The effect of alterations in effective seat tube angle on cycling performance, economy and muscle recruitment.

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Declaration

I, Teo Choon Chye, hereby declare that the work on which this dissertation is based on my original work (except where acknowledgements indicate otherwise) and that neither the whole work nor any part of it has been, is being, or is to be submitted for another degree in this or any other university.

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List of abbreviations

American College of Sports Medicine	ACSM
Analysis of Variance	ANOVA
Beats per minute	BPM
Body Mass Index	BMI
Bottom Dead Centre	BDC
Effective seat tube angle	ESTA
Electromyography	EMG
Hear rate	HR
Peak Power Output	PPO
Rating of Perceived Exertion	RPE
Respiratory exchange ratio	RER
Revolution per minute	RPM
Seat tube angle	STA
Standard Deviation	SD
Top Dead Centre	TDC
Oxygen consumption	$\dot{V}O_2$
Watts	W

Abstract

Introduction: The bicycle seat tube angle (STA) has been used in scientific research to investigate cycling performance since the early 1980's and has led to inconclusive findings when manipulated between 69^o and 82^o STA configuration. Most of these studies did not clearly indicate the handlebar positioning in relation to the change in STAs. In addition, the studied duration and intensity were not a true reflection for cycling performance during races. **Aim:** The study aimed to compare the effect of independent alteration of effective seat tube angle (ESTA) on gross muscle activities, body kinematics and gross economy for well-trained cyclists. **Methods:** Ten well-trained male cyclists (mean ± SD; age 37.8 ± 3.6 years, height 178.2 ± 3.8 cm, body mass 76.9 ± 8.0 kg, $\dot{V}O_{2max}$ 51.6 ± 5.3 ml/kg/min with 6.8 ± 2.6 years cycling experience and an average training load of 5.8 ± 2.3 hours per week for three months prior) were volunteered for this study. All cyclists were randomly assigned to either a forward or rearward saddle position after an initial preferred saddle cycling position. Each cycling position was performed at 60% of W_{Peak} for one hour with forty reflective markers placed on bony landmarks described by Vicon full body model Plug-in gait and EMG electrodes placed on the right lower limb on seven muscles. **Results:** The mean power output and cadences during one hour submaximal steady state cycling differed by a maximum of 0.7W and 3.5 repetitions per minute respectively between three trials. $\dot{V}O_2$ values (P=0.95), respiratory exchange ratio (P=0.39) and heart rate (P=0.92) for the trials were not significantly different. Mean angles for each joint and gross muscle activation patterns across the three trials were not significantly different. Magnitude-based inferences statistics showed "possible beneficial effects" on knee and ankle joint kinematics when comparing the forward and rearward saddle displacement. A progressive increase in integrated EMG values was observed for gluteus maximus, biceps femoris and rectus femoris from forward to rearward position. Both vastus lateralis and vastus medialis decreased activation in forward and rearward positions as compared to preferred position. However, none of these changes were statistically significant. **Conclusion:** Preserving the joint kinematics of the elbow, shoulder, hip, knee and ankle joint of the cyclist when changing the saddle displacement effectively negate any change in heart rate, oxygen consumption and respiratory exchange ratio. Nonetheless, the knee and ankle joints were increased by 1^o and decreased by 1.5^o respectively when saddle was moved forward. Similar knee and ankle joints effects were also detected with when saddle was moved rearward, which were decreased by 3^o and increased by 2^o respectively. Therefore, dynamic joint angles should be controlled for future studies when manipulating saddle displacement during cycling. The seven lower limb muscles activations were not statistically significant different when using traditional statistical methods and magnitude type statistic also indicates most unlikely or very unlikely benefits for all surface EMG variables between saddle displacements. These could be due to the high degrees of variability in EMG signal during cycling. Therefore, greater numbers of participants are encouraged for future studies aimed at understanding the coordination of agonist and antagonist muscles at different ESTA. **Key words:** Effective seat tube angle, submaximal cycling, 3D joint kinematics, electromyography (EMG).

Chapter 1

1.1.INTRODUCTION

The seat tube angle (STA) is an important component affecting the distance between the hip and the crank axle, which affects power production during the cycling motion (Gonzalez and Hull, 1989). The seat tube angles for road racing bicycles and triathlon bicycles are manufactured at 72-76^o and 76-78^o respectively (Heil, Wilcox, & Quinn, 1995; Road GALLIUMPRO - Argon 18, n.d.; What Is The Difference Between a Road Bike and Triathlon Bike, 2015). The steeper seat tube angle for triathlon bicycles were claimed to allow for greater comfort, efficiency, improve power production and to reduce wind resistance by placing the cyclist in a position whereby the body is rotated over the front of the bicycle to reduce frontal surface area (Garside & Doran, 2000; ; Hausswirth et al., 2001; Heil, Wilcox, & Quinn, 1995; Hunter et al., 2003; Price & Donne, 1997). In contrast, shallow seat tube angle for road bicycles was proposed to allow the cyclists to move fore and aft on the saddle with an adjustment during downhill, uphill and flat terrain for comfort (Burke & Pruitt, 2003). The difference between triathlon bicycles and road cycling is that the terrain for road cycling is consistently changing whereas most triathlons are conducted on flat terrain. Therefore, road cyclists have to make adjustment to accommodate for the road conditions to prevent them from sitting too far forward or too far backward which may increase knee joint force or loss of cycling efficiency (Bini et al., 2013; Chung et al., 2011; Domalain et al., 2016a; Domalain et al., 2016b).

An important distinction to note is that the seat tube is a fixed structure on the bicycle frame, where the angle is measured by the seat tube (a physical structural element of the bicycle) and the crank axle line parallel to the floor (Figure 1), whereas the effective seat tube angle (ESTA (Figure 2) is defined as the angle subtended by the point where the ischial tuberosities make contact with the saddle and the crank axle line relative to a line parallel to the floor. One of the strategies that cyclists can, therefore, use to manipulate the ESTA is to shift the saddle fore and aft at the position where the seat is clamped onto the seat post so to optimise pedaling efficiency.

Figure 1.1: Seat tube angle

Figure 1.2: Effective seat tube angle

In the early nineties, Too (1990) conducted a series of studies to investigate the relationship between body and hip orientation as well as seat-to-pedal distance to assess the effects on cycling performance (Too, 1989, 1990, 1991, 1994). Around the same period, Gonzalez and Hull (1989) specifically analysed the optimization of cycling biomechanics and reported that the chosen ESTA varied depending on leg length and cadence, which resulted in changes in the direction of the force applied to the pedals. In recent years, more scientific articles have confirmed that increasing the ESTA while keeping the handlebar contact points in the same position leads to an increase in the inclination of the trunk (Bisi et al., 2012) and hip joint angle (Hunter et al., 2003; Savelberg, Port, & Willems, 2003), which place the cyclists more directly above the crank axis. This posture allows more hip extension (Umberger, Scheuchenzuber, & Manos, 1998) and enables cyclists to generate greater hip torque during cycling. A similar position over the crank axis is commonly used in triathlon and time trial cycling but with the handlebar lowered to reduce the torso angle and maintain a similar hip joint angle as the more rearward saddle position but with improved aerodynamics (Bisi et al., 2012; Grappe et al., 1997). An additional hypothesis is that a steeper seat tube angle facilitates pre-stretching of the gluteus maximus muscle that improves propulsion during cycling (Mestdagh, 1998; Burke & Pruitt, 2003). A few studies that have compared conventional and steeper seat tube angles by electromyography of the leg muscles and revealed alterations in muscle recruitment (Brown, Kautz, & Dairaghi, 1996; Hayot et al., 2013; Ricard et al., 2006). However, a limitation of these studies is that the reach of the bicycle position was not controlled. Shifting the ESTA will result in shortening or lengthening the reach and this will result in an alteration of the trunk angle and hip angle without independently assessing the effects of the ESTA.

Another group of studies reported no statistically significant differences in lower limbs kinematics, oxygen uptake and muscle recruitment patterns between 72° and 82° STA configurations (Maria Cristina Bisi et al., 2012; Garside & Doran, 2000; Ricard et al., 2006). These studies once again did not clearly indicate the handlebar position in relation to the change of the STA. This could have resulted in the altered trunk and hip joint angles and may have caused the body to rotate forward or backward, which affects muscle activation and kinematics (Chen et al., 2013), thereby, resulting in inconsistent experimental results. In addition, the duration of many studies which investigated the effects of seat tube angle used short, high–intensity or maximal effort cycling bouts, during which the pedaling techniques used are different to submaximal efforts (Faria et al., 2005b). Therefore, it is important to investigate how different ESTAs affect lower limbs muscle recruitment strategies and kinematics as well as changes in physiological parameters during prolonged steady-state cycling.

1.2.STATEMENT OF THE PROBLEM

To date, the studies investigating ESTA have produced inconsistent results which may be due to equipment limitations and lack of control of the handlebar position in relation to the seat position. Most of the studies 1) have not clearly indicated if the handlebar position was altered when manipulating the ESTA, and 2) if the distance and height between the handlebar and the saddle were adjusted to accommodate the change in the distance between the saddle and the handlebar due to the limitation of the bicycle ergometer, and 3) current information is limited to short cycling durations or a testing posture is not realistic to actual athletic positioning. Therefore, cycle ergometers that allow manipulation of the distance between the bicycle handlebar and the saddle may provide more insightful information regarding the relationship between bicycle configuration and lower extremity kinematics, muscle recruitment, and other physiological parameters. In addition, short duration exercise may not reflect the physiological stresses or requirements of cycling performance, hence, it is more practical to examine a longer duration exercise bout at the submaximal intensity to understand the effects of changes in ESTA during cycling.

