from the initial, pre- intervention assessment and the follow up, post- intervention assessment. Mean differences were all negative, indicating that the average starting value for perceived exertion was higher than the average follow up value, representing a decrease in perceived exertion post- intervention. Table 4.5.1 reflects these results.

Table 4.5.1 Mean (± SD) Rate of Perceived Exertion Statistics for TT1 and TT2

Initial – Follow Up	Mean (± SD)	*P* value
First Flat	-0.643 (± 1.032)	0.000
Second Flat	-0.571 (± 1.039)	0.001
Incline	-0.571 (± 1.346)	0.009
Decline	-0.667 (± 1.426)	0.004
Actual HR First Flat	-4.071 (± 8.469)	0.003
Actual HR Second Flat	-5.476 (± 9.115)	0.000
Actual HR Incline	-2.810 (± 8.451)	0.037
Actual HR Decline	-3.429 (± 9.402)	0.023

$p < 0.001$; paired *t*-tests

In the 20 to 35 age strata, the results reflected much the same changes as the whole sample, with mean differences being negative. The heart rate changes in this age strata were however not significant. These results are reflected in Table 4.5.2.

Table 4.5.2 Mean (± SD) Rate of Perceived Exertion Statistics for TT1 and TT2 in the 20 - 35 Age Strata

Initial – Follow Up	**Mean (± SD)**	***P* value**
First Flat	-0.773 (± 0.973)	0.001
Second Flat	-0.682 (± 1.129)	0.010
Incline	-0.636 (± 1.002)	0.007
Decline	-0.591 (± 0.959)	0.009
Actual HR First Flat	-2.409 (± 8.770)	0.212
Actual HR Second Flat	-3.773 (± 9.118)	0.066
Actual HR Incline	-1.864 (± 8.055)	0.290
Actual HR Decline	-1.591 (± 8.319)	0.380

$p < 0.001$; paired *t*-tests

Table 4.5.3 reflects the results for the rate of perceived exertion scale for the 36 to 50 age strata. This group differs to the 20 to 35 age strata, with significant changes in heart rate measurements in all areas of assessment excluding the incline. The rate of perceived exertion values did not show significant changes in any areas of assessment, excluding the second flat, which only indicated slight significance.

Table 4.5.3 Mean (± SD) Rate of Perceived Exertion Statistics for TT1 and TT2 in the 36 - 50 Age Strata

Initial – Follow Up	**Mean (± SD)**	***P* value**
First Flat	-0.500 (± 1.1000)	0.056
Second Flat	-0.450 (± 0.945)	0.046
Incline	-0.500 (± 1.670)	0.196
Decline	-0.750 (± 1.832)	0.083
Actual HR First Flat	-5.900 (± 7.940)	0.004
Actual HR Second Flat	-7.350 (± 8.964)	0.002
Actual HR Incline	-3.850 (± 8.958)	0.070
Actual HR Decline	-5.450 (± 10.298)	0.029

$p < 0.001$; paired *t*-tests

4.7 Numerical Rating Scale

The numerical rating scale was included in this study for the purpose of assessing discomfort related to the exertion during the cycling performance assessment.

Table 4.6.1 represents the NRS for the whole sample, the 20 – 35 age strata, and the 36 – 50 age strata, where no significant difference in NRS was noted between the initial and follow up assessments.

Table 4.6.1 Mean (± SD) Numerical Rating Scale Statistics for Initial and Follow Up Consultations

Initial – Follow Up	Mean (± SD)	*P* value
Whole Sample	-0.286 (± 1.088)	0.096
20 – 35	-0.409 (± 1.221)	1.131
36 – 50	-0.150 (± 0.933)	0.481

$p < 0.05$; paired *t*-tests

4.8 Participants' Perception of Change in Speed, Power and Cadence

The majority of participants experienced an increase in all outcomes following the core strengthening intervention. The percentages of participants that experienced an increase in all outcomes were similar in both age strata.

There was a general perception of increase in speed with 88.1% of the whole sample, 86.4% in the 20 to 35 age strata, and 90.0% in the 36 to 50 age strata. The participants' perception of change in speed is represented in Figure 4.3.1.

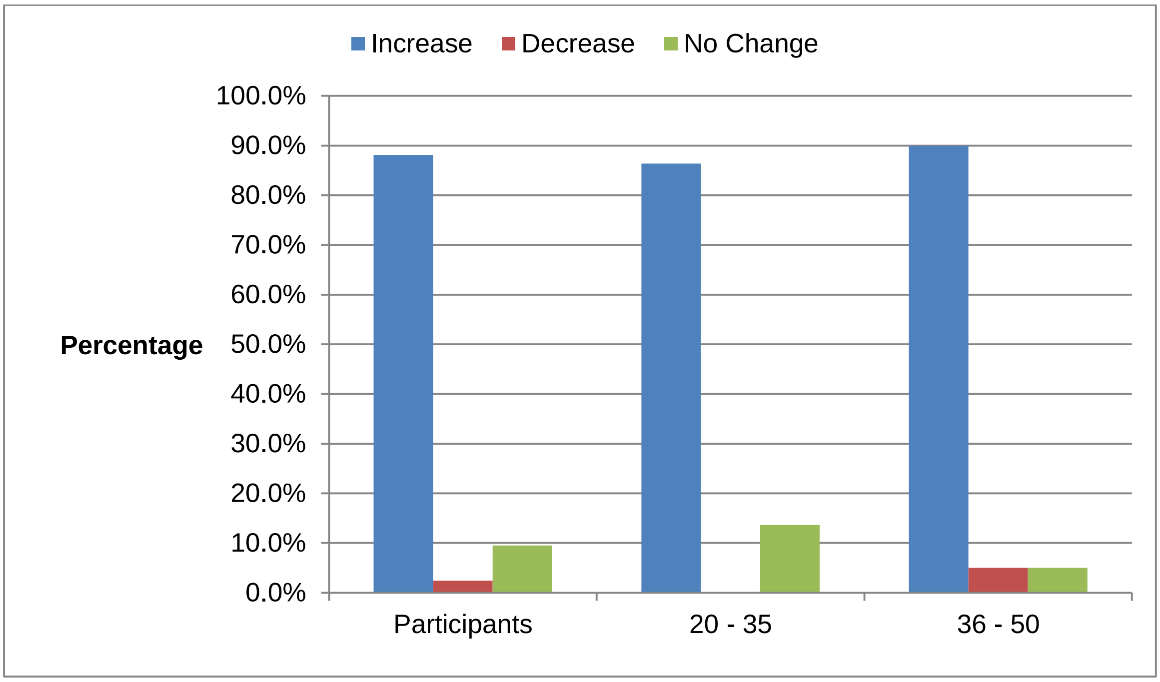

Figure 4.3.1 Participants Perception of Change in Speed

The participants' perception of change in power is represented in Figure 4.3.2. A majority increase across the whole sample, as well as within the two age strata is illustrated. Throughout the sample, no decrease was noted. An increase of 88.1% in the whole sample was experienced, with 95.5% increase in the 20 to 35 age strata, and 80.0% increase in the 36 to 50 age strata. No change was experienced by 11.9% within the whole sample, and 4.5 % and 20.0% within the 20 to 35 and 36 to 50 age strata respectively.

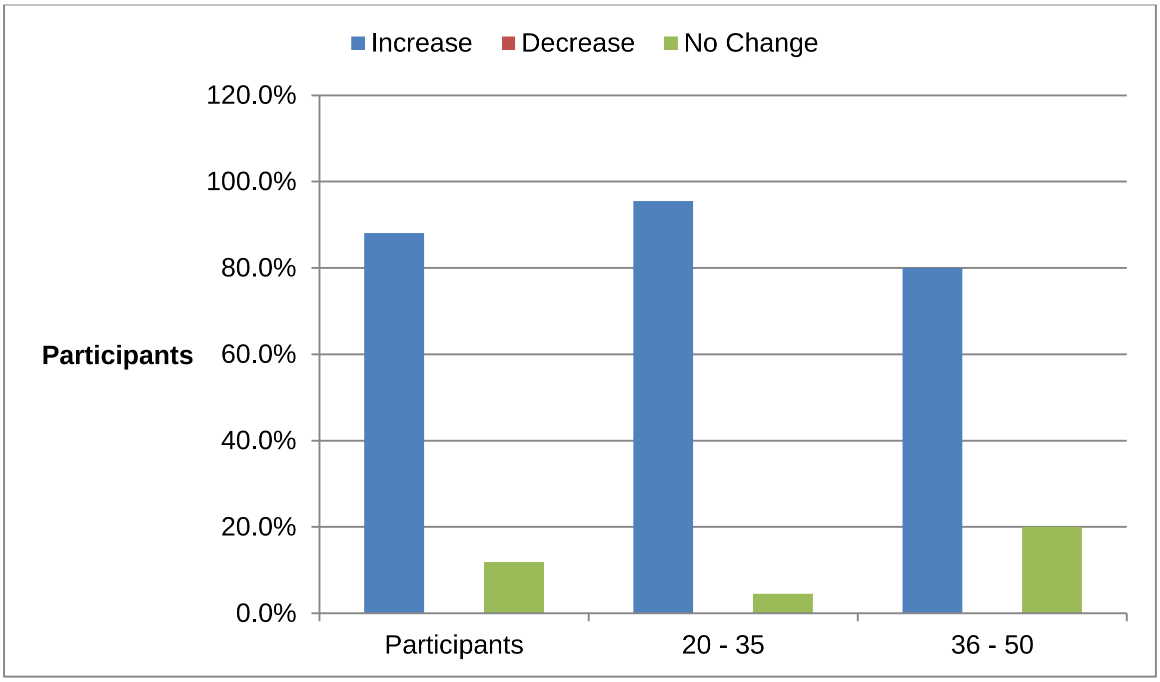

Figure 4.3.2 Participants Perception of Change in Power

The participants' perception of change in cadence was slightly lower than that of both speed and power. In the whole sample, 69.0% of participants experienced an increase, 4.8% experienced a decrease, and 26.2% experienced no change in cadence. In the 20 to 35 age strata, no decrease in cadence was noted. An increase was experienced by 68.2%, whilst the remaining 31.8% experienced no change in cadence. The 36 to 50 age strata experienced a similar increase with 70.0%, with a 10.0% decrease and 20.0% experiencing no change in cadence. The participants' perception of change in cadence is represented in Figure 4.3.3.