1.3.AIMS

This thesis aims to further our understanding of cycling biomechanics specific to endurance cycling. More specifically, the study sought to investigate the effect of independent alterations on ESTA on:

a. Gross muscle recruitment patterns

b. Whole body kinematics
c. Oxygen consumption
d. Heart rate
e. Respiratory exchange ratio (RER)

1.4.SIGNIFICANCE OF THE STUDY

To date, limited scientific knowledge exists on the optimal STA for cycling performance, economy and comfort. By establishing the effects of changes in ESTA, sports scientists, coaches, and cyclists will better understand the optimal bicycle configuration and cyclist posture required to enhance cycling performance and potentially prevent overuse injury, hence directing their preparation in a systematic approach instead of a “trial and error” way. The study results in joint angles and EMG data can also be used to optimise the bicycle configuration for different terrains and racing strategies.

1.5.ASSUMPTIONS

The training load was self-reported by recording it to the training log provided to the participants, therefore, the assumption is made that the participants reported their training load truthfully and accurately.

The analysis of joint kinematics and kinetics are based on rigid mechanical movement, in reality, joint movements are subjected to agonist and antagonist muscle contraction which influence the kinematics and kinetics of human movements.

1.6.LIMITATIONS

The crank arm of the ergometer was fixed at 170 millimetres as opposed to the cyclist’s own bicycle crank length and the effect of this was not accounted for in the kinetics analysis. This additional length could affect the angular velocity, thus affected the cadences and the exact joints range of motion, which affects the moment arms and force production. However, the crank arm was not different between trials and therefore valid comparisons can be made between three trials.

The participants were conditioned to the altered ESTA for a 1-week period which might not have been sufficient to assess long-term muscle adaptations to the altered position.

The requirement from the participated well-trained cyclists to maintain their training program for 4-weeks and visit the laboratory on a weekly basis with an average of 2.5 hours per session can limits the sample size for this study.

Chapter 2

2.1.REVIEW OF THE LITERATURE

The aim of this chapter is to review the published research on the effect of changes in the effective STA on cycling biomechanics and performance. The current evidence suggests that steeper STA (>76^o) permit greater comfort, efficiency and improved power production during cycling (Garside & Doran, 2000; Heil at al, 1995; Hunter et al., 2003). This chapter will review the current understanding of cycling biomechanics and the variables investigated from the existing literature. The definition of the cycling motion will be outlined in paragraph 2.2 cycling motion and performance. In paragraph 2.3 onwards, the current evidence for cycling kinematics, cycling kinetic and cycling economy are discussed. The instruments and methodology to determine variables in analyses of cycling biomechanics will be discussed in paragraph 2.6 onwards.

2.2.CYCLING MOTION AND PERFORMANCE

Cycling performance has been examined using power output in watts and oxygen consumption in litre per minute (L/minute) during an incremental cycle until exhaustion or steady state for a period of time (Bini et al., 2008; Bini et al., 2010; Moseley and Jeukendrup, 2001). A combination of these data can be translated to cycling economy, which is power output (watts) divided by oxygen consumption (L/minute). This refers to the power output generated at a cost of one litre of oxygen per minute of cycling. Before discussing the components affecting gross economy during cycling, it is essential to understand the crank movement that propels the bicycle forward. The driving mechanism of the bicycle consists of two crank arms that are fixed in opposite directions to each other, which rotate around the central axle in a 360^o cycle. This angle represents the crank arm movement around the crank axle and is commonly referenced as the pedal cycle. The pedal cycle can be divided into two parts, starting at 0^o (top dead center (TDC)) through to 180^o, which is also known as the propulsion phase or knee extension phase and 180^o (bottom dead center (BDC)) to 360^o, which is often referred to as the recovery phase or knee flexion phase. The cranks move in opposite phases; i.e. one crank arm moving through the propulsion phase and the contralateral side moving through the recovery phase. Several mechanical factors such as seat height, STA, crank length and longitudinal foot position could affect the kinematics and kinetics of the pedal cycle (Gonzalez & Hull, 1989). These variables affect the effectiveness of the force production by altering the joint angles, muscle length, and muscle moment arms.

2.3.CYCLING KINEMATICS

There are five contact points between the cyclist and bicycle regardless of the purpose of the cycle. The feet make contact with the bicycle pedals for propulsion and the upper limbs make contact with the handlebar and steer the handlebar for stability, controlling the direction and counterbalance the force exerted during pedalling. The pelvis provides a link between the feet and the upper limbs to provide stability during cycling (Neptune & Hull, 1995; Nordeen-Snyder, 1977). More importantly, the pelvis functions as a pivot point to transmit muscle energy from the hip joint to the pedals (Bini & Diefenthaeler, 2009; Raasch & Zajac, 1999; Raasch et al., 1997) and the upper body will function as a stable structure during cycling (Duc et al., 2008). The knee, hip, and ankle are the three joints which link between the pelvis and the feet (figure 2.1). The knee undergoes extension during the propulsive phase after TDC and begins to flex again near to the BDC position. The knee range of motion reaches maximal flexion of approximately 68^o at the TDC and a minimal flexion angle of 134^o (Ericson, Nisell, & Nemeth, 1988). The hip extends from the maximal flexion at about 110^o at the TDC to its minimal flexion angle of about 148^o that occurs at BDC (Ericson, Nisell, & Nemeth, 1988). The ankle goes through plantar flexion movement with about 20^o of the range of motion (Ericson et al., 1988; Faria & Cavanagh, 1978). This is a smaller range of motion in the ankle compared to knee and hip as the ankle is required to be stiff to transmit the energy generated by the leg muscles to the pedal (Bini & Diefenthaeler, 2009). These contact point positions can be variably altered and may result in an excessive saddle height, extreme STAs, excessive or insufficient reach or excessive or insufficient drop. This can result in an uncomfortable position, an inefficient application of power in terms of force or metabolic economy, or could require greater efforts for the upper body and extremity musculatures to manage the bicycle. Additionally, a suboptimal or excessive altered position may lead to overuse injury (Douris et al., 2011).

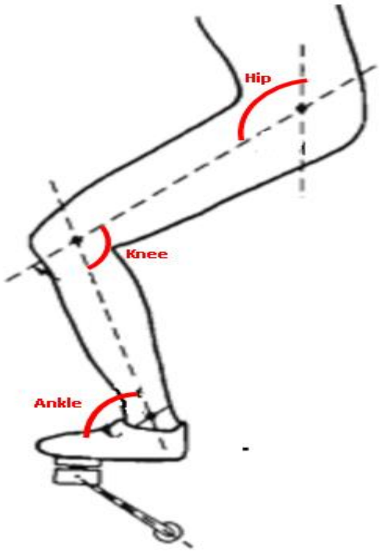

Figure 2.1: Common joint angles measurement during cycling

The sagittal plane allows assessment of all of the joints and parameters mentioned above and is therefore commonly used for detailed kinematics analysis and observations of movement (Nordeen-Snyder, 1977; Sanderson & Amoroso, 2009). Any alteration on the bicycle configuration or the cyclists' position could potentially manipulate the interaction between the muscle length and the muscle moment arm of the joint angles (Sanderson & Amoroso, 2009; Too, 1991), which, in turn, affects total work done and the influence of the fatigue process during cycling performance (Bini et al., 2010; Ericson, Nisell, & Nemeth, 1988; Sanderson & Black, 2003).

2.3.1. SEAT HEIGHT AND JOINT KINEMATICS

Seat height is a well-recognised variable that affects lower limb kinematics of the hip, knee and ankle joints (Bini, Tamborindeguy, & Mota, 2010; Ericson, Ekholm, Svensson, & Nisell, 1985; Ericson, Nisell, & Nemeth, 1988; Ferrer-Roca et al., 2014; Garside & Doran, 2000; Heil et al., 1997; Heil et al., 1995; Nordeen-Snyder, 1977; Price & Donne, 1997; Too, 1991; Umberger et al., 1998). Studies have demonstrated that a 5% alteration in seat height could lead up to a 17^{o} change in knee range of motion (Ericson et al., 1988; Sanderson & Amoroso, 2009), and a 8^{o} change in ankle angle when the pedal was at the BDC (Ericson et al., 1988; Price & Donne, 1997). Ferrer-Roca and colleagues (2014) reported that increases in the seat height by 2% contribute to an increase in extension of the hip, knee, and ankle joint by 4°,7°, and 8°, and a decrease of flexion by 3°,4° and 4° respectively. Consequently, there was an increase in the range of movement by 1°, 3° and 4° of the hip, knee, and ankle joint (Ferrer-Roca et al., 2014). However, Bini and colleagues (2010) only observed changed in ankle joint when increased the seat height by three centimetres for nine male healthy participants. This phenomenon could be compensated for the reduction of knee joint work contribution to minimized soft tissue damage to the knee joint when increased in seat height (Bini et al., 2010). Generally, seat height affects the muscle lengths and moment arms during pedalling, and therefore, the correct knee angle was recommended to enhance cycling performance and reduce the risk of injury (Callaghan, 2005; Peveler, Pounders, & Bishop, 2007; Peveler & Green, 2011). Three methods have been recommended in the literature to obtain a proper seat height. Price and Donne (1997) recommended seat height be set at 96-100% of the trochanteric leg length to optimise cycling performance (Price & Donne, 1997). Hamley and Thomas (1967) recommended measuring the inseam from the ischium to the ground and then multiplying this by 1.09 (Hamley & Thomas, 1967). Peverler and colleagues using a knee flexion angle between 25° and 35° when measured statically with the pedal at BDC position and the pedal placed horizontally (Peveler, Pounders, & Bishop, 2007; Peveler et al., 2012) for both injury prevention and optimal cycling performance regardless of cycling experience (Callaghan, 2005; Peveler et al., 2007; Peveler, 2008; Peveler & Green, 2011). Peveler and colleagues (2012) performed a series of studies and found that the use of 109% of inseam resulted in participants falling outside the recommended 25° to 35° knee flexion angle up to 74% of the time (Peveler et al., 2005; Peveler et al., 2007; Peveler, 2008; Peveler et al., 2012). The large deviation of knee flexion angles was the inseam method assumed the upper and lower leg ratios and the length of the foot are consistent when determining the seat height (Peveler et al., 2012).