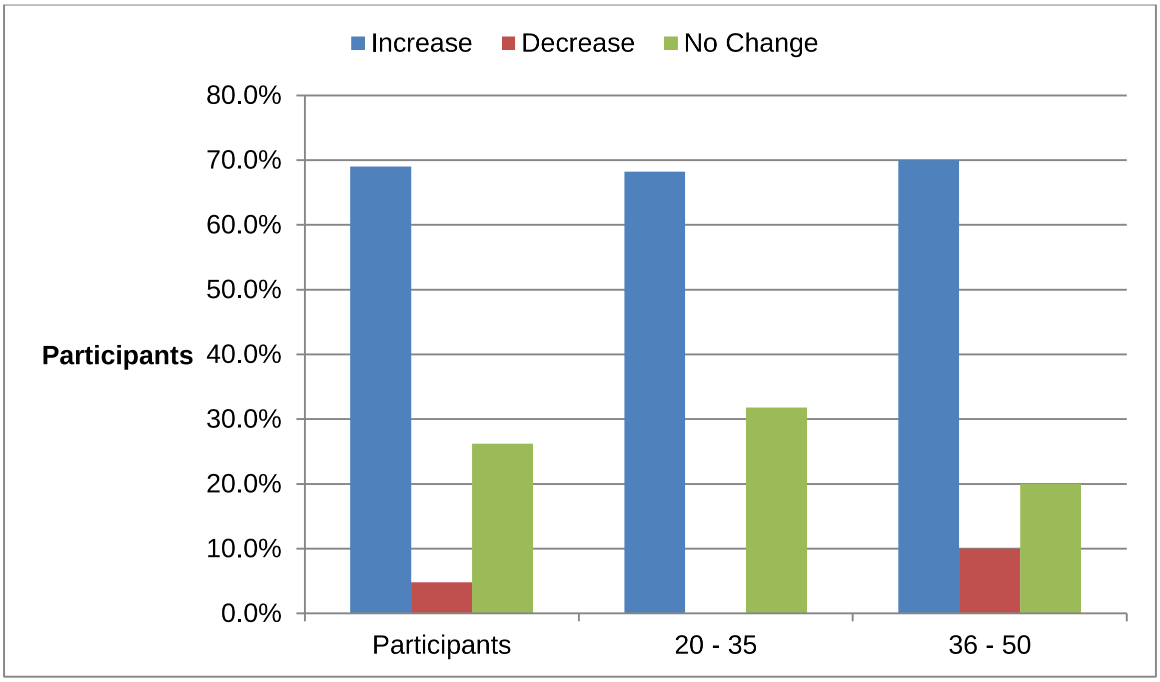

Figure 4.3.3 Participants Perception of Change in Cadence

4.9 Conclusion

The core strengthening intervention resulted in significant improvements in the participants' core strength measurements, for the abdominal draw in test, and the test for lumbopelvic posture, when analysed in terms of the whole sample and within the two age strata.

Significant improvements in maximum and average cycling speed, power, cadence and completion time were indicated, when analysed in terms of the whole sample and within the two age strata.

The rate of perceived exertion scale and accompanying heart rate measurements showed significant improvements post- intervention, when analysed in terms of the whole sample.

However, when analysed in terms of the two age strata, results were inconclusive, with significant results found only in the rate of perceived exertion of the younger age strata, and heart rate measurements of the older age strata

The numerical rating scale showed no significance, when analysed in terms of the whole sample, nor within the two age strata.

The perception of change in speed, power and cadence were significant post-intervention, when analysed in terms of the whole sample, and within the two age strata.

CHAPTER FIVE

DISCUSSION

5.1 Introduction

This chapter will discuss the outcome measures of this study, as well as addressing any methodological issues.

The objectives at the onset of this study were:

Objective One:
To determine the participants' core strength (mmHg), pre- and post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

Objective Two:
To determine the participants' power output (w), cycling speed (km/h), cadence (rpm) and completion time (seconds), pre- and post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

Objective Three:
To determine the participants' rate of perceived exertion, and corresponding heart rate (bpm), pre- and post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

Objective Four:
To determine the participants' perception of a change in power output (w), cycling speed (km/h) and cadence (rpm) post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

Objective Five:
To compare outcomes of the pre- and post- intervention measures, in the whole sample and within the two age strata.

For the purpose of discussion in this chapter, it is important to bear in mind the following:

- All participants were asymptomatic in regions from the lumbar spine to the lower extremity, including the hip, knee, and ankle.
- This study had only one group, with each participant being considered their own control in analysis of the results. The sample was however stratified into two age strata following data collection, for the purposes of analysis.
- The Tacx Trainer was used to assess maximum and average speed, power and cadence, as well as completion time and heart rate, for the 1.5 km time trial. The results for speed, power, cadence and completion time were automatically recorded by the Tacx Trainer Software. The Tacx trainer was calibrated automatically as per the Tacx I-Magic Manual.
- The Pressure Biofeedback Unit was used to assess core strength, in both the abdominal draw in test and the lumbopelvic posture with leg loading movements. The Pressure Biofeedback Unit was purchased and calibrated prior to the commencement of the research study.
- Although the study aimed to maintain a homogenous sample group, participants varied in terms of training status, riding style and level of experience.

5.2 Physical Characteristics and Demographics

The participants in this study included 42 asymptomatic cyclists between the ages of 20 and 50 years. The mean age of the participants was 34.1 (± 9.0) years. This mean age represents the highly competitive and most populated age groups in cycling, the sub veteran (30 – 34) and veteran (35+) groups (Duncan, 2012; Beneke *et al*., 1989). The mean age of this study is comparable to that of Cannon, Kolkhorst and Cipriani (2007), at 38 (± 10) years. Cyclists display is minimal change in performance with relation to age, which may contribute to the prevalence of this age group in cycling (Beneke *et al*., 1989). Other factors that may affect this age group spread may be attributed to the financial means of this age group to participate at a competitive level, as cycling is an expensive sport. In addition, cyclists of this age group would be more likely to have the time management skills, as well as availability of time, and discipline for training more consistently. The older age strata may have a greater interest in possible methods of improvements to their cycling performance. It should also be noted that as cycling is considered to be a low impact, non-weight bearing sport (Faria, Parker and Faria, 2005a; Burke, 2003; Sheets and Hochschuler, 1990; Beneke *et al*., 1989), it is often considered a secondary sport, and involvement often begins at an age when primary, high contact sports are no longer viable in which to participate. These factors may also influence the mean age of the cycling population.

The male participants in this study comprised 85.7% of the sample population. When stratified into two groups, 90.9% of the 20 to 35 age strata were male, whilst 80.0% in the 36 to 50 age strata were male. This sample is representative of the Kwa-Zulu Natal cycling population, which is made up of a majority male population (Duncan, 2012), and is comparable to that of Mills (2006).

The mean BMI of the participants of this study was 24.6 (± 3.7). When compared between the two age strata, BMI showed slight differences, with the 20-35 age strata at a mean BMI of 24.1 (2.6) and 36-50 age strata at a mean BMI of 25.2 (4.5). The difference in BMI between the two age strata may be attributed to the age related physiological changes that occur. The 42 cyclists that participated in this study had a mean mass 76.4 (± 15.0) kg. This is comparable to those of competitive cyclists described by McGhie and Ettema (2011), at 76.2 kg (± 9.4), and Ettema, Loras and Leirdal (2009), at 76.7 kg (± 10.0). Mean mass differed between the two groups, with the younger age strata at 74.4 (± 10.6) and the 36-50 age strata at a heavier mean mass of 78.6 (± 18.7). The mean height of the participants at 1.80 m (± 0.1), falls between those described by McGhie and Ettema (2011), at 1.82 m (± 6.6), Ettema, Loras and Leirdal (2009) at 1.81 m (±0.05), and Swart, Lamberts, Derman and Lambert, (2009), at 1.82 m (±0.07); and those described by Cannon, Kolkhorst and Cipriani (2007) , at 1.79 m (± 8.0), and Bertucci *et al*., (2005), at 1.78 m (± 0.04). In the 20 to 35 age strata, the mean height matched that of the 36-50 age strata at 1.80 m (± 0.1).

5.3 Training Status and Riding Style

Statiscitcs of Cycling South Africa 2012, indicate that both road and mountain biking are especially popular, with road cycling having 2 321 members, and mountain biking having 3 160 members, of the 5 705 members in Kwa-Zulu Natal. A large portion of these cyclists paricpate in more than one discipline, combining road cycling with track or mountain biking. The participants in this study showed a preference to road cycling, closely followed by mountain biking and a combination of road and mountain biking. The combination of these two disciplines was most popular in the older age strata, whilst the younger age strata were more specific in their preference to either road or mountain biking. This could be due to the expense of the two different bicycles and the associated costs of events and memberships, as well as the availability of time for training and event participation, which may be more attainable to the older, more financially capable participants.

Track cyclists comprise 105 members of the 5 705 members in Kwa-Zulu Natal. Track cyclists comprised 4.8% of the participants in this study, with one particpant in each age strata. The variations in skills between the cycling discplines may have affected the efficiency of the cyclist, as well as their approach to the assessment.

Cyclists may also have preferences to specific cycling styles. The participants in this study, when analysed in terms of the whole sample and the two age strata, identified a preference to hill climbing, closely followed by high cadences, of over 100 rpm. These preferences are unexpected when compared to the mean BMI of the cyclists. Hill climbing, is favourable to a lighter cyclist, and a lighter bicycle (Beneke *et al*., 1989). However, with the mean BMI of the participants at 24.6 (± 3.7), these cyclists fall into a normal range for BMI. The participants' preference for higher cadences may be associated with the lowered perception of exertion associated with higher cadences (Burke, 2003). A small portion of the participants in the younger age strata showed a preference to cadence below 60 rpm, whereas most of the remaining participants in the older age strata showed a preference to sprinting. Sprinting requires higher cadences, therefore, the similarity between the style choices may account for the selection of high cadences instead of sprinting, by the majority of the sample. This may be associated with the slower development of cyclists (Beneke *et al*., 1989), the favourability of a higher BMI for sprinting, as well as the development of higher cadence utilisation with cycling experience (Ansley and Cangley, 2009).

Cycling efficiency is greatly affected by the hours spent training (Ettema and Loras, 2009; Wilmore, Costill and Kenney, 2008; Faria, Parker and Faria, 2005b; Burke, 2003; Carter *et al*., 2003). The average training hours per week recorded by the participants in this study showed a vast majority of the sample training for 6 to 10 hours per week, which would result in between 312 and 520 hours per year. This is comparable to McGhie and Ettema (2011) at 500 (± 75) hours per year, and Ettema, Loras and Leirdal (2009) at 530 (± 144) hours per year. The 11-15 hours per week category was populated by seven participants from the older age strata, as opposed to five from the younger age strata. This may be attributed, as previously mentioned, to the time availability of the older cyclists. Two participants in each age strata populated the highest training hour's category, with cyclist spending over 21 hours cycling per week. Cyclists, regardless of age, are competitive and determined (Beneke *et al*., 1989), as illustrated by these findings.

The level of experience of a cyclist greatly influences both their skill and efficiency (Ettema and Loras, 2009; Atkinson *et al*., 2003; Burke, 2003). The majority of participants in this study had been actively participating in cycling for between 1 and 5 years. This level of experience includes both the novice cyclists, to those that are competing and consider themselves elite cyclists, which for the purposes of this study, indicated regular top ten percent finishers in competitive events. The participants of this study, across the whole sample and within the two age strata also showed prevalence in the experience of 6 to 10 years and 10 to 15 years. Few contestants were categorised in the 15 to 20 years experience bracket, however, four participants were included in the over 20 years experience category. In relation to this, participants of this study were required to classify their level of cycling ability. The majority of participants in this study classified themselves as serious amateurs, with only three participants considering themselves to be social cyclists. Eight participants were classified as elite cyclists, competing at a high level, and with experience and consistent training. These results are comparable to those of studies by McGhie and Ettema, (2011); Swart *et al*., (2009); Ettema, Loras and Leirdal, (2009); Cannon, Kolkhorst and Cipriani, (2007); and Bertucci *et al*., (2005), with a sample population of competitive cyclist. Strictly professional cyclists did not participate in this study, which is comparable to the above mentioned studies (McGhie and Ettema, 2011; Swart *et al*., 2009; Ettema, Loras and Leirdal, 2009; Cannon, Kolkhorst and Cipriani, 2007; Bertucci *et al*., 2005). Professional cyclists generally train under professional coaches, and as such, would not be expected to participate in training interventions other than those prescribed by their coaches or managers.

5.4 Modifications to Methodology

An initial sample size of 40 participants was set out at the onset of this study, however, it was decided that additional participants would be recruited, to account for the possible exclusion of participants due to non-compliance or injury. Twelve additional participants were recruited to participate in this study. During the clinical trial, six participants were excluded due to non-compliance during the intervention period. This was mostly attributed to time constraints, and the subsequent inability to complete the core strengthening intervention. In addition, three participants developed injuries, unrelated to the core strengthening intervention. Two of these participants developed ankle injuries during cross training, with the remaining participant involved in a water-skiing accident. This is similar to that of Swart *et al*., (2009), with a proportionally comparable drop out due to injury. One participant fell ill on the day of the follow up assessment, and was therefore excluded from the study. Therefore, data was analysed for two additional participants, resulting in a sample of 42 participants. It should be noted that no participants developed pain related to the core strengthening intervention, and therefore no participants required referral to the Chiropractic Day Clinic as a result of the intervention.

5.5 Assessment of the Intervention Effect

5.5.1 Core Strength

Objective One:

To determine the participants' core strength (mmHg), pre- and post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

The PBU was utilised to assess the core strength of the participants' pre- and post-intervention. Activation of the trunk musculature as a result of core strengthening has been suggested to allow for improved performance of the axial and appendicular skeleton in various sporting environments (Asplund and Ross, 2010; Akuthota *et al.,* 2008; Hibbs *et al*., 2008; Abt *et al.,* 2007; Akuthota and Nadler, 2004; McGill *et al*., 2003; Hedrick, 2000).

However, the effects of improved core strength on cycling performance have not been directly measured.

This study required participants to complete core strength assessments in the prone position for the abdominal draw in test and in the supine position for the lumbopelvic posture and leg loading tests (Tables 4.3.1 and 4.3.2). Core strength measurements were analysed using paired *t*-tests, to compare the pre- intervention and post- intervention measurements.

The abdominal draw in test reflected a significant change in fluctuation, difference and timing from pre- to post- intervention. Mean changes were statistically significant for fluctuation and difference, and negative for timing, indicating a decrease in fluctuation and difference, and an increase in timing (Table 4.3.3 and 4.3.4). Therefore, participants were able to contract the transversus abdominis independently of the global muscles, as well as displaying an increased endurance of the core musculature post- intervention (Richardson *et al*., 1999; Richardson and Jull, 1995). It should be noted however, that this has not previously been assessed in terms of the relationship with cycling performance. Grading for the test for lumbopelvic posture and leg loading increased significantly on both the left and right side, indicating an improved ability of the trunk muscles to stabilise the lumbopelvic region during a sequence of progressive leg loading exercises core strength and pelvic stability post- intervention (Richardson *et al*., 1999). The results of this study are in line with scientific findings, that there is a measurable improvement in skeletal muscle tissue after four weeks of a structured exercise programme, with significant results after four weeks of core strengthening exercise (Defreitas *et al*., 2011; Camera *et al*., 2010; Clarke, 2009; Kendall *et al*., 2009; Kuszewski, Gnat and Saulicz, 2009; Smit, 2009; Spangenburg, 2009; Campbell, 2007; Ludmila *et al*., 2003; Piegaro, 2003; Boden, 2002; Staron *et al*., 1994).

When analysed in terms of the 20 to 35 age strata, significant changes ($p < 0.001$) were again noted, with results matching those of the whole sample for the abdominal draw in test. The test for lumbopelvic posture in this age strata however, decreased significantly on the right only, whilst grading increased significantly on both the right and left side, as per the whole sample results. Therefore, gains in pelvic stability were directed more significantly to the right in the younger age strata, However, improved pelvis stability during leg loading movements was noted bilaterally post- intervention (Table 4.3.5 and 4.3.6). The right side dominance of the majority of patients may have contributed to the exercises being perfected in a shorter time on the right side, resulting in stronger measurements being recorded for the right side. Similarly, results for the 36 to 50 age strata again showed statistically significant changes ($p < 0.001$). Abdominal draw in tests matched those of the whole sample and the 20 to 35 age strata. In terms of the test for lumbopelvic posture and leg loading movements, improvements post- intervention were similar to that of the younger age strata (Table 4.3.7 and 4.3.8). Based on the methodology of this study, comparable results post- core strengthening intervention are lacking.

As suggested by Faria, Parker and Faria (2005b), muscle recruitment differs depending on the demands placed on them. For shorter sprint distances, recruitment of fast twitch type II muscles takes place. However, for longer endurance distances, slow twitch, type I fibres are recruited. Future studies could assess the effect of core strengthening on cycling performance over an endurance event, which may assist even more over the longer distance as a result of the improved core strength, and resistance to fatigue associated with it. In addition, the stratification into anthropometric measurements of the cyclist would provide interesting results for analysis.

5.5.2 Speed, Power, Cadence and Completion Time

Objective Two:

To determine the participants' power output (w), cycling speed (km/h), cadence (rpm) and completion time (seconds), pre- and post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

The Tacx Trainer was utilised in this study, to accurately measure the cyclists maximum and average speed, power, cadence and completion time for the 1.5 km time trial, as well as recording the results with the Trainer Software. This specific cycle ergometer used an electromagnetic brake, as well as tyre friction, providing rolling resistance. The software allowed for the course to be selected to include an incline and decline, as well as flat stages. This feature allowed for better simulation of outdoor riding. However, external conditions, such as wind direction and speed, drafting, and riding surfaces, all contributing to increased resistance, cannot be accounted for in the testing setting on a cycle ergometer (Burke, 2003). In addition, changes in saddle positioning in response to inclination of the bicycle, did not occur on the cycle ergometer. These factors support the recommendation that future research should be conducted in an outdoor environment, specific to the road, mountain bike, or track cyclist.

A cyclists' desire for optimum efficiency results in selection of the lightest bicycle available, to minimise the leg power required to resist gravity (Beneke *et al*., 1989). This results in a lighter cyclist on a lighter bicycle having an advantage, requiring less power production. As previously mentioned, the mean BMI of the sample population at 24.6 (± 3.7) depicts a normal range BMI, which would not be expected to benefit the cyclists in terms of minimising the leg power required. The improvement in completion time can therefore be attributed to the core strengthening intervention. However, future studies could investigate this further by assessing the BMI post- intervention for comparison. Bicycle quality is also specific to the cyclist, usually dependent on their level of expertise and experience (Liggett, 1992). This study required participants to perform both the pre- and post- intervention cycling assessments on the same road bicycle, with no changes to the bicycle during the intervention period, to maintain standard riding setup to allow for comparison between the pre- and post- intervention cycling assessments. The use of the same bicycle eliminated variables such as varying weight of the bicycle, and quality and comfort of the bicycle. Although friction between the bottom bracket, chain components and the rear transmission result in a loss of a small amount of energy produced by the cyclist (Burke, 2003), this would not have had any effect on the results due to the use of the same bicycle for both assessments.

The maximum and average speed, power, cadence, and completion time for the participants were recorded during the 1.5 km time trial on the Tacx Trainer. The analysis of these results revealed a statistically significant change ($p < 0.001$) in all cycling performance indicators, from pre- to post- intervention, in the whole sample (Table 4.4.3), and within the two age strata (Table 4.4.4 and 4.4.5).

5.5.2.1 Speed

Participants' were encouraged to aim to complete the 1.5 km time trial in as fast a speed as possible for both the initial and follow up assessments. The time trial required the cyclist to exert a substantially large amount of power to reach maximum speed. Most participants reached their maximum speed by the end of the second 550 m flat, at 1100 m of the 1500 m course. The inclusion of the hill in this time trial allowed for better simulation of outdoor riding, as well as providing a comprehensive assessment of the cyclists' abilities, by placing additional load on the power producing muscles required for cycling, and therefore testing the ability of the core to enhance the force distribution to the lower limbs.

The results in Table 4.4.3, 4.4.4 and 4.4.5 reflect a statistically significant improvement in maximum and average speeds for the whole sample and within the two age strata. Speed improvements in this study were significant for the whole sample, with mean maximum speed pre- intervention at 49.8 (± 7.1), compared to post- intervention at 52.7 (± 5.1). Average speed improvements were also significant from 37.2 (± 4.6) to 39.4 (± 3.9). In the younger age strata, maximum speeds showed improvement from 51.5 (± 7.1) to 54.1 (± 4.8) post- intervention, whilst the older age strata showed improvements on a slightly slower mean maximum time of 47.9 ± 6.8 to 51.2 ± 5.2 post- intervention. In the 20 to 35 and 36 to 50 age strata, mean average speeds post- intervention were 40.0 ± 4.3 and 38.7 ± 3.3 respectively.

As discussed in the literature review, in addition to the external environment, the cyclists' potential for speed is influenced by training status and fitness levels, as well as the muscle fibres that predominate. The percentage of type I muscle fibres in the trained cyclist will have a positive effect on efficiency due to the association of an increased percentage of type I fibres with a lower sub-maximal oxygen expense (Faria, Parker and Faria, 2005b; Burke, 2003). Type I fibre recruitment is however more commonly associated with endurance events, whilst Type II, fast twitch fibres are associated with sprint distances (Faria, Parker and Faria, 2005b; Baker, 1998). Future studies should investigate the effect of core strengthening in a longer, endurance time trial, to assess whether this would improve the potential speed of the cyclist even further.

5.5.2.2 Power

The increase in a cyclists power output is exceptionally valuable, as it is highly correlated with cycling success (Faria, Parker, Faria, 2005b). Power is also considered one of the most significant measures of cycling performance (Burke, 2003). All stratifications of this research study showed significant improvements in the maximum and average power measurements post- intervention ($p < 0.001$). In the whole sample, maximum power improved from 472.7 (± 137.8) to 533.1 (± 146.1) post- intervention, and average power from 279.5 (± 87.3) to 321.1 (± 80.0) post- intervention. Peak mean maximum power measurements were recorded in the 20 to 35 age strata, at 550.7 (± 157.5), from 489.9 (± 156.6). The 36 to 50 age strata showed improvements in maximum power, from 453.8 (± 114.7) to 513.7 (± 133.8). The lower pre- intervention power measurements in the older age strata may be due to the effect that aging has on muscle type ratios, with a decrease in type II muscle fibres with age (Williams, Higgins and Lewek, 2002). Average power post- intervention for the two age strata was recorded at 329.0 (± 83.0) and 312.5 (± 77.8), for the younger and older age strata respectively.