2.3.2. WORKLOAD AND JOINT KINEMATICS

The relationship between workload and joint kinematics was also documented in the literature (Abt et al., 2007; Bini et al., 2011; Bini & Diefenthaeler, 2010; Bini, Diefenthaeler, & Mota, 2010; Mornieux, Guenette, Sheel, & Sanderson, 2007; Sanderson & Amoroso, 2009; Vrints, Koninckx, Van Leemputte, & Jonkers, 2011). Bini and Diefenthaeler (2010) reported an increase in ankle and knee range of motions by 4^o and 2^o respectively and a decrease in hip range of motion by 2^o with 5-8% increases in cycling workload. This result was conflicting to Mornieux and colleagues study, which observed an increase only contributed by the hip joint when the workload is increased (Mornieux et al., 2007). However, the different participants' characteristic of the two studies could contribute to the differing results. It has previously been demonstrated that there are differences in technique between elite and novice cyclists (Chapman, Vicenzino, Blanch, & Hodges, 2009). One study of fifteen competitive male cyclists reported that the cycling technique was altered after a core fatigue workout (Abt et al., 2007). The role of the core muscles is to maintain a neutral pelvic position on the saddle for stability and leverage for the psoas and gluteal muscles contraction when a greater power output is required (Juker, McGill, Kropf & Steffen, 1998). The fatiguing workout consisted of seven exercises designed to target core stabilizer muscle in multiple planes of motion performance over 32 minutes. The post-fatigue workout increased the knee valgus when transiting from recovery phase to the propulsion phase during cycling (Abt et al., 2007). The excessive valgus on the frontal plane could disrupt tracking of the patella leading to an increase in shear forces in the knee (Bini et al., 2013), particularly the posterior surface of the patella, which increases the knee injury risk during cycling (Abt et al., 2007). In addition, core fatigue may increase energy expenditure during cycling. McDaniel and colleagues (2005) examined the energy expenditure between participants whose torso was either supported or unsupported with a torso stabilization device. The results suggested that the supported torso position significantly reduced the energy expenditure during submaximal cycling (McDaniel et al., 2005). These studies demonstrate that a stable and effective core is important to both performance and injury prevention. Optimising the bicycle configuration may reduce core fatigue and improve stability.

2.4.MUSCLE ACTIVITY DURING CYCLING

Researchers have been studying muscle activation patterns to enhance cycling performance and prevent injury for more than a decade (Dorel et al., 2009; Raasch & Zajac, 1999; Ryan & Gregor, 1992; So, Ng, & Ng, 2005). Raasch and Zajac (1999) stated that the gluteus maximus, vastus lateralis and vastus medialis, working alternately with iliacus, psoas and the short head of biceps femoris during cycling contribute to the control of cadence and generate the majority of the power to propel the crank during pedaling. Raasch and colleagues (1997) showed that the gluteus maximus provides 55% of all energy delivered to the crank to overcome the resistive load. Ryan and Gregor (1992) demonstrated that gluteus maximus assists in hip flexion during the recovery phase and subsequently provides active hip extension during the propulsion phases from 340^o to 130^o, peaking at 80^o on a forward pedalling crank cycle.

Another group of muscles consists of rectus femoris and tibialis anterior, which alternate with the medial hamstring and the long head of biceps femoris (Raasch & Zajac, 1999) This group helps control the crank velocity trajectory and provides smooth pedalling (Raasch & Zajac, 1999). The knee extensors muscles contract from 315^o to 105^o and knee flexors muscles contract from 45^{o} to 200^{o} during the forward pedalling of the crank (Faria & Cavanagh, 1978). There is co-activation between the knee extensors muscles and the knee flexors muscles are from 45^{o} to 105^{o} (Faria & Cavanagh, 1978). Ryan and Gregor (1992) reported a similar finding that the vastus lateralis and vastus medialis were actively extending the knee from 300^{o} to 130^{o}, and peaked at 30^{o}, and the semitendinosus and semimembranosus were active from 10^{o} to 230^{o}, and peaked at 100^{o} on a forward pedalling crank cycles (Ryan & Gregor, 1992). EMG studies have found the identical timing of action potentials in the rectus femoris, vastus lateralis, vastus medialis, semitendinosus, and semimembranosus (Houtz & Fischer, 1959; Ryan & Gregor, 1992).

The major muscles contribute to the forward pedalling at distal legs are soleus and gastrocnemius that alternates with tibialis anterior (Ericson et al., 1985; Wozniak-Timmer, 1991). This muscle group controls foot orientation, safeguarding the effective transfer of the generated energy to the crank (Bini & Diefenthaeler, 2009; Raasch & Zajac, 1999; Raasch et al., 1997). With the smooth transition through BDC, plantarflexion transmits the force from the soleus and gastrocnemius to the forefoot via tarsal binding ligaments (Wozniak-Timmer, 1991). The soleus and gastrocnemius contract after both the hip and knee extensors are activated. The soleus is active through 27^{o} to 145^{o}, whereas, the gastrocnemius is active from 35^{o} to 260^{o} during the cycling motion (Wozniak-Timmer, 1991). However, Ryan and Gregor (1992) reported that the soleus and gastrocnemius were active almost the entire cycle motion, from 340^{o} to 270^{o} and peak at 110^{o} on a forward pedalling crank cycle (Ryan & Gregor, 1992). The tibiais anterior serves to stabilise the talocrural joint and is active throughout the cycling motion with a peak at 280^{o} (Ryan & Gregor, 1992). Two other studies found that the tibialis anterior only contracts from 270^{o} to 88^{o} during the cycling motion (Ericson et al., 1985; Wozniak-Timmer, 1991).

The inconsistency finding in the above studies on muscles activation at the different crank angle can be due to the lack of standardized ways when measuring joint kinematic during cycling. Any kinematic changes related to riding position, workload during the ride and mechanical limitation such as seat height and distance between the handlebar and the saddle could alter the muscle activation pattern on the basis of the length-tension relationship of the muscle. It has been suggested that changed hip kinematics facilitates pre-stretch of the gluteus maximus muscle that improves the action of the muscle (Mestdagh, 1998). Nevertheless, the above findings seem clear that the muscles work in a coordinated way to maximize energy transfer from the cyclist to the crank and propel the bicycle forwards. However, there are a large number of factors affecting cycling performance and more research is required to establish the effects of these interactions.

2.4.1. SEAT TUBE ANGLE AND MUSCLE ACTIVITY

Ricard and colleagues (2006) examined the effects of bicycle STAs on power output and EMG amplitude for vastus lateralis, vastus medialis, semimembranosis and biceps femoris during a Wingate test. The results show that EMG amplitude for biceps femoris was significantly reduced when the STA was moved from 72° to 82° but there was no significant difference in the power output and EMG amplitude for vastus lateralis, vastus medialis and semimembranosis (Ricard et al., 2006). Silder and colleagues (2006) conducted a comprehensive simulated triathlon trial to examine the triathletes hand positions (hoods, drops, and aero) at three different STAs (73°, 76°, 79°) followed by running on the treadmill at 80%, 90% and 100% of their 10 km triathlon race pace. The results show that an altered STA had no significant effect on muscle recruitment patterns for lower limbs other than an increased rectus femoris activity when increased from 73° to 79° during cycling (Silder, Gleason, & Thelen, 2011). However, the seat height was self-selected for comfort by the participants for Ricard and colleagues (2006) study and Silder and colleagues (2011) did not indicate any control of the seat height. Previous studies have indicated that changes of more than 4% of seat height could significantly change in the resultant pedal force (Bini et al., 2011), which could lead to increase in glutues medius, medial hamstring and medial gastrocnemius muscle activation (Ericson et al., 1985). This was confirmed by another study, which demonstrated a decrease in integrated EMG value of gastrocmemius muscle with a decrease in seat height (Sanderson & Amoroso, 2009).

Another recent study examined the ESTA by comparing the preferred saddle position to a saddle position 5cm forward or backward in 10 experienced male cyclists (Hayot et al., 2013). The results have shown that the forward position was associated with the greater peak for rectus femoris, vastus lateralis and vastus medialis activity throughout both the extension and recovery phase of the pedal cycle (Hayot et al., 2013). The backward position led to a greater peak for peroneus longus, lateral and medial gastrocnemius, and soleus, as well as semitendinosus and biceps femoris forces, compared with the forward position (Hayot et al., 2013). However, the seat height was adjusted so that the knee angle was positioned between 25° and 35°, which may have been different to the preferred bicycle set-up of the participants. In addition, this study only manipulated the saddle displacement with the handlebar stayed at the preferred saddle position on SRM cycle ergometer. It is therefore not possible to exclude the effect of altered hip joint kinematics on the muscle recruitment patterns as the hip joint position may have changed significantly with the change in STA.