Most participants reached these maximum power outputs within the first 550 m flat of the time trial, in an attempt to gain speed as quickly as possible. Most participants, immediately following the initial time trial, commented on how much tougher it was than expected. This could have posed a problem with the pacing strategy of the participant in preparation for the follow up time trial. Interestingly, participants approached the follow up time trial with much the same effort as the first time trial. This may be due to the time period of the intervention, resulting in participants not recalling the perceived levels of exertion at the follow up time trial.

The fact that a lighter cyclist on a lighter bicycle has an advantage over a heavier cyclist on a heavier bicycle, is particularly applicable to hill climbing, where the power required to resist the forces of gravity is much greater (Burke, 2003). The Tacx Trainer, through the use of the electromagnetic brake, caused the hill climb sensation in the assessments, and therefore, no gravitational forces were applicable without the actual inclination of the bicycle. The weight of the bicycle would therefore not have as great an effect on the cyclists' power output as in outdoor cycling. The use of the same bicycle removes numerous variables including gearing, tyres, and riding position, however, the most accurate assessment of cyclists' performance would take place in an outdoor setting (Burke, 2003).

5.5.2.3 Cadence

Cadence selection choice was specific to each participant in this study. Significant increases in cadence were recorded for the whole sample, and within the two age strata ($p < 0.001$). The mean maximum cadences post- intervention, for the whole sample, 20 to 35 and 36 to 50 age strata were 127.0 ± 10.7, 126.2 ± 11.7 and 128.0 ± 9.6 respectively. Averages cadences post- intervention were recorded at 105.9 ± 10.7 for the whole sample, 105.5 ± 11.8 for the 20 to 35 age strata, and 106.3 ± 9.6 for the 36 to 50 age strata. These results support the literature, which suggests that an improved core strength would improve the force distribution to the lower extremities and thereby improving the pedalling efficiency (Asplund and Ross, 2010; Abt *et al*., 2007; McGill *et al*., 2003) As discussed, there is large variability in optimal cadence between cyclists, independent of training status and fitness levels (Burke, 2003). Although the mean average cadences support the overall efficiency of the cyclists at the upper limit of the proposed optimal cadences of 100 rpm (Umberger, Gerritsen and Martin, 2006; Burke, 2003), the maximum cadences are higher than that of optimal cadences mentioned, at approximately 127 rpm. Higher cadences (above 90 rpm) do however tend to minimise the force required per pedal stroke, and subsequently reducing the force required per muscle contraction as well as decreasing the recruitment of type II muscle fibres (Atkinson *et al*., 2003; Burke, 2003).

Higher cadences may also be adopted due to the influence on the blood flow to muscles, as well as the correlation with perceived exertion (Atkinson *et al*., 2003; Burke, 2003). Higher cadences produce an increased frequency of contraction and relaxation of the muscle, resulting in shorter periods of restricted blood flow to the muscles (Atkinson *et al*., 2003; Burke, 2003). Increased power output measurements also correlate with the increased cadence measurements post- intervention, as power output, in addition to the testing environment, the cyclist's fitness levels, and the duration of the exercise may influence cadence (Burke, 2003). The cyclist's level of experience could also contribute to the higher cadence selection, due to the development of higher cadence utilisation in well-trained, cyclists (Ansley and Cangley, 2009). Participants in this study may have opted for higher cadences in order to minimise the perceived exertion for the 1.5 km sprint, regardless of the higher economy of the type I muscle fibres associated with the higher cadence (Burke, 2003).

Fluctuations in cadence may occur as a result of varying terrain, including hill climbs (Burke, 2003). Although the cycling ergometer utilised in this study most closely simulated outdoor cycling with its inclusion of a hill, no gravitational forces would have been experienced by the cyclist. Outdoor assessment would therefore produce greater fluctuations in cadence over changing terrains.

5.5.2.4 Completion Time

The completion time of each cyclist was recorded by the Tacx Trainer software, pre- and post- intervention. A significant decrease in completion time ($p < 0.001$) was recorded for the whole sample, as well as both the 20 to 35 and 36 to 50 age strata (Tables 4.4.3, 4.4.4 and 4.4.5). Mean completion time decreased from 156.6 (± 21.0) seconds to 146.2 (± 15.7) seconds in the whole sample, whilst the 20 to 35 age strata reflected an improvement from 153.1 (± 23.6) seconds to 144.1 (± 17.6) seconds. The 36 to 50 ages strata showed the most marked improvement from 160.5 (± 17.5) to 148.5 (± 13.4). These results reflect a significant improvement that would give the cyclist the advantage over their opponents in this highly competitive sport.

The results of this study illustrate significant improvements in completion time, and may be especially applicable to participants in individual road races, and in sprinters, such as track sprint cyclists, where the shorter performance time trial used in this study is most closely matched. However, with the importance of the mere seconds that may separate the winner from second place in races spanning 21 days, further research is warranted for endurance assessments, as it is expected that the improvements in completion time could be cumulative over longer distances.

5.5.3 Rate of Perceived Exertion and Heart Rate

Objective Three:

To determine the participants' rate of perceived exertion, and corresponding heart rate (bpm), pre- and post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

The rate of perceived exertion scale, adapted from Borg (1998), was used to compare with actual heart rate readings, pre- and post- intervention. Statistically significant changes ($p < 0.001$) in all rate of perceived exertion from the pre- to post- intervention were noted (Table 4.5.1, 4.5.2 and 4.5.3). The average starting value for perceived exertion was higher than that of the follow up value, representing a decrease in perceived exertion post- intervention.

Assessment of heart rate throughout the cycling performance assessment showed interesting results, and warrants further research. Statistically significant changes ($p < 0.001$) in heart rate measurements from the pre- to post- intervention were noted (Table 4.5.1, 4.5.2 and 4.5.3). Heart rate increases during exercise is highly correlated to the increased metabolic rate and oxygen consumption (VO_2) with increasing workload (Powers and Howley, 1997). Oxygen consumption then remains at an increased level following cessation of exercise (Powers and Howley, 1997). Exercise also results in an increase in blood concentrations of lactate (Powers and Howley, 1997). Although this was not within the scope of this research study, future studies investigating the effects of a core strengthening programme in cyclists on the lactate and VO_2 levels could provide interesting outcome measures.

Interestingly, when analysed individually, the two age strata showed conflicting results. The younger age strata reflected similar, significant rate of perceived exertion measurements (Table 4.5.2), however heart rate changes in this age strata were not significant. In contrast, the older age group showed significant changes ($p < 0.001$) in heart rate from pre- to post- intervention (Table 4.5.3); however, rate of perceived exertion measurements showed no significance in any areas ($p < 0.001$), excluding the second 550 metre flat of the time trial. This may be due to most participants reaching their maximum power output within the first 550 metres of the trial, thus levels of perceived exertion would be higher immediately thereafter. Endurance training affects the age related decrease in maximum heart rate, as a result of the enhanced parasympathetic response, reducing the rate of increase and return to normal post- exercise (Wilmore, Costill and Kenney, 2008; Carter, Banister and Blaber, 2003). This may have had an effect on the significant change in heart rate from pre- to post- intervention in the older age strata.

Future studies should assess the participants' heart rate prior to starting the initial time trial, and analyse the return to the resting heart rates following the initial time trial. This could then be repeated for the follow up time trial, and the differences could be analysed. This may be indicative of a reduced metabolic load, which would further support the inclusion of a core strengthening programme to cycling training schedules.

5.5.4 Numerical Rating Scale

The numerical rating scale was included in this study, for the purpose of assessing discomfort related to the exertion during the cycling performance assessment, as a statistical significance measure (Kendrick and Strout, 2005). Numerical rating scales are generally utilised in the assessment of pain in participants (Jenson, Karoly and Braver, 1986).

With exertion, discomfort may increase, due to factors including muscle fatigue, sweating, increased heart rate and breathlessness (Sellers, 2007). However, results of this study showed that no significant difference in NRS was recorded in the whole sample ($p = 0.096$), or in either the 20 to 35 ($p = 1.221$) or 36 to 50 ($p = 0.481$) age strata, from pre- to post- intervention (Table 4.6.1). This is possibly due to the fact that inclusion criteria required participants to have participated in cycling for at least the last one year, and to have been training for a minimum of six hours per week, to qualify to participate in this study. The NRS is, therefore, not recommended for future use as a statistical measure in studies with asymptomatic participants, as it revealed no significance or relevance in this study.

5.5.5 Participants' Perception of Change

Objective Four:

To determine the participants' perception of a change in power output (w), cycling speed (km/h) and cadence (rpm) post- the core muscle strengthening intervention, in the whole sample and within the two age strata.

The majority of participants in this study experienced an improvement in all outcome measures following the core strengthening intervention. The increase in perception experienced in all outcomes was similar in both age strata.

The participants' perception of change in speed showed a vast majority increase (Figure 4.3.1), as was similarly reflected in the perception of change in power (Figure 4.3.2) The participants' in this study reported a lower perception of change in cadence than that of both speed and power, however majority increases were still reflected (Figure 4.3.3).

The Hawthorne effect was taken into consideration when conducting this clinical study. Due to the small sample size of this study, there is a chance of type two error. However, the perceived improvements in cycling speed, power and cadence are in line with the cycling performance parameters assessed in this study, and are supported by the suggestion that the psychology of improved performance may result in actual improved results (Armstrong and Carmichael, 2003; Beneke *et al*., 1989).

5.6 Conclusion

Although this study was based on a sample of forty-two amateur cyclists, all cycling performance indicators assessed showed a significant improvement post- intervention, in the whole sample, and within the two age strata. In addition, core strength parameters showed a significant improvement post- intervention, in the whole sample and within the two age strata. Rate of perceived exertion, and corresponding heart rate measurements showed significant changes post- intervention when analysed in terms of the whole sample. However, results were inconclusive when the sample was stratified. Significant changes were noted in the rate of perceived exertion in the younger age strata, and the heart rate measurements in the older age strata, however rate of perceived exertion in the older age strata were insignificant, as were the heart rate measurements in the younger age strata. Numerical rating scale results were not significant in the whole sample, nor in either of the stratified groups. The majority of participants' experienced an increased perception in all outcomes post- intervention.

Therefore, in addressing the null hypotheses of this study, the following conclusions can be made:

Null Hypothesis One:
The null hypothesis was that the core muscle strengthening intervention would result in no significant difference in core strength (mmHg), in the whole sample and within the two age strata. The null hypothesis is rejected, as a significant improvement was recorded for all assessments, in the whole sample and within the two age strata.

Null Hypothesis Two:
The null hypothesis was that the core muscle strengthening intervention would result in no significant difference in the participants' cycling speed (km/h), power (w), cadence (rpm) and completion time (s), in the whole sample, and within the two age strata. The null hypothesis is rejected, as a significant improvement was recorded for all cycling assessment parameters, in the whole sample and within the two age strata.

Null Hypothesis Three:
The null hypothesis was that the core muscle strengthening intervention would result in no significant change in heart rate (bpm) and rate of perceived exertion, in the whole sample and within the two age strata. The null hypothesis is rejected for the rate of perceived exertion and corresponding heart rate measurements for the whole sample, as a significant decrease was observed post- intervention. In terms of the 20 to 35 age strata, a significant decrease in rate of perceived exertion was reflected, however heart rate measurements were not significant, and results were therefore inconclusive. Similarly, the 36 to 50 age strata showed significant changes in heart rate measurements, however, no significance in rate of perceived exertion measurements was recorded, and therefore no definitive conclusion can be made.

Null Hypothesis Four:
The null hypothesis was that the core muscle strengthening intervention would result in no difference in the participants' perception of change in speed, power and cadence, in the

whole sample and within the two age strata. The hypothesis is rejected, as most participants experienced an improvement in speed, power, and cadence post- intervention

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

This chapter will conclude the study by determining the effect of core strengthening of cycling performance in asymptomatic cyclists. Conclusions will be made from the results in Chapter Four and discussion in Chapter Five, and recommendations will be made regarding possible future directions for research, and modifications to methodologies for future studies, based on the outcomes of this study.

6.2 Conclusion

The aim of this study was to determine whether core muscle strengthening would have a statistically significant effect on cycling performance in asymptomatic cyclists. Cycling performance indicators, including speed, power, cadence and completion time showed a significant improvement post- intervention, in the whole sample, and within the two age strata. Core strength indicators showed a significant improvement post- intervention, in the whole sample and within the two age strata. A significant decrease in rate of perceived exertion and corresponding heart rate measurements post- intervention was observed in the whole sample. When stratified by age group for the purpose of analysis, the 20 to 35 age strata reflected a significant decrease in rate of perceived exertion; however heart rate measurements were not significant. In contrast, the 36 to 50 age strata showed significant changes in heart rate measurements, with no significance in rate of perceived exertion measurements. The majority of participants experienced an increased perception in all outcomes post- intervention.

The results of this study therefore reflect that core strengthening had a statistically significant effect on cycling performance. Numerous recommendations for future research in this field have been outlined below.

6.3 Recommendations

Future research studies could include:

1. This research study could be repeated using two groups of participants, which could include a control group and an intervention group. This may allow for further analysis of the effects of core strengthening. This could specifically stratify the elite and amateur cyclists, and thus determine the difference in gains from a core strengthening programme on the well-trained cyclists in comparison to amateur cyclists.
2. Future studies may find it beneficial to stratify partipants according to cycling discpline, to further assess the effects these particular discipline preferences have on the cycling performance. In addition, studies could assess the pedal strokes of the participants, to identify the effect of core strenghening on the pedal stroke directly, as well as to assess the difference in pedal strokes between participants of different cycling disciplines.
3. This research study could be repeated, with focus on Body Fat percentage and the effect of a core strengthening programme. Body Fat percentages could be recorded pre- and post- intervention. Studies could also include the assessment of waist circumference, allowing for assessment of the effect of core strengthening on Body Fat percentage and waist circumference, and possibly investigating an association between cycling preference and Body Fat percentage.
4. This research study could be repeated, with focus on hip flexor involvement, and the possible improvements in cycling performance as a result of a hip flexor rehabilitation program.
5. Research could be conducted analysing the posture of the cyclist on the bicycle pre- and post- core strengthening intervention. This could be done using a photographic record of cyclist during the assessment pre- and post- intervention. This would allow for further assessment of the effect of core on the cyclist positioning on the bicycle, and the resultant effect on the cyclists performance parameters.
6. Research could be conducted to determine the effect of core strengthening on cycling performance in symptomatic cyclists', particularly those with injury to the lower back and lower limbs.
7. Research could be conducted to investigate the effects of core strengthening on the endurance capabilities of the cyclist. Testing would need to be done over a greater distance, such as a 20 or 30 km time trial. This would allow for further

analysis of the effects of effects of core strengthening on cycling performance parameters over a longer distance.

8. Research could be conducted to compare the effects of core strengthening on cycling performance to the effects of stretching on cycling performance. The sample could be split into four groups to include a core strengthening group, a stretching group, a combined group and a control group.
9. Future research could assess the heart rate of participants' prior to the time trial, and analyse the return to resting heart rate following the time trial. This could then be repeated following the core strengthening intervention, to analyse the effects of the intervention on heart rate and recovery.
10. Future research could incorporate analysis of the pedal stroke of the cyclist, which may be used to assess the difference between participants based on cyclist training status or experience, as well as to determine the direct effect of core strengthening on the cyclists pedal stroke. In addition, analysis of the blood lactate and VO2 max levels could be performed, creating another outcome measure for assessment.
11. Future research could incorporate the use of resistance rollers for the purpose of assessment of cycling performance. This would give a greater indication of the effects of core strengthening on power and balance, simulating riding actual corners.
12. The use of a numerical rating scale (NRS) did not reveal any significance or relevance in determining discomfort following participation in the cycling assessments. NRS could therefore be excluded from future studies in asymptomatic participants'.
13. Ideally, future research could be conducted in an outdoor setting, specifically in a road, mountain biking, or track cycling setting.

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APPENDIX A

ATTENTION ALL

CYCLISTS

Are you healthy, between the ages of 20-50 and interested in having your cycling performance and core strength assessed?

Cyclists are required to participate in research which is being conducted at the Chiropractic Day Clinic at the Durban University of Technology, to assess core strength and cycling performance.

For an assessment call Kate Wiseman

031 373 2205

APPENDIX B

LETTER OF INFORMATION AND CONSENT

Dear Participant

Welcome to my research study. My study is being conducted to establish whether core muscle strengthening will have an effect on cycling performance.

Title of the Research Study: An investigation into the effectiveness of core muscle strengthening on cycling performance in asymptomatic cyclists.

Principle Investigator/s/researcher: Kate Wiseman
Co-Investigator/s/supervisor/s: Dr Andrew Jones (MTech: Chiropractic. MMed Sci: Sports Medicine)

Brief Introduction and Purpose of the Study:
This study aims to investigate the effectiveness of core muscle strengthening on cycling performance. Forty cyclists between the ages of 20 to 50 will be chosen to participate in the study. You will undergo a core strength assessment and cycling performance assessment.

Outline of the Procedures:
Consultations will take place at the Durban University of Technology Chiropractic Day Clinic. You will be required to visit the Clinic on two occasions with your own road bicycle, where your cycling performance and core strength will be assessed. The initial consultation will take approximately 90 minutes, including a thorough case history and physical examination, as well as assessment of your core strength and cycling performance. The follow up consultation will take approximately 45 minutes, including assessment of your core strength and cycling performance, as well as your feedback on the core strengthening program.

To be part of this study, you must currently be pain free with regard to your lower back and lower limbs, have participated in cycling for at least 6 hours per week for the past one year, and must train consistently on a road bicycle. You will be required to avoid participation in competitive events for the duration of the research study.

You will not be eligible to take part in this study if you have any injuries or health disorders that impair cycling biomechanics, or if you are currently including a core strengthening program into your training.

Following the initial assessment, you will be provided with a training diary, to complete over the duration of the research study, and an exercise handout sheet, detailing the core strengthening exercises. You will continue with normal cycling training and supplementation, whilst incorporating a core strengthening program to your training.

The core strengthening program should take approximately 20 minutes to complete, and you will be required to complete the program every day for the duration of the research study (4 weeks). A suitable time will be established for you to be contacted telephonically by the researcher on a weekly basis to monitor your progress and address any concerns you may have.
A follow up consultation will take place after the 4 week core strengthening program, where your core strength and cycling performance will again be assessed and data collected.

Risks or Discomforts to the Participant:
Tests that evaluate core strength and cycling performance are painless and non-invasive. There is a likelihood of muscle discomfort of short duration within the first two weeks of the core strengthening program.

Benefits:
The theory is that there shall be an improvement in cycling performance.

Reason/s why the Participant May Be Withdrawn from the Study:
If you are unable to comply with the core strengthening program, or do not return to the Chiropractic Day Clinic for your follow up consultation, you will be excluded from the study. If you do not meet the inclusion criteria, you will not be admitted into this research study. If at any stage you wish to withdraw from the research study, you are free to do so and you shall not suffer any adverse consequences.

Remuneration:
Assessments for the duration of the research study will be free of charge. You will not be offered any other form of remuneration for taking part in this study.

Costs of the Study:
You will not be expected to cover any costs towards the study.

Confidentiality:
All personal details and relevant information gathered through the research process will only be accessible to the researcher (Kate Wiseman) and the supervisor (Dr Andrew Jones). All participant information will remain confidential. The results of the study will be made available in the Durban University of Technology Library in the form of a thesis.

Research-related Injury:
Participants included in the study will be asymptomatic and healthy, thereby ruling out risk factors for injury. The core strengthening program is non-invasive, therefore no injury or adverse reaction is expected.

Persons to Contact in the Event of Any Problems or Queries:
Please contact the researcher: Kate Wiseman (031 373 2205), supervisor: Dr Andrew Jones (031 903 4467) or the Institutional Research Ethics Administrator (031 373 2900).

Statement of Agreement to Participate in the Research Study:
(I,………………………………………………..participant's full name, ID number………………..……………………., have read this document in its entirety and understand its contents. Where I have had any questions or queries, these have been explained to me by ………………………...to my satisfaction. Furthermore, I fully understand that I may withdraw from this study at any stage without any adverse consequences and my future health care will not be compromised. I, therefore, voluntarily agree to participate in this study.

Participants name (print): ……………………………………………..…

Participants signature: …………………………………………..…….. Date:……………...…

Researcher's name (print): …………………..………...

Researcher's signature: ……………………………………..…..…..Date:.........................

Witness name (print): ……………………………………...