2.4.2. EXHAUSTIVE CYCLING AND MUSCLE ACTIVITY

During short duration and high intensity cycling, fatigue might modify the muscle activity patterns during cycling (Dorel et al., 2009). Ten well-trained cyclists performed a 22 minute warm-up (10 minutes at 100 watts, 6 minutes at 150 watts, 3 minutes each at 250 watts and 100 watts) with 3 minutes passive rest followed by a constant load of 80% maximal power output until complete exhaustion (Dorel et al., 2009). Dorel and colleagues (2009) reported a decrease in muscle activity of medial and lateral gastrocnemius, tibialis anterior, vastus lateralis, vastus medialis and rectus femoris in the last quarter of the trial (75% of time to exhausion). The decrease in knee extensors coincided with an increase of hip extensors (gluteus maximus and biceps femoris) and this could be a compensation for potential fatigue and loss of force of the knee extensors (vastus lateralis, vastus medialis) (Dorel et al., 2009). Hautier and colleagues (2000) conducted an exhaustive cycle protocol consisting of submaximal and maximal efforts in the laboratory. Ten participants performed a set of 15 maximal velocities for 5 seconds with 25 seconds rest periods on a cycle ergometer. The load was set at around 8% of the participant’s body mass to ensure high cadence of 150 repetitions per minute were achieved for first sprint. Before and after the maximal intermittent cycles, the participants cycled at a submaximal level for 2 minutes at 50 repetitions per minute. The results demonstrated a significantly higher mean muscle activity for biceps femoris and lateral gastrocnemius while there were no changes for gluteus maximus and vastus lateralis after the 13th maximal sprint (Hautier et al., 2000). The vastus lateralis activity was increased significantly at submaximal exercise after the maximal intermittent cycles (Hautier et al., 2000). Bini and colleagues (2008) investigated the relationship of muscle activity and power output during a 40km time trial. The results showed that vastus lateralis was the only muscle that presented significant increases in muscle activity at the 10th km, 20th km, 30th km and 38th km when compared to the 3rd km during the trial.

The above three studies have clearly distinguished selective muscle activation changes in relation to intensity, cadence and during time trial cycling. At submaximal cycling, quadriceps are the predominant muscles contributing to the power output and the posterior muscles such as gluteus maximus, biceps femoris and gastroncemius are highly activited during fatiguing cycling protocol and higher cadences cycling. These findings were similar with Hug and colleagues (2008) investigation, which investigated the inter-participant variability of muscle contraction at 150 and 250 watts from the observation of EMG activity. The results showed that vastus lateralis and vastus medialis had good repeatability at 150 watts and only gluteus maximus had good repeatability at 250 watts. The muscle activation patterns could be related to the pedalling techniques compared between high intensity or maximal effort and submaximal efforts during cycling (Bini & Diefenthaeler, 2010; Faria et al., 2005b). In addition, number of studies have shown that cadence will affect the muscular activity in the lower extremity during cycling (Baum & Li, 2003; Brisswalter, et al., 2000). For all of these reasons, exhaustive cycling protocols or high cadence exercises may not reflect the physiological stresses or requirements of performance cycling.

2.4.3. BODY POSITIONING AND MUSCLE ACTIVITY

Altering the upper body orientation (dropped torso angle / aerodynamic position) can also alter muscle activation patterns (Dorel, Couturier, & Hug, 2009). Dorel and colleagues (2009) reported that an aerodynamic position significantly altered the timing and amplitude of the EMG activity for gluteus maximus, rectus femoris, semimembranosus, vastus lateralis and vastus medialis muscles when compared to upright and dropped positions but had no effects on muscles crossing the ankle (Dorel, Couturier, & Hug, 2009). Chapman and colleagues (2008) examined the distal leg with upright and aerodynamic positions on three groups of participants (novice cyclists, elite cyclists, and triathletes) and reported no effect on the leg and foot kinematics during a three minutes trial at moderate intensity (RPE 15). Changing only the upper body orientation may have trivial effects because the distal leg muscles regulated the stiffness for effective transmission of muscle energy to the cranks (Bini & Diefenthaeler, 2009; Raasch & Zajac, 1999; Raasch et al., 1997). Origenes and colleagues (1993) examined a group of triathletes, high-altitude climbers, and healthy active individuals in an upright and aerodynamic position. The participants were made to cycle at 50 watts with an increase of 50 watts every 3 minutes until complete exhaustion in upright and aerodynamic positions. The results showed that $\dot{V}O2_{max}$, heart rate, and power outputs were not significantly different between positions (Origenes, Blank, & Schoene, 1993).

2.4.4. TRUNK ORIENTATIONS AND MUSCLE ACTIVITY

Bicycle configuration can affect muscle activity patterns, due to the moment arm and length-tension relationship, which manipulate the joint kinematics and leads to changes in joint kinetics and energy expenditure during cycling (Ferrer-Roca, Roig, Galilea, & Garcia-Lopez, 2012; Garside & Doran, 2000; Heil et al., 1995; Underwood, Schumacher, Burette-Pommay, & Jermy, 2011). Savelberg and colleagues (2003) examined the effect of altering the trunk orientation by rotating it 18.6° rearward or 22.3° forward in relation to the upright position and how this affected muscle activity patterns when pedalling at 80% of peak power output. The gluteus maximus EMG activity was highest in the forward position, and the biceps femoris, rectus femoris, tibialis anterior and semitendinosus were higher in a rearward position (Savelberg, Port, & Willems, 2003). The study demonstrated that biceps femoris, rectus femoris, semiteninosus, gluteus maximus, tibialis anterior, soleus and lateral gastrocnemius were influenced by the trunk angle orientation independent of any other changes (Savelberg, Port, & Willems, 2003). Another study examined different body orientation between horizontal and vertical from 0° to 80° with the workload and cadences same as Savelberg and colleagues (2003) study during the trial. The results showed that tibialis anterior, rectus femoris and biceps femoris had increased muscle activity and triceps surae had decreased muscle activity when the body orientations moved from horizontal to vertical (Brown et al., 1996). In two separate studies, Fonda and colleagues (2011), as well as Sarabon and colleagues (2012) investigated the biceps femoris, rectus femoris, semiteninosus, gluteus maximus, tibialis anterior, soleus, vastus lateralis, and vastus medialis when cycling on level ground and a 20% uphill cycling. The results showed that uphill cycling altered both the timing and intensity of the EMG activity on the lower limb, with the most affected muscles being those crossing the hip joint (rectus femoris, biceps femoris and gluteus maximus) and tibialis anterior (Fonda et al., 2011; Sarabon et al., 2012).

Very few studies have explored the relationship between muscle activation patterns and body orientation or bicycle configuration in cycling. Three studies had clearly demonstrated that manipulating of the body orientation, particularly, the trunk angle changes the muscle activation patterns of the lower limb (Brown et al., 1996; Sarabon et al., 2012; Savelberg, Port, & Willems, 2003). However, two studies were not in conventional cycling positions and Sarabon and colleagues (2012) examined 20% uphill cycling as opposed to altering the contact positions of the bicycle itself.

2.5.METABOLIC ECONOMY DURING CYCLING

Road cyclists are using STAs between 72° and 76° to enhance cycling efficiency in racing. In contrast, triathletes often ride with STAs of greater than 76° for greater comfort, efficiency, and higher power production. To date, there are four studies examined the effect between the

STA manipulation and the physiological parameters (Garside & Doran, 2000; Heil, Derrick, & Whittlesey, 1997; Heil et al., 1995; Garside & Doran, 2000; Jackson et al., 2008), only one study had showed significant effect when compared between the STA at 83^{o} and 90^{o}, and 69^{o} (Heil et al., 1995). However, two major limitations may be the reason the data does not coincide with the other three studies. First, STA at 69^{o} is not a commonly used manufacture angle in the commercial road bike. Secondly, it's only lasted 10 minutes for each testing position and the bike was set-up based on cyclists subjective needs. A more in-depth discussion on physiological parameters and power output in relations to STA are as follows.

2.5.1. SEAT TUBE ANGLE AND PHYSIOLOGICAL PARAMETERS

There is a question of whether a change in STA would independently affect the power output and the physiological response to cycling performance. Heil and colleagues (1995) demonstrated that an STA of 69^{o} resulted in higher $\dot{V}O_2$ values, heart rates and ratings of perceived exertion compared to STAs of 83^{o} and 90^{o}. The authors observed that the cardiorespiratory decreases were associated with greater hip extension and ankle plantar flexion (Heil, Wilcox & Quinn, 1995). Another similar study that manipulated two variables; STA and trunk angle reported similar submaximal $\dot{V}O_2$ and heart rate values for fourteen competitive cyclists (Heil, Derrick & Whittlesey, 1997). Although there was no significant difference between manipulating STA and trunk angle independently, extreme combinations of STA 70^{o} with 10^{o} trunk angles elicited higher $\dot{V}O_2$ and heart rate responses in all the participants. These results agreed with Heil and colleagues (1995) study, who found that STAs of 69^{o} with 20^{o} trunk angles elicited significantly higher submaximal $\dot{V}O_2$ and heart rate values compared to STAs of 76^{o}, 83^{o} and 90^{o}. Within the same period, another study found that an STA of 80^{o} resulted in significantly lower mean $\dot{V}O_2$ values with higher work done compared to STA of 68^{o} and 74^{o} during submaximal cycling performance (Price & Donne, 1997). A more recent study showed no significant variation in $\dot{V}O_2$ value and HR for STAs between 73^{o} and 81^{o} (Garside & Doran, 2000). Jackson and colleagues (2008), who conducted a shorter version of simulated triathlon with only 40 minutes of cycling at STA between 73^{o} and 81^{o} follow by 5 minutes of running reported lower heart rates at a 73^{o} STA during cycling. The authors did not find any significant differences in oxygen consumption between the two STAs during cycling and during running (Jackson et al., 2008). This was confirmed by Bisi et al. (2012), which reported no significant difference in oxygen consumption, respiratory exchange ratio and power output between STAs of 73.5^{o} and 78^{o} for ten well-trained triathletes.