Witness signature: …………………………………..........................Date:………………..…

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APPENDIX C

DURBAN UNIVERSITY OF TECHNOLOGY
CHIROPRACTIC DAY CLINIC
CASE HISTORY

Participant Code: ______________________________ Date: __________

Sex : __________ Age: __________

Intern : __________________________________ Signature ______________________

FOR CLINICIANS USE ONLY:

Initial visit

Clinician: Signature :

Case History:

Examination:

Previous: Current:

X-Ray Studies:

Previous: Current:

Clinical Path. lab:

Previous: Current:

CASE STATUS:

PTT:	Signature:	Date:

CONDITIONAL: Reason for Conditional:	
Signature:	Date:

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

Case Summary signed off:	Date:

<u>Intern's Case History:</u>

1. Source of History:

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

3. Present Illness:

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

4. Other Complaints:

5. Past Medical History:

< General Health Status

< Childhood Illnesses

< Adult Illnesses

< Psychiatric Illnesses

< Accidents/Injuries

< Surgery

< Hospitalizations

6. Current health status and life-style:

< Allergies

< Immunizations

< Screening Tests incl. x-rays

< Environmental Hazards (Home, School, Work)

< Exercise and Leisure

< Sleep Patterns

< Diet

< Current Medication
Analgesics/week:

< Tobacco

< Alcohol

< Social Drugs

7. Immediate Family Medical History:

< Age
< Health
< Cause of Death
< DM
< Heart Disease
< TB
< Stroke
< Kidney Disease
< CA
< Arthritis
< Anaemia
< Headaches
< Thyroid Disease
< Epilepsy
< Mental Illness
< Alcoholism
< Drug Addiction
< Other

8. Psychosocial history:

< Home Situation and daily life
< Important experiences
< Religious Beliefs

9. Review of Systems:

< General

< Skin

< Head

< Eyes

< Ears

< Nose/Sinuses

< Mouth/Throat

< Neck

< Breasts

< Respiratory

< Cardiac

< Gastro-intestinal

< Urinary

< Genital

< Vascular

< Musculoskeletal

< Neurologic

< Haematologic

< Endocrine

< Psychiatric

APPENDIX D

Durban University of Technology

PHYSICAL EXAMINATION: SENIOR

Participant Code : ____________________ **Date :** __________

Student : **Signature :**

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

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

SYSTEM SPECIFIC EXAMINATION:
CARDIOVASCULAR EXAMINATION
RESPIRATORY EXAMINATION
ABDOMINAL EXAMINATION
NEUROLOGICAL EXAMINATION
COMMENTS

Clinician: **Signature :**

APPENDIX E

Training Status and Riding Style Questionnaire

Participant Code: __________

Please answer all questions by ticking the appropriate block.

1. **How many hours do you ride per week on average?**

6-10	
11-15	
16-20	
21+	

2. **How many years have you actively participated in cycling for?**

1-5	
6-10	
10-15	
15-20	
20+	

3. **What type of riding do you mostly participate in?**

Road Riding	
Mountain Biking	
Track Cycling	
Road and MTB	

4. **How would you classify your riding ability?**

Social (weekend riding)	
Serious Amateur (>5 races per year)	
Elite (regular top 10% finisher)	
Professional (paid to ride)	

5. **In terms of riding style, do you prefer...**

Sprinting?	
Hill Climbing?	
Cadence over 100rpm?	
Cadence below 60rpm?	

APPENDIX F

Rate of Perceived Exertion Scale

6	No exertion at all (complete rest)
7	
8	
9	Very light
10	
11	Light
12	Moderate
13	Somewhat hard (able to continue)
14	
15	Hard (heavy)
16	
17	Very hard (strenuous)
18	
19	Extremely hard (extremely strenuous)
20	Maximal exertion (exhaustion)

(Borg, 1998)

Participant Code: ____________

Rate of Perceived Exertion Scale - Initial

Stage of course	RPE	Actual Heart Rate
First 550m flat sprint		
Second 550m flat sprint		
Incline 300m		
Descent 100m		

Rate of Perceived Exertion Scale – Follow Up

Stage of course	RPE	Actual Heart Rate
First 550m flat sprint		
Second 550m flat sprint		
Incline 300m		
Descent 100m		

Participants' Perception of Change in Speed, Power and Cadence

Mark as increased (↑), decreased (↓), or no noticable change (↔)

	Speed	Power	Cadence
Participants perception			

APPENDIX G

Training Diary

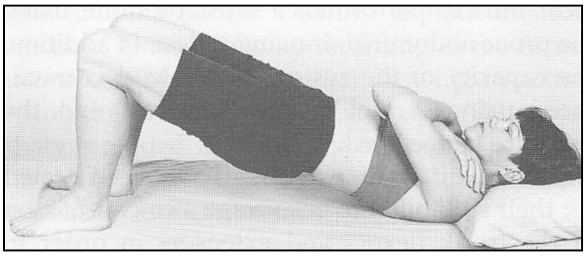
Participant Code: _____________

Cycling						Core		
Day	Date	Distance (KM)	Time (Mins)	Ave Speed (KM/hr)	Intensity Rating (1-10)	Core Training Completed	Intensity Rating (1-10)	Comments
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								
26								
27								
28								

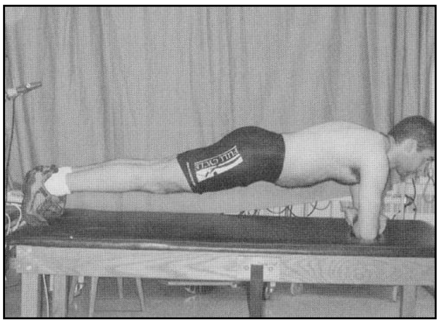
APPENDIX H

Core Training Exercises

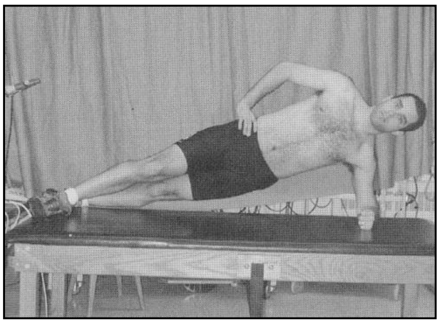
1. **Power Bridge**



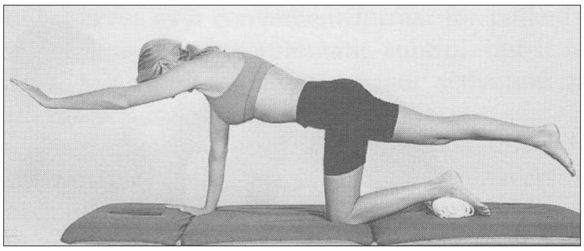
2. **Plank**



3. **Transverse Plank**



4. **Quadruped Reach**



(Liebenson, 2007. Richardson *et al*, 1999)

1. **Power Bridge**
    - Lying on your back, with knees bent, feet flat and shoulder width apart, toes pointing straight ahead and arms at your side with palms facing down.
    - In one smooth motion, activate your core and squeeze your gluteal muscles, and lift your hips off the floor so that your body forms a straight line from shoulders to knees.
    - Hold for 10 seconds and then lower down slowly.
    - Repeat for 10 sets.

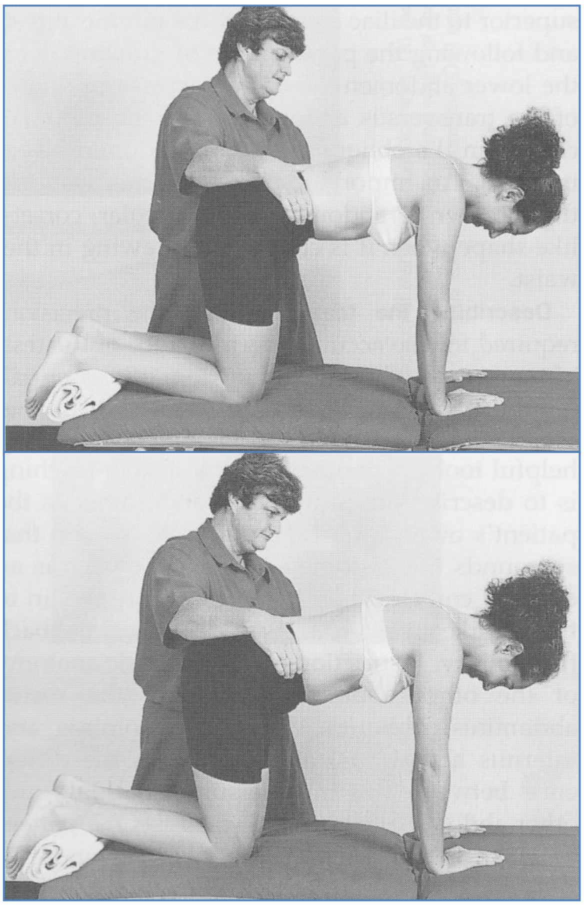
2. **Plank**
    - Lying on your stomach, place your elbows under your shoulders, with forearms and hands on the floor.
    - Lift your hips off the floors, resting on your toes, keeping your core activated, back straight.
    - Hold for 10 seconds and then lower down slowly.
    - Repeat for 10 sets.

3. **Transverse Plank**
    - Lie on your right side, with your right elbow under your right shoulder, and forearm in front to stabilise, and place your left foot on top of your right.
    - Activate your core, and lift your body in one smooth motion, to create a straight line down your left side.
    - Hold for 10 seconds and then lower down slowly.
    - Repeat for 10 sets.

4. **Quadruped Reach**
    - Kneeling on all fours, place your hands flat on the floor, directly under your shoulders, and your knees directly under your hips.
    - Activate your core, and extend your right arm forward and your left leg back, holding in line with your body.
    - Hold for 10 seconds and then lower down slowly.
    - Repeat for 10 sets.

APPENDIX I

Four Point Kneeling – Procedure and Position



- The position assumed is such that the hips should be over the knees and the shoulders directly over the hands
- Abdomen should be relaxed and the spine should be in neutral position
- Avoid deep inspiration to prevent abdominal wall movement
- Take a relaxed breath in and out, and then without breathing in, slowly draw the abdomen up and in towards the spine.
- Once contraction has been performed, continue breathing slowly, whilst maintaining the contraction for 10 seconds.

(Richardson *et al*, 1999)

APPENDIX J

Data Collection Sheet

Participant Code: __________

Age: __________ Gender: __________

Height: __________ Weight: __________

BMI: $\frac{\text{Weight}}{\text{Height}^2}$ = __________

Speed, Power, Cadence and Completion Time Readings

(Tacx Cycle Ergometer)

	Initial Time Trial	Follow Up Time Trial
Maximum speed		
Average speed		
Maximum power		
Average power		
Maximum cadence		
Average cadence		
Completion time		

Core Assessment – Abdominal Draw In Test

(Pressure Biofeedback Unit - PBU)

	Initial		**Follow Up**	
	Fluctuation from set value 70mmHg during core contraction (mmHg)	Difference between set value 70mmHg and fluctuation from this value during core contraction (mmHg)	Fluctuation from set value 70mmHg during core contraction (mmHg)	Difference between set value 70mmHg and fluctuation from this value during core contraction (mmHg)
Test				

Core Assessment – Test for Lumbopelvic Posture - Initial

(Pressure Biofeedback Unit – PBU)

	Grading		Fluctuation from set value 40mmHg at point core contraction cannot be maintained (mmHg)		Difference between set value 40mmHg and fluctuation from this value at point core contraction cannot be maintained (mmHg)	
	R	L	R	L	R	L
Test Saggital Bias						
Test Rotary Bias						

Core Assessment – Test for Lumbopelvic Posture – Follow Up

(Pressure Biofeedback Unit – PBU)

	Grading		Fluctuation from set value 40mmHg at point core contraction cannot be maintained (mmHg)		Difference between set value 40mmHg and fluctuation from this value at point core contraction cannot be maintained (mmHg)	
	R	L	R	L	R	L
Test Saggital Bias						
Test Rotary Bias						

NRS Discomfort Scale – Initial

- Subjects are required to select a number from 0 to 10 that best signifies the level of discomfort related to exertion during the cycling trial.
- 0 is equal to no discomfort, 5 is equal to moderate discomfort and 10 is equal to severe discomfort.

0 1 2 3 4 5 6 7 8 9 10

NRS Discomfort Scale – Follow Up

0 1 2 3 4 5 6 7 8 9 10

APPENDIX K

Letter from Statistician

6 Brittlestar Drive

Atlantic Beach Golf Estate

Melkbos

7441

The Research Committee

Health Sciences Faculty

Durban University of Technology

19 March 2012

Re: Research by Chiropractic student Kate Wiseman

To whom it may concern

The above mentioned student has contacted me and asked me to be her statistician for her Masters project. I have agreed to this, and have consulted with her with her regarding the sample size, sampling procedure and intended methods of statistical analysis for her study.

I have endorsed a sample size of 40 participants in total, stratified into two age groups to ensure representation of the sample. The data will be analysed using IBM SPSS version 19, and quantitative data will be compared between pre and post intervention using paired t-tests in order to assess the effect of the intervention. Categorical data will be compared using paired McNemar chi square tests. A p value <0.05 will indicate statistical significance.

Yours sincerely

Tonya Esterhuizen (Mrs)

MSc Epidemiology

APPENDIX L

Ethics Clearance Letter

DURBAN
UNIVERSITY of
TECHNOLOGY

INSTITUTIONAL RESEARCH ETHICS COMMITTEE (IREC)

31 July 2012

IREC Reference Number: **REC 29/12**

Ms K Wiseman
P O Box 52526
Moore Road
4083

Dear Ms Wiseman

An investigation into the effectiveness of core muscle strengthening on cycling performance in asymptomatic cyclists

I am pleased to inform you that Full Approval has been granted to your proposal REC 29/12.

The Proposal has been allocated the following Ethical Clearance number IREC **024/12**. Please use this number in all communication with this office.

Approval has been granted for a period of one year, before the expiry of which you are required to apply for safety monitoring and annual recertification. Please use the Safety Monitoring and Annual Recertification Report form which can be found in the Standard Operating Procedures [SOP's] of the IREC. This form must be submitted to the IREC at least 3 months before the ethics approval for the study expires.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the IREC according to the IREC SOP's. In addition, you will be responsible to ensure gatekeeper permission.

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

Yours Sincerely

[redacted]

Dr D F Naude
Chairperson: IREC

APPENDIX M

Statistical Results

Table 1: Gender

Gender					
		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	male	36	85.7	85.7	85.7
	female	6	14.3	14.3	14.3
	Total	42	100.0	100.0	100.0

Table 2: Physical characteristics

	Mean	Standard Deviation	Minimum	Maximum
Age	34.1	9.0	20.0	47.0
Height	1.8	.1	1.5	2.0
Weight	76.4	15.0	52.0	122.0
BMI	24.6	3.7	19.4	34.7

Table 3: Training status and riding style

		Frequency	Percent
1.How many hours do you ride per week on average?	6-10	25	59.5%
	11-15	12	28.6%
	16-20	1	2.4%
	21+	4	9.5%
2.How many years have you actively participated in cycling for?	1-5	18	42.9%
	6-10	10	23.8%
	10-15	9	21.4%
	15-20	1	2.4%
	20+	4	9.5%
3. What type of riding do you mostly participate in?	Road	18	42.9%
	Mountain bike	11	26.2%
	Track	2	4.8%
	Road and MTB	11	26.2%
4. How would you classify your riding ability?	Social	3	7.1%
	Serious amateur	31	73.8%
	Elite	8	19.0%
	Professional	0	0.0%
5. In terms of riding style, do you prefer	Sprinting	7	16.7%
	Hill climbing	17	40.5%
	Cadence over 100 rpm	13	31.0%
	Cadence below 60 rpm	5	11.9%

Table 4: Gender – Stratified

		Age group			
		20-35		36-50	
		Frequency	Percent	Frequency	Percent
Gender	male	20	90.9%	16	80.0%
	female	2	9.1%	4	20.0%

Table 5: Physical characteristics - Stratified

	Age group			
	20-35		36-50	
	Mean	Standard Deviation	Mean	Standard Deviation
Age	26.7	5.2	42.3	3.4
Height	1.8	0.1	1.8	0.1
Weight	74.4	10.6	78.6	18.7
BMI	24.1	2.6	25.2	4.5

Table 6: Training status and riding style - Stratified

		Age group			
		20-35		36-50	
		Frequency	Percent	Frequency	Percent
1.How many hours do you ride per week on average?	6-10	14	63.6%	11	55.0%
	11-15	5	22.7%	7	35.0%
	16-20	1	4.5%	0	0.0%
	21+	2	9.1%	2	10.0%
2.How many years have you actively participated in cycling for?	1-5	10	45.5%	8	40.0%
	6-10	6	27.3%	4	20.0%
	10-15	5	22.7%	4	20.0%
	15-20	0	0.0%	1	5.0%
	20+	1	4.5%	3	15.0%
3. What type of riding do you mostly participate in?	Road	10	45.5%	8	40.0%
	Mountain bike	7	31.8%	4	20.0%
	Track	1	4.5%	1	5.0%
	Road and MTB	4	18.2%	7	35.0%
4. How would you classify your riding ability?	Social	2	9.1%	1	5.0%
	Serious amateur	14	63.6%	17	85.0%
	Elite	6	27.3%	2	10.0%
	Professional	0	0.0%	0	0.0%
5. In terms of riding style, do you prefer	Sprinting	3	13.6%	4	20.0%
	Hill climbing	9	40.9%	8	40.0%
	Cadence over 100 rpm	6	27.3%	7	35.0%
	Cadence below 60 rpm	4	18.2%	1	5.0%

Table 7: Cycling performance TT1

	Mean	Standard Deviation	Minimum	Maximum
Initial Speed max	49.8	7.1	36.0	61.0
Initial Speed ave	37.2	4.6	27.8	46.0
Initial Power max	472.7	137.8	209.0	870.0
Initial Power ave	279.5	87.3	128.0	512.0
Initial Cadence max	117.9	12.3	90.0	144.0
Initial Cadence ave	101.1	11.4	77.0	125.0
Initial Completion Time	156.6	21.0	125.0	206.0

Table 8: Core strength pre-intervention

	Mean	Standard Deviation	Minimum	Maximum
Initial fluctuation	62.8	1.4	60.0	64.0
Initial difference	-7.2	1.4	-10.0	-6.0
Initial timing	63.6	43.0	16.0	242.0
Initial fluctuation right	34.6	6.6	28.0	48.0
Initial fluctuation left	34.3	6.5	28.0	48.0
Initial difference right	-5.4	6.6	-12.0	8.0
Initial difference left	-5.7	6.5	-12.0	8.0
Initial grading right	2.0	.6	1.0	3.0
Initial grading left	1.9	.6	1.0	3.0

Table 9: Cycling performance TT1 - Stratified

	Age group			
	20-35		36-50	
	Mean	Standard Deviation	Mean	Standard Deviation
Initial Speed max	51.5	7.1	47.9	6.8
Initial Speed ave	38.2	5.1	36.1	3.9
Initial Power max	489.9	156.6	453.8	114.7
Initial Power ave	297.4	95.3	259.8	74.9
Initial Cadence max	117.1	13.9	118.7	10.5
Initial Cadence ave	100.1	13.0	102.1	9.7
Initial Completion Time	153.1	23.6	160.5	17.5

Table 10: Core strength pre-intervention - Stratified

	Age group			
	20-35		36-50	
	Mean	Standard Deviation	Mean	Standard Deviation
Initial fluctuation	62.9	1.3	62.7	1.5
Initial difference	-7.1	1.3	-7.3	1.5
Initial timing	63.6	25.5	63.5	57.1
Initial fluctuation right	33	6	36	7
Initial fluctuation left	34	7	35	6
Initial difference right	-7	6	-4	7
Initial difference left	-6	7	-5	6
Initial grading right	1.91	.61	2.00	.65
Initial grading left	1.86	.56	1.95	.60

Table 11: Cycling performance TT2

	Mean	Standard Deviation	Minimum	Maximum
Follow up Speed max	52.7	5.1	42.0	59.0
Follow up Speed ave	39.4	3.9	28.0	47.0
Follow up Power max	533.1	146.1	239.0	867.0
Follow up Power ave	321.1	80.0	136.0	502.0
Follow up Cadence max	127.0	10.7	106.0	149.0
Follow up Cadence ave	105.9	10.7	88.0	133.0
Follow up Completion Time	146.2	15.7	123.0	196.0

Table 12: Core strength post-intervention

	Mean	Standard Deviation	Minimum	Maximum
Follow up fluctuation	61.2	1.4	60.0	64.0
Follow up difference	-8.8	1.4	-10.0	-6.0
Follow up timing	147.3	137.8	24.0	644.0
Follow up fluctuation right	35.1	4.7	28.0	48.0
Follow up fluctuation left	35.0	5.0	28.0	48.0
Follow up difference right	-4.9	4.7	-12.0	8.0
Follow up difference left	-5.0	5.0	-12.0	8.0
Follow up grading right	2.9	.6	2.0	4.0
Follow up grading left	2.9	.6	2.0	4.0

Table 13: Cycling performance TT2 - Stratified

	Age group			
	20-35		36-50	
	Mean	Standard Deviation	Mean	Standard Deviation
Follow up Speed max	54.1	4.8	51.2	5.2
Follow up Speed ave	40.0	4.3	38.7	3.3
Follow up Power max	550.7	157.5	513.7	133.8
Follow up Power ave	329.0	83.0	312.5	77.8
Follow up Cadence max	126.2	11.7	128.0	9.6
Follow up Cadence ave	105.5	11.8	106.3	9.6
Follow up completion time	144.1	17.6	148.5	13.4

Table 14: Core strength post-intervention - Stratified

	Age group			
	20-35		36-50	
	Mean	Standard Deviation	Mean	Standard Deviation
Follow up fluctuation	60.9	1.2	61.5	1.6
Follow up difference	-9.1	1.2	-8.5	1.6
Follow up timing	133.3	78.1	162.8	183.8
Follow up fluctuation right	35.5	5.0	34.8	4.5
Follow up fluctuation left	34.7	5.5	35.3	4.5
Follow up difference right	-4.5	5.0	-5.2	4.5
Follow up difference left	-5.3	5.5	-4.7	4.5
Follow up grading right	2.8	.6	3.1	.6
Follow up grading left	2.8	.6	3.0	.6

Table 15: Participant perception of change - Stratified

		Age group			
		20-35		36-50	
		Count	Column N %	Count	Column N %
Participant perception of a change in Speed	increase	19	86.4%	18	90.0%
	decrease	0	0.0%	1	5.0%
	no change	3	13.6%	1	5.0%
Participant perception of a change in Power	increase	21	95.5%	16	80.0%
	decrease	0	0.0%	0	0.0%
	no change	1	4.5%	4	20.0%
Participant perception of a change in Cadence	increase	15	68.2%	14	70.0%
	decrease	0	0.0%	2	10.0%
	no change	7	31.8%	4	20.0%