Importantly, none of the studies to date have investigated STA independently of changes in hip flexion angle. A shallow STA theoretically increases the hip flexion angle by moving the hip backward relative to the crank axis (Browning, Gregor, & Broker, 1992; Price & Donne, 1997). Previous studies have shown that decrease in hip angle associated with decrease in gross efficiency (Fintelman et al., 2015) and reduced peak power output during cycling (Fintelman et al., 2014; Gnehm et al., 1997; Grappe et al., 1997; Jobson et al., 2008). It is therefore not possible to determine whether the alterations in a gross economy were as a result of changes in the hip position of the body in relation to the crank axis. Hence, it is important to control the joint position to measures ESTA independently.

2.5.2. SEAT TUBE ANGLE AND POWER OUTPUT

In terms of power output, Umberger and colleagues (2006) reported that higher power output values (peak power, mean power, and total work) were observed at 69^o STA when compared with more than 76^o STAs during fifteen seconds maximal effort cycling. However, Too (1991) reported that an STA of 75^o produced higher anaerobic power with the trunk and upper body in an upright orientation. The participants in the study also reported muscular fatigue to be more generalized throughout the lower extremities at a 75^o STA compared to other angles during the experiment. Both findings were consistent using both conventional and recumbent bicycles. In contrast, no significant differences were found in peak power, average power, minimum power and percentage of power drop between STAs of 72^o and 82^o in twelve triathletes (Ricard et al., 2006).

Of the studies investigating physiological responses to different STAs, there seems to be an optimal range of STA between 80^o and 90^o, which results in lower $\dot{V}O_2$ values, heart rates and ratings of perceived exertion values for triathletes and cyclists during maximal and submaximal cycling in the laboratory. In contrast, shallow STA ($<70^o$) with the combinations of lower trunk angle ($<20^o$) seemed to contribute to higher $\dot{V}O_2$, heart rate values and higher power outputs during cycling (Heil, Derrick, & Whittlesey, 1997; Heil et al., 1995; Too, 1991; Umberger et al., 1998).

2.6.INSTRUMENTS AND METHODOLOGY

Cycling studies are commonly conducted in the laboratory. In this section, cycling ergometer limitations, cycling duration and intensity will be discussed and how these limitations affect the transfer of knowledge from science to practicality for cycling.

2.7.CYCLE ERGOMETER

Cycle ergometers have been commonly used in cycling research because it allows easy manipulation of the STA and other relevant variables within and between the trials. However, these ergometers have their limitation; for example, Monark cycle ergometers can only adjust the handlebar height when changing the STA. This can cause the cyclists to rotate forward or backward, which increases the pressure on the arms or on the saddle with the changed in STA and may result in altered torso angle, hip flexion angle and shoulder angle. In addition, some studies did not provide adequate information about the cycle ergometer used during the trial. A summary of the cycle ergometer used during the studies is presented in Table 2.1. This makes it difficult to make any comparison between the cycle ergometer and the manipulation of the STA. These could be the reasons that showed inconsistent results from previous studies. A cycle ergometer that allows the researchers to manipulate the distance between the saddle and the handlebar with a standardized way to alter ESTA without affecting other parameters or joint angles may provide insightful information regarding the relationship between cycling configuration and lower extremity geometries. This could result in proper control of the joint kinematics that might have effects on power output and muscle activity pattern during cycling between trials.

Table 2.1: Summary of studies using a cycle ergometer for manipulating of the STAs during cycle trials.

Study	Cycle ergometer used	Manufacturer or model of the ergometer	Country of manufacturing
Bini et al. (2013)	Own bike on a computrainer	RaceMate	United States of American
Bisi et al. (2012)	RP3	Not indicated	Italy
Chung et al. (2011)	Self-manufactured cycle ergometer	NA	South Korea
Domalain et al. (2016a)	SRM indoor trainer	Schoberer	Germany
Domalain et al. (2016b)	SRM indoor trainer	Schoberer	Germany
Garside & Doran (2000)	Kingcycle air-braked ergometer	High Wycombe	United Kingdom
Heil, Derrick, Whittlesey (1997)	Monark cycle ergometer	829E	Sweden
Heil et al. (1995)	Monark cycle ergometer	Not indicated	Sweden

Menard et al. (2016)	SRM indoor trainer	Schoberer	Germany
Price & Donne (1997)	Kingcycle air-braked ergometer	High Wycombe	United Kingdom
Pouliquen et al. (2016)	SRM indoor trainer	Schoberer	Germany
Ricard et al. (2006)	Monark cycle ergometer	895E	Sweden
Silder, Gleason & Thelen (2011)	Self-manufactured cycle ergometer	NA	United States of American
Umberger, Scheuchenzuber & Manos (1998)	Monark cycle ergometer	Not indicated	Sweden

2.7.1. DURATION AND INTENSITY

Cycling is a repetitive activity involved in the optimisation of intramuscular coordination for best efficiency (Hug et al., 2008). However, most of the studies related to cycling are relatively short, higher intensity or maximal efforts during cycling performance. This does not reflect the real stresses of a cycling event. For instance, gastrocnemius muscle activity level is fairly stable up to 50-60% of maximal power and increase moderately as the intensity increases (Hug et al., 2004; Jorge & Hull, 1986; Laplaud, Hug, & Grelot, 2006) whereas, vastus lateralis, and gluteus maximus may be affected by the workload during cycling (Hautier et al., 2000; Hug et al., 2008). In addition, muscle coordination also affected by high intensity cycling. Psek and Cafarelli (1993) reported that vastus lateralis muscles fatigue after high intensity exercises increased biceps femoris activity during cycling. In order to maintain the power output during high intensity cycling, the synergistic and antagonistic muscles have been recruited to compensate for decrements in force from the fatiguing agonistic muscles (Abbiss & Laursen, 2005). This suggests that fatigue of a muscle group decreases the global overall movement efficiency by disorganizing muscular coordination.

2.8.SUMMARY OF CHAPTER

Body orientation or bicycle configuration may have effects on muscle activity pattern. These alterations can change the moment arm and length-tension relationship, which manipulate the joint kinematics and leads to changes in joint kinetic and energy expenditure during cycling.

Future research examining the ESTA and the seat height should focus on manipulating one component and mimic the intensity of the races and duration for as close as possible. This type of research will provide greater insight to the coaches and the cyclists, and allows this information to be translated to performance application.

Chapter 3

3.1.METHODOLOGY

3.1.1. PARTICIPANT SELECTION

Fifteen trained male cyclists were recruited through a local cycling community forum (www.thehubsa.co.za) and social media (facebook and twitter) to participate in this study. All participants conformed to De Pauw's performance level 2 or greater (De Pauw et al., 2013). The participants were asked to avoid the consumption of alcohol, caffeine or other stimulants for 12hrs prior to any laboratory visits, and to follow a similar diet in the 24hr period prior to all testing sessions. A Physical Activity Readiness Questionnaire (PAR-Q) (ACSM, 2009), training history questionnaire and an informed consent form were completed and signed by each participant prior to starting the study. The study was approved by Research and Ethics Committee of the Faculty of Health Sciences, University of Cape Town (HREC REF 649/2014). The study was performed according to the World Medical Association Declaration of Helsinki and the ACSM Guidelines for the use of Human Participants (ACSM, 2009).

3.1.2. EXPERIENTIAL DESIGN

The experiment was conducted in the biomechanics laboratory of the Sports Science Institute of South Africa. The participants were required to visit the laboratory on four separate occasions, each one week apart. A preliminary visit was followed by three experimental conditions where the bicycle configuration was set to either.

1) Freely chosen position
2) Saddle and handlebar position adjusted 3cm forward in comparison to the freely chosen position
3) Saddle and handlebar position adjusted 3cm rearward in comparison to the freely chosen position

The order of the experimental conditions was randomized.

Before each trial, the participants were familiarised to the adjusted position on the road bike for one week. In addition, the participants performed a washout period by riding in the freely chosen position for one week before the adjustment for the next adjusted position experimental trial if they were performed sequentially. This was to prevent the carry over effect from the previous adjusted position.

3.1.2.1. PRELIMINARY VISIT

During the first session, a complete anthropometric assessment was performed as described in section 3.2.2. The participants were then seated on the CycleOps 400 Indoor Pro Cycle (Power Tap: Saris Corp., Madison, WI, USA) which was set up to match their freely chosen position on the road bike using an objective standard set of definitions (see section 3.2.1). The participants then completed a standardised warm-up protocol (Lamberts et al., 2011) which was followed immediately by a Peak Power Output and Peak Oxygen Consumption test to determine the descriptive characteristics of the participants and to determine the fixed workload for the subsequent experimental trials.

3.1.2.2. EXPERIMENTAL TRIALS

From the second to the fourth session, on the participant's arrival at the laboratory, forty reflective markers were placed on bony landmarks described by Vicon full body model Plug-in gait (Oxford Metric Vicon) (Appendix 7). A minor modification of the standard Plug-in gait was made by moving the T10 marker to the T5 position. This modification allowed for a greater approximation of true shoulder flexion in comparison to static measurement techniques (Holliday, Fisher, Theo, & Swart, 2017). Four reflective markers were placed on the bicycle cranks and pedals to determine the crank quadrant position.

EMG electrodes were placed on the right lower limb. After shaving the hair, the skin was cleaned with alcohol and a pair of electrodes (Blue Sensor, Medicotest, Denmark) were placed on each of seven muscles (medial gastrocnemius (MG), biceps femoris (BF), gluteus maximus (GM), tibialis anterior (TA), rectus femoris (RF), vastus lateralis (VL) and vastus medialis (VM)) according to the recommendations by SENIAM (Surface EMG for Non-invasive Assessment of Muscles).

The participants then performed a standardised warm-up (Lamberts et al., 2011) on the CycleOps 400 Indoor Pro Cycle (Power Tap: Saris Corp., Madison, WI, USA) which was set to match their standard position on the road bike as previously described. After a one minute rest period, two five minutes EMG normalizations were performed either with both normalizations in the same position (standard position trials) or on the preferred and then the displacement saddle positions (intervention trials) at 70% of the peak power output recorded during the graded exercise test (Albertus-Kajee et al., 2010). This allowed for comparison of EMG activity for the adjusted positions as normalised to the freely chosen position. The participants wore the same cycling attire and shoes for training and competition during testing.

Following the EMG normalization, each trial consisted of an hour steady state cycle at 60% of peak power output and was started three minutes after completion of the normalization protocol. The 3D Vicon, EMG, oxygen consumption pain and RPE data were recorded during three-time segments (1-20 minutes, 21-40 minutes and 41-60 minutes). The data collection timeline is shown in figure 3.1. There were three recording in each time segment for fifteen seconds each for 3D Vicon and EMG data. The first recording started 10 minutes into each of the time segments and subsequent recordings were started two minutes from the initial recording until completion of the three recordings for each time segment. The Vicon and EMG were synchronized to start recording at the same time by a custom-made electronic trigger box. The participants were not informed of the data capturing to avoid conscious changes to the pedaling action. The oxygen consumption was recorded at 15-20, 35-40 and 55-60 minutes of each trial. The oxygen mask was fitted for these time periods and removed during the remaining time intervals. The pain and RPE measurements were recorded immediately after oxygen consumption, which were 20, 40 and 60 minutes of the trial. Power output, heart rate, speed, cadence, and distance were recorded throughout the 1-hour steady state. The three segments were divided equally over an hour to allow the data to be compared if the physiological parameters, muscle activation pattern and joint kinematics will change over time during cycling. This finding may help to quantify the duration needed during cycling for future research.

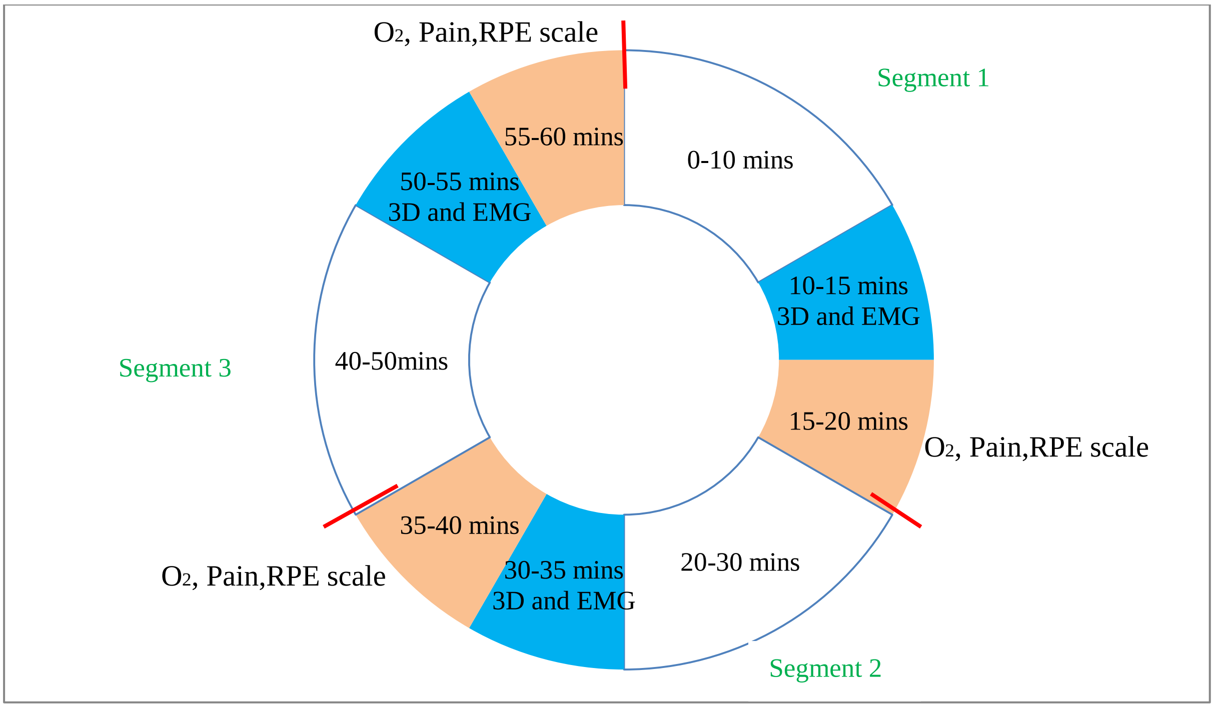

Figure 3.1: Visualization of data capture during an hour long steady state cycling.

3.2 EQUIPMENT AND TESTING PROTOCOLS

3.2.1. CYCLE ERGOMETER

A CycleOps 400 Indoor Pro Cycle (Power Tap: Saris Corp., Madison, WI, USA) with a controlled resistance technology, which communicates wirelessly with an IPad (Virtual Training V2.0.6; https://itunes.apple.com/us/app/virtualtraining/id699418485?mt=8) was used for all ergometry. The geometry of the ergometer was set to the geometrical characteristics of the participant's road bike or a modified position as previously described. These measurements are described in Appendix 6. The clip-less pedals used were those from the participant's own road bike.

3.2.2. BODY COMPOSITION

Body mass and stature of each participant was measured when participants reported for the trial sessions. Skinfold thickness of each participant was measured for the biceps, triceps, subscapular, abdomen, suprailiac, thigh and calf sites (Marfell-jones, Olds, Stewart, & Carter, 2006) during the first session. The body fat percentage was determined using the formula recommended by Jackson and Pollock (1978).

3.2.3. LAMBERTS AND LAMBERT SUBMAXIMAL TEST (LSCT)

The Lamberts and Lambert Submaximal Cycle Test (LSCT) consisted of three stages with a total duration of 15 minutes (Lamberts et al., 2011), and was performed as a standardised warm-up protocol before all experiment trials. The participants were asked to elicit target heart rates of 60% (stage 1; 0 – 6 minutes), 80% (stage 2; 6 – 12 minutes) and 90% (stage 3; 12 – 15 minutes) of their maximum heart rate (HRmax), which was obtained from the PPO test on the CycleOps 400 Indoor Pro Cycle (Power Tap: Saris Corp., Madison, WI, USA). Participants were allowed to change the electronically simulated gear setting to elicit the targeted heart rate (within 1 beat per minute) on each stage. Throughout the LSCT, the power, cadence and heart rate were measured continuously by the CycleOps 400 Indoor Pro Cycle (Power Tap: Saris Corp., Madison, WI, USA), while the rating of perceived exertion (RPE) was recorded 30 seconds before the end of each stage. The target heart rates for the initial warm-up before the peak power output test was based on a predicted HR_{max} (220-age).

3.2.4. PEAK POWER OUTPUT (PPO)

The peak power output test protocol includes respiratory gas analysis ($\dot{V}O_2max$) (Oxycon, Viasys, Hoechberg, Germany). The participants performed the LSCT as a warm-up followed by PPO test with gas analyser and pneumotach. The test began 3 minutes after the warm-up with an initial workload of 100 watts (W) and increased at a rate of 5 watts every 15 seconds on a step protocol loaded onto the CycleOps 400 Indoor Pro Cycle (Power Tap: Saris Corp., Madison, WI, USA) software. The participants were encouraged to cycle at a cadence of between 90 and 105 revolutions per minute (RPM). The test was terminated when the participant was unable to maintain a cadence of at least 60 RPM. Maximal PPO was determined as the mean power output during the final minute of the PPO test and $\dot{V}O_2max$ (ml/kg/min) was determined as the highest recorded 15 seconds average $\dot{V}O_2max$ during the test.

3.2.5. NORMALIZATION

Dual five minutes normalizations were performed in both the freely chosen position and the trial position, which was either 3cm forward or backward (for both reach and saddle setback) from the freely chosen position, and were performed before the 1-hour steady state trial. The normalizations were performed at 70% of PPO (the freely chosen position was performed twice for the non-adjusted trial). EMG was captured for 10 seconds at the end of each minute for each of the five minutes periods. The second to fourth-minute data were then averaged and used as the reference (100% voluntary effort) to compare with the 1-hour steady state cycling trial EMG data. Normalization to the freely chosen position allowed comparison between the altered position and the freely chosen position for muscle recruitment (Albertus-Kajee et al., 2010).

3.2.6. CONSTANT WORKLOAD

Prior to all constant load cycling trials (session 2-4), participants warmed up as described in LSCT section. The constant load cycling tests required the participants to cycle at 60% of PPO. The power output was constantly regulated by the ergometer. The power output, heart rate, speed, cadences and distance were recorded continuously throughout the 1-hour steady state cycling.