Table 16: Core strength assessment

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Initial fluctuation - Follow up fluctuation	1.619	1.413	.218	1.179	2.059	7.424	41	.000
Pair 2	Initial difference - Follow up difference	1.619	1.413	.218	1.179	2.059	7.424	41	.000
Pair 3	Initial timing - Follow up timing	-83.762	107.055	16.519	-117.123	-50.401	-5.071	41	.000
Pair 4	Initial fluctuation right - Follow up fluctuation right	-.571	5.306	.819	-2.225	1.082	-.698	41	.489
Pair 5	Initial fluctuation left - Follow up fluctuation left	-.714	4.974	.768	-2.264	.836	-.931	41	.358
Pair 6	Initial difference right - Follow up difference right	-.571	5.306	.819	-2.225	1.082	-.698	41	.489
Pair 7	Initial difference left - Follow up difference left	-.714	4.974	.768	-2.264	.836	-.931	41	.358
Pair 8	Initial grading right – follow up	-.97619	.34838	.05376	-1.08475	-.86763	-18.159	41	.000

	grading right								
Pair 9	Initial grading left – follow up grading left	-1.00000	.31235	.04820	-1.09733	-.90267	-20.748	41	.000

Table 17: Cycling performance assessment

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Initial Speed max - Follow up Speed max	-2.9238	4.6514	.7177	-4.3733	-1.4743	-4.074	41	.000
Pair 2	Initial Speed ave - Follow up Speed ave	-2.1310	2.2512	.3474	-2.8325	-1.4294	-6.134	41	.000
Pair 3	Initial Power max - Follow up Power max	-60.357	73.165	11.290	-83.157	-37.557	-5.346	41	.000
Pair 4	Initial Power ave - Follow up Power ave	-41.667	44.070	6.800	-55.400	-27.934	-6.127	41	.000
Pair 5	Initial Cadence max - Follow up Cadence max	-9.167	8.754	1.351	-11.895	-6.439	-6.786	41	.000
Pair 6	Initial Cadence ave - Follow up Cadence ave	-4.833	7.679	1.185	-7.226	-2.440	-4.079	41	.000
Pair 7	Initial Completion Time - Follow up Completion Time	10.381	10.883	1.679	6.990	13.772	6.182	41	.000

Table 18: Rate of perceived exertion

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	initial1st Flat – Follow up1st Flat	-.643	1.032	.159	-.964	-.321	-4.038	41	.000
Pair 2	initial2nd Flat – Follow up 2nd Flat	-.571	1.039	.160	-.895	-.248	-3.563	41	.001
Pair 3	Initial Incline - Follow up Incline	-.571	1.346	.208	-.991	-.152	-2.751	41	.009
Pair 4	Initial Decline - Follow up Decline	-.667	1.426	.220	-1.111	-.222	-3.031	41	.004
Pair 5	actual hr 1st Flat - HR F1st Flat	-4.071	8.469	1.307	-6.711	-1.432	-3.116	41	.003
Pair 6	actual hr 2nd Flat - HR F2nd Flat	-5.476	9.115	1.406	-8.317	-2.636	-3.894	41	.000
Pair 7	actual hr Incline - HR F Incline	-2.810	8.451	1.304	-5.443	-.176	-2.154	41	.037
Pair 8	actual hr Decline - HR F Decline	-3.429	9.402	1.451	-6.358	-.499	-2.363	41	.023

Table 19: NRS

Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	NRS Initial - NRS Follow Up	-.286	1.088	.168	-.625	.053	-1.701	41	.096

Table 20: Core strength assessment – Stratified 20-35

Paired Samples Test[a]									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Initial fluctuation - Follow up fluctuation	2.000	1.512	.322	1.330	2.670	6.205	21	.000
Pair 2	Initial difference - Follow up difference	2.000	1.512	.322	1.330	2.670	6.205	21	.000
Pair 3	Initial timing - Follow up timing	-69.636	64.908	13.839	-98.415	-40.858	-5.032	21	.000
Pair 4	Initial fluctuation right - Follow up fluctuation right	-2.182	3.487	.743	-3.728	-.636	-2.935	21	.008
Pair 5	Initial fluctuation left - Follow up fluctuation left	-.909	3.069	.654	-2.270	.452	-1.389	21	.179
Pair 6	Initial difference right - Follow up difference right	-2.182	3.487	.743	-3.728	-.636	-2.935	21	.008
Pair 7	Initial difference left - Follow up difference left	-.909	3.069	.654	-2.270	.452	-1.389	21	.179
Pair 8	Initial grading right – follow up	-.90909	.29424	.06273	-1.03955	-.77863	-14.491	21	.000

	grading right								
Pair 9	Initial grading left – follow up grading left	-.95455	.21320	.04545	-1.04907	-.86002	-21.000	21	.000
a. Age group = 20-35									

Table 21: Cycling performance assessment – Stratified 20-35

Paired Samples Test[a]									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Initial Speed max - Follow up Speed max	-2.5591	4.2121	.8980	-4.4266	-.6916	-2.850	21	.010
Pair 2	Initial Speed ave - Follow up Speed ave	-1.7273	2.1366	.4555	-2.6746	-.7800	-3.792	21	.001
Pair 3	Initial Power max - Follow up Power max	-60.773	75.196	16.032	-94.113	-27.433	-3.791	21	.001
Pair 4	Initial Power ave - Follow up Power ave	-31.545	43.372	9.247	-50.775	-12.315	-3.411	21	.003
Pair 5	Initial Cadence max - Follow up Cadence max	-9.045	9.639	2.055	-13.319	-4.772	-4.402	21	.000
Pair 6	Initial Cadence ave - Follow up Cadence ave	-5.409	9.022	1.923	-9.409	-1.409	-2.812	21	.010
Pair 7	Initial Completion Time - Follow up Completion Time	9.000	9.967	2.125	4.581	13.419	4.236	21	.000
a. Age group = 20-35									

Table 22: Rate of perceived exertion – Stratified 20-35

Paired Samples Test[a]									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	initial1st Flat - F1st Flat	-.773	.973	.207	-1.204	-.342	-3.727	21	.001
Pair 2	Initial 2nd Flat - F2nd Flat	-.682	1.129	.241	-1.182	-.181	-2.832	21	.010
Pair 3	Initial Incline - F Incline	-.636	1.002	.214	-1.081	-.192	-2.978	21	.007
Pair 4	Initial Decline - F Decline	-.591	.959	.204	-1.016	-.166	-2.890	21	.009
Pair 5	actual hr 1st Flat - HR F1st Flat	-2.409	8.770	1.870	-6.298	1.479	-1.288	21	.212
Pair 6	actual hr 2nd Flat - HR F2nd Flat	-3.773	9.118	1.944	-7.815	.270	-1.941	21	.066
Pair 7	actual hr Incline - HR FIncline	-1.864	8.055	1.717	-5.435	1.708	-1.085	21	.290
Pair 8	actual hr Decline - HR FDecline	-1.591	8.319	1.774	-5.279	2.098	-.897	21	.380
a. Age group = 20-35									

Table 23: NRS – Stratified 20-35

Paired Samples Test[a]									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	NRS Initial - NRS Follow Up	-.409	1.221	.260	-.951	.132	-1.571	21	.131
a. Age group = 20-35									

Table 24: Core strength assessment – Stratified 36-50

Paired Samples Test[a]									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Initial fluctuation - Follow up fluctuation	1.200	1.196	.268	.640	1.760	4.485	19	.000
Pair 2	Initial difference - Follow up difference	1.200	1.196	.268	.640	1.760	4.485	19	.000
Pair 3	Initial timing - Follow up timing	-99.300	139.962	31.296	-164.804	-33.796	-3.173	19	.005
Pair 4	Initial fluctuation right - Follow up fluctuation right	1.200	6.404	1.432	-1.797	4.197	.838	19	.412
Pair 5	Initial fluctuation left - Follow up fluctuation left	-.500	6.549	1.464	-3.565	2.565	-.341	19	.737
Pair 6	Initial difference right - Follow up difference right	1.200	6.404	1.432	-1.797	4.197	.838	19	.412
Pair 7	Initial difference left - Follow up difference left	-.500	6.549	1.464	-3.565	2.565	-.341	19	.737
Pair 8	Initial grading right – follow up	-1.05000	.39403	.08811	-1.23441	-.86559	-11.917	19	.000

	grading right								
Pair 9	Initial grading left – follow up grading left	-1.05000	.39403	.08811	-1.23441	-.86559	-11.917	19	.000
a. Age group = 36-50									

Table 25: Cycling performance assessment – Stratified 36-50

Paired Samples Test[a]									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Initial Speed max - Follow up Speed max	-3.3250	5.1725	1.1566	-5.7458	-.9042	-2.875	19	.010
Pair 2	Initial Speed ave - Follow up Speed ave	-2.5750	2.3441	.5241	-3.6721	-1.4779	-4.913	19	.000
Pair 3	Initial Power max - Follow up Power max	-59.900	72.810	16.281	-93.976	-25.824	-3.679	19	.002
Pair 4	Initial Power ave - Follow up Power ave	-52.800	43.159	9.651	-72.999	-32.601	-5.471	19	.000
Pair 5	Initial Cadence max - Follow up Cadence max	-9.300	7.915	1.770	-13.004	-5.596	-5.255	19	.000
Pair 6	Initial Cadence ave - Follow up Cadence ave	-4.200	6.040	1.351	-7.027	-1.373	-3.110	19	.006
Pair 7	Initial Completion Time - Follow up Completion Time	11.900	11.881	2.657	6.340	17.460	4.479	19	.000
a. Age group = 36-50									

Table 26: Rate of perceived exertion – Stratified 36-50

Paired Samples Test[a]									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	initial1st Flat - F1st Flat	-.500	1.100	.246	-1.015	.015	-2.032	19	.056
Pair 2	initial2nd Flat - F2nd Flat	-.450	.945	.211	-.892	-.008	-2.131	19	.046
Pair 3	initialIncline - FIncline	-.500	1.670	.373	-1.282	.282	-1.339	19	.196
Pair 4	initialDecline - FDecline	-.750	1.832	.410	-1.607	.107	-1.831	19	.083
Pair 5	actual hr 1st Flat - HR F1st Flat	-5.900	7.940	1.775	-9.616	-2.184	-3.323	19	.004
Pair 6	actual hr 2nd Flat - HR F2nd Flat	-7.350	8.964	2.004	-11.545	-3.155	-3.667	19	.002
Pair 7	actual hr Incline - HR FIncline	-3.850	8.958	2.003	-8.042	.342	-1.922	19	.070
Pair 8	actual hr Decline - HR FDecline	-5.450	10.298	2.303	-10.270	-.630	-2.367	19	.029
a. Age group = 36-50									

Table 27: NRS – Stratified 36-50

Paired Samples Test[a]									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	NRS Initial - NRS Follow Up	-.150	.933	.209	-.587	.287	-.719	19	.481
a. Age group = 36-50									