3.2.7. THREE DIMENSIONAL (3D) KINEMATICS

An eight-camera Vicon motion capture system (Oxford Metric Vicon) was used to measure the body movement during the cycling session and was recorded at a 250Hz sampling frequency. The bike was positioned in the center of the calibrated volume, which was 2m x 2m x 2m in dimension. The motion analysis software (Nexus Vicon 1.8.3, Oxford Metric Vicon) tracked the location of reflective markers placed on the body and bike in each camera view and calculated the location of each marker in the three-dimensional volume.

The 3D kinematics data were created using Nexus Vicon software (Nexus 1.8.3, Oxford Metric Vicon) and filtered using a fourth order, zero-lag Butterworth filter at cut-off frequencies of 6Hz. A custom code is written in MATLAB (2013a, The Mathworks Inc., Natick, MA) was used to process, synchronize and extract the phases of the pedal cycle.

3.2.8. ELECTROMYOGRAPHY (EMG)

Concurrently with the recording of the 3D kinematics, EMG readings were recorded using an 8-channel EMG system (Telemyo 2400 G2, Noraxon, USA, Inc., Arizona, USA) with a 50 Hz notch filter applied to the raw EMG data (Myoresearch 2.02). The signal was filtered using a 15-500 Hz bandpass filter to exclude movement artefact below 15 Hz and non-physiological signals above 500 Hz to be removed. The data were smoothed using root mean squared analysis (RMS), which was calculated for a 50ms window. The two electrodes (Blue Sensor, Medicotest, Denmark) were taped to the belly of each muscle, parallel to the muscle fibres with an inter-electrode distance of 20mm with activity captured at 2000 Hz. The EMG system was synchronized with the motion capture system, and the data were collected simultaneously with the motion data.

The data were first processed by a DC offset based on the zero-offset using the non-muscle contraction trial data. Data were then processed using a band-pass (20-500 Hz) Butterworth filter. All three trials were processed using root mean square (RMS) with a window of 50ms to obtain linear envelopes.

The magnitude of the EMG data for the cycling trial was expressed as the percentage of the normalization trial for the freely chosen position. The data were divided into sections representing different functions of the muscle during a pedal cycle.

3.3. STATISTICAL ANALYSES

All results were analysed using a statistical software programme (Statistica 13, StatSoft, Tulsa, OK, USA). Results were expressed as means ± standard deviation (SD). Analysis of Variance (ANOVA) with repeated measures was used to detect significant differences between positions. A tukey post hoc test was used to detected differences in muscle activity, joint kinematics, oxygen consumption and the respiratory exchange rate between trials. The level of statistical significance will be set at $p < 0.05$. The power will be based error rate of 0.05 and a beta error rate of 0.20, which corresponds to a power of 80%, is a commonly accepted standard (Zlowodzki & Bhandari, 2009). The participant's average speed will be 36km per hour. With the change in STAs contribute to 5% changes in performance distance, which translate to a standard deviation of 2km per hour. Hence, fifteen participants can contribute to 95% confident interval of this study designed.

Further analyses of differences in variables between trials were assessed using magnitude-based inferences based on the procedure described by Batterham and Hopkins (Batterham & Hopkins, 2006). Mean effects of trials and their 90% confidence intervals (CI) were estimated using an excel spreadsheet (www.sportsci.org/0201/wghprop.htm) with values obtained from the t-test for each independent variable between groups. The spreadsheet computes the chance that the true effect is substantial when a value for the smallest worthwhile change is entered. A value of 1% was defined as a meaningful difference for the performance measures, as used in previous cycling studies (Paton & Hopkins, 2005; Swart et al., 2009)

Chapter 4

4.1. RESULTS

The purpose of this study was to examine the effect of different cycling positions which manipulated the saddle fore and aft to alter the effective seat tube angle. It was hypothesized that cycling in a more forward seat position (movement of pelvis closer to the crank axle in the sagittal plane) would result in changing the muscle recruitment patterns, gross economy, and heart rate. In this section, the results of physiological parameters, joint kinematics, and gross muscle activation variables are presented.

4.1.1. SUBJECT CHARACTERISTICS

Fifteen participants voluntarily enrolled for this study. Five participants were unable to complete the study. One cyclist data was corrupted and unable to retrieve from the computer system and one cyclist was unable to complete an hour of steady state cycling. Two cyclists withdrew from the trial due to cycling training and competition commitment and one cyclist fractured his elbow in a cycling accident. Therefore, these data were excluded from further analysis.

The participants' mean training load was 5.8 ± 2.3 hours per week for three months prior to the study and the mean experience of the participants was 6.8 ± 2.6 years. A summary of participants' profiles, training, and competition history are presented in Table 4.1 and participant characteristics are presented in Table 4.2.

Table 4.1: Summary of participant training history and status.

Participant#	Age	Avg hrs of cycling/week	Yrs of cycling experience	Performance level	Last Argue race timing
1	41	4	8	2	3h 10min
2	32	4	3	2	4h 14min
3	38	10.5	6	3	2h 55min
4	39	4	7	2	3h 09min
5	42	6	5	3	2h 56min
6	38	6	13	3	2h 53min
7	34	4	6	2	3h 45min
8	36	9	7	2	3h 20min
9	35	6	5	3	2h 58min
10	43	4.5	7.5	3	3h 06min
Mean	37.8	5.8	6.8	2.5	3h 14min
SD	3.4	2.3	2.6	0.5	25min

Performance level: Classifications based on De Pauw's criteria **Average hours of cycling per week:** Average for 12 weeks prior to participation. **Argus cycling tour:** This is an annual 109km cycling event in Cape Town.

4.1.2. INCREMENTAL CYCLE TEST

Descriptive statistics were determined by an incremental cycle test to determine $\dot{V}O_2$ max, peak power output, and peak heart rate. Means and standard deviations for each physiological attribute from the incremental cycle test are presented in Table 4.2.

Table 4.2: Participant characteristics and physiological attributes of the ten trained cyclists measured during an incremental cycle test.

Physiological attribute	Mean ± SD
Age (years)	37.8 ± 3.6
Height (centimeters)	178.2 ± 3.8
Body mass (kilograms)	76.9 ± 8.0
$\dot{V}O_2$ max (L/min)	3.96 ± 0.48
$\dot{V}O_2$ max (ml/kg/min)	51.63 ± 5.29
W_{peak} (W)	338.7 ± 35.9
W_{peak} (W/kg)	4.4 ± 0.4
HR_{max} (bpm)	185.1 ± 10.1

$\dot{V}O_2$ max: maximal oxygen consumption, L/min: litres per minute, millilitres per kilogram per minute, ml/kg/min: milliliters per kilogram per minute, W_{peak}: peak power output, W: watts, W/kg: watts per kilogram, HR_{max}: maximal heart rate, bpm: beats per minute.

4.2. SUBMAXIMAL STEADY STATE CYCLING PHYSIOLOGICAL VARIABLES

Mean values for all three trials for physiological variables (Mean ± SD and p-values for Time x Trial interaction) are presented in Table 4.3.

Table 4.3: Physiological attributes of the ten trained cyclists measured during submaximal cycling tests. P-values for Time x Trial interaction. The physiological attributes were an average of an hour over the three time segments in each saddle position.

Physiological attribute	Forward saddle	Preferred saddle	Rearward saddle	p-value
$\dot{V}O_2$ (ml/kg/min)	39.00 ± 2.97	39.54 ± 3.01	37.98 ± 3.90	0.95
RER	0.90 ± 0.05	0.89 ± 0.03	0.91 ± 0.04	0.39
Power output (W)	202.2 ± 20.9	201.5 ± 21.2	201.8 ± 20.7	0.83
Cadences (rpm)	87.3 ± 13.3	90.4 ± 12.7	86.9 ± 16.6	0.99
Heart rate (bpm)	149 ± 16	150 ± 15	149 ± 15	0.92

$\dot{V}O_2$: oxygen consumption, ml/kg/min: millilitres per kilogram per minute, W: watts, rpm: revolutions per minute, bpm: beats per minute.

The mean power output and cadences for trials differed by a maximum of 0.7W and 3.5 repetitions per minute respectively in keeping with the method of fixed submaximal workload. $\dot{V}O_2$ for the trials (39.00 ± 2.97 ml/kg/min, 39.54 ± 3.01 ml/kg/min, 37.98 ± 3.90 ml/kg/min) were not significantly different (F(4, 36)=0.17, P=0.95). Respiratory exchange ratios (RER) for the trials (0.90 ± 0.05, 0.89 ± 0.03, 0.91 ± 0.04) were not significantly different (F(4, 36=1.07, P=0.39). Heart rate for the trials (149 ± 16 bpm, 150 ± 15 bpm, 149 ± 15 bpm) were not significantly different (F(4, 36)=0.05, P=0.95).

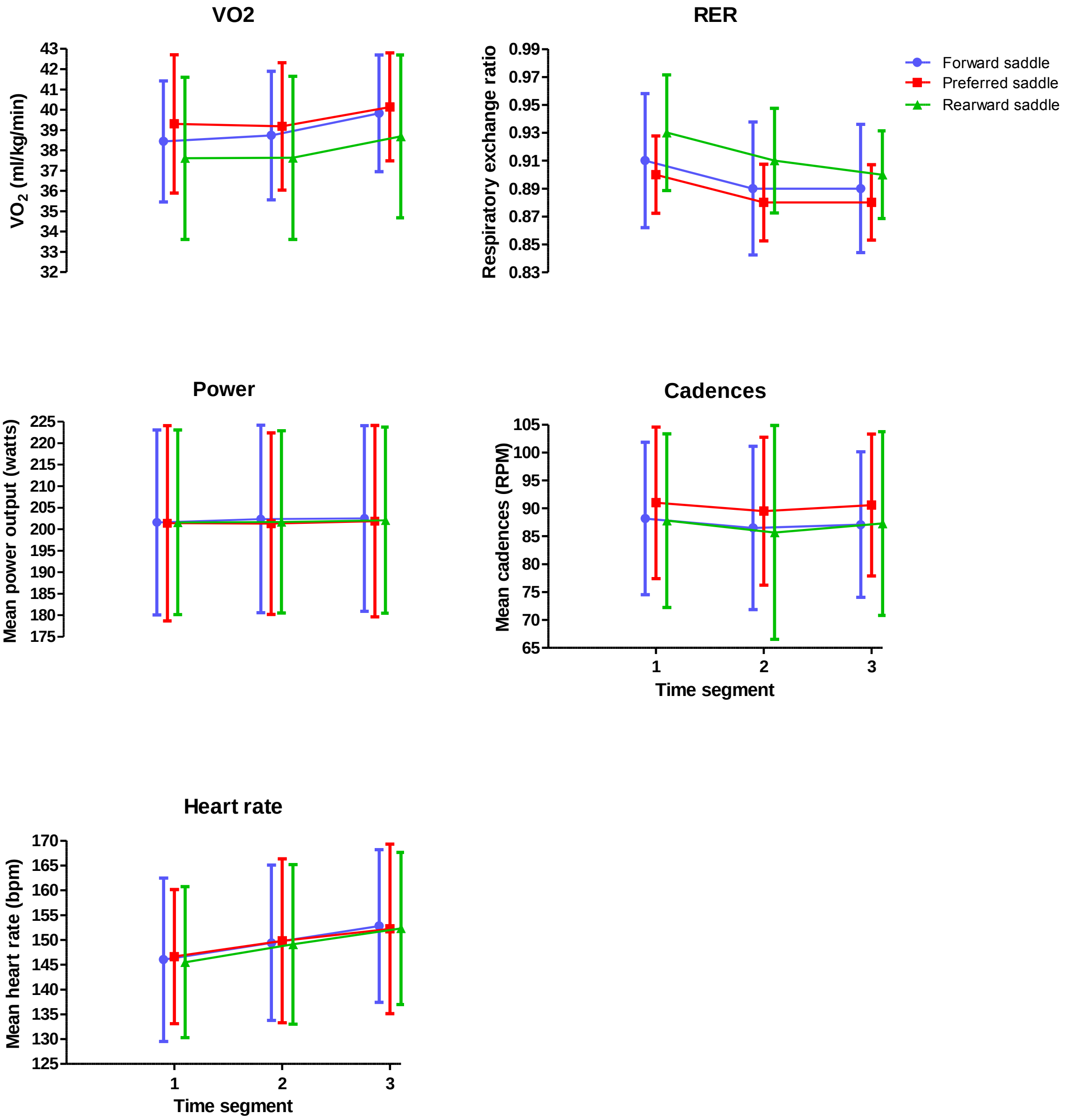

Figure 4.1: Mean physiological attributes between saddle displacements for the three time points recorded in each trial.

The x-axis is physiological attributes.

The y-axis represents the time segment of the trial for forward saddle (blue), preferred saddle (red), and rearward saddle (green). Each graph shows the mean data ± SD across ten participants.

4.2.1. MAGNITUDE-BASED INFERENCES FOR PHYSIOLOGICAL VARIABLES

The mean changes in physiological variables and magnitude-based statistics for the differences on the three cycling positions are shown in Table 4.4 and Table 4.5.

Table 4.4: Value differences for physiological attributes between saddle displacements. Substantial is a change of more than 1.0% for all measures of performance; ± 90%CL: add and subtract this number to the mean effect to obtain the 90% confidence limits for the true difference.

$\dot{V}O_2$ (ml/kg/min)	Mean values	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	39.00 ± 2.97	0.54	1.56	1.02
Preferred saddle	39.54 ± 3.01			
Rearward saddle	37.98 ± 3.90			
RER	Mean value	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	0.90 ± 0.05	-0.01	-0.02	-0.01
Preferred saddle	0.89 ± 0.03			
Rearward saddle	0.91 ± 0.04			
Power output (watts)	Mean power	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	202.2 ± 20.9	-0.63	-0.27	0.37
Preferred saddle	201.5 ± 21.2			
Rearward saddle	201.8 ± 20.7			
Cadences (RPM)	Mean repetitions	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	87.3 ± 13.3	-3.10	-3.43	0.33
Preferred saddle	90.4 ± 12.7			
Rearward saddle	86.9 ± 16.6			
Heart rate (bpm)	Mean beats	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	149 ± 16	-0.13	-0.57	0.43
Preferred saddle	150 ± 15			
Rearward saddle	149 ± 15			

For $\dot{V}O_2$ values, the rearward saddle displacement showed a decrease in oxygen consumption of 1.56±0.65 ml/kg/min (76.0%, likely) and 1.02±0.86 ml/kg/min (28.3%, possibly) when compared to the preferred saddle and forward saddles positions respectively. The $\dot{V}O_2$ value changed 0.54±0.75 ml/kg/min (4.8%, very unlikely) when the preferred saddle was compared to forward saddle positions. The magnitude of change remained constant for RER, heart rate, power output and cadences, which there were unlikely, very unlikely and most unlikely differences for the various saddle displacements.

Table 4.5: Mean changes in physiological attributes between saddle displacements. Qualitative refers to the likelihood of the difference exceeding the smallest worthwhile change.

	Difference; ± 90% CL	Chances that true differences are substantial	
$\dot{V}O_2$ (ml/kg/min)		%	Qualitative
PS vs. FS	0.54, ±0.75	4.8	Very unlikely
PS vs. RS	1.56, ±0.65	76.0	Likely
FS vs. RS	1.02, ±0.86	28.3	Possibly
RER		%	Qualitative
PS vs. FS	-0.01, ±0.01	0.0	Most unlikely
PS vs. RS	-0.02, ±0.01	0.0	Most unlikely
FS vs. RS	-0.01, ±0.01	0.0	Most unlikely
Power output		%	Qualitative
PS vs. FS	-0.63, ±0.67	0.0	Most unlikely
PS vs. RS	-0.27, ±0.83	0.0	Most unlikely
FS vs. RS	0.37, ±0.40	0.0	Most unlikely
Cadences		%	Qualitative
PS vs. FS	-3.10, ±2.50	0.1	Most unlikely
PS vs. RS	-3.43, ±2.60	0.1	Most unlikely
FS vs. RS	-0.33, ±3.30	4.7	Very unlikely
Heart rate		%	Qualitative
PS vs. FS	-0.13, ±2.20	6.4	Unlikely
PS vs. RS	-0.57, ±1.80	1.8	Very unlikely
FS vs. RS	-0.43, ±1.70	1.7	Very unlikely

4.3. JOINT KINEMATICS

Mean angles for each joint across the three trials (Mean ± SD and p-values for Time x Trial interaction) are presented in Table 4.6 and Figure 4.3.

Table 4.6: Shoulder, hip, knee, ankle, and elbow joint kinematics of the fifteen pedal cycles during submaximal steady state cycling in each saddle position. P-values for Time x Trial interaction. The joint kinematics values were an average of fifteen cycle pedals over the three time segments in each saddle position.

	Forward saddle	Preferred saddle	Rearward saddle	p-value
2D Shoulder joint	106.9 ± 5.7 ^{o}	107.6 ± 6.3 ^{o}	105.0 ± 5.7 ^{o}	0.87
2D Hip joint	119.5 ± 3.6 ^{o}	121.1 ± 4.8 ^{o}	120.4 ± 3.9 ^{o}	0.47
Knee joint	36.9 ± 7.1 ^{o}	35.9 ± 7.5 ^{o}	33.0 ± 7.9 ^{o}	0.55
Ankle joint	-6.1 ± 6.7 ^{o}	-7.6 ± 6.5 ^{o}	-9.5 ± 5.9 ^{o}	0.48
Elbow joint	28.2 ± 4.7 ^{o}	30.8 ± 6.8 ^{o}	30.9 ± 6.2 ^{o}	0.89

The mean 2D hip angle (measured at TDC pedal position for the three trials changed at a maximum of 1.6^{o} (119.5 ± 3.6 ^{o}, 121.1 ± 4.8 ^{o}, 120.4 ± 3.9^{o}) was not significantly different (F(4, 36)=0.90, P=0.47) between saddle positions.

The mean 2D shoulder angle and elbow angle for the three trials changed at a maximum of 2.6^{o} (106.9 ± 5.7^{o}, 107.6 ± 6.3^{o}, 105.0 ± 5.7^{o}) and changed at a maximum of 2.7^{o} (28.2 ± 4.7^{o}, 30.8 ± 6.8 ^{o}, 30.9 ± 6.2 ^{o}) were not significantly different for 2D shoulder (F(4, 36)=0.31, P=0.87) and elbow (F(4, 36)=0.28, P=0.89) between saddle positions respectively.

Both the mean knee angle and ankle angle measured at BDC pedal position (36.9 ± 7.1 ^{o}, 35.9 ± 7.5^{o}, 33.0 ± 7.9^{o}) and changed at a maximum of 3.4^{o} (-6.1 ± 6.7^{o}, -7.6 ± 6.5^{o}, -9.5 ± 5.9^{o}) were not significantly different for knee (F(4, 36)=0.77, P=0.55) and ankle (F(4, 36)=0.89, P=0.48) between saddle positions respectively.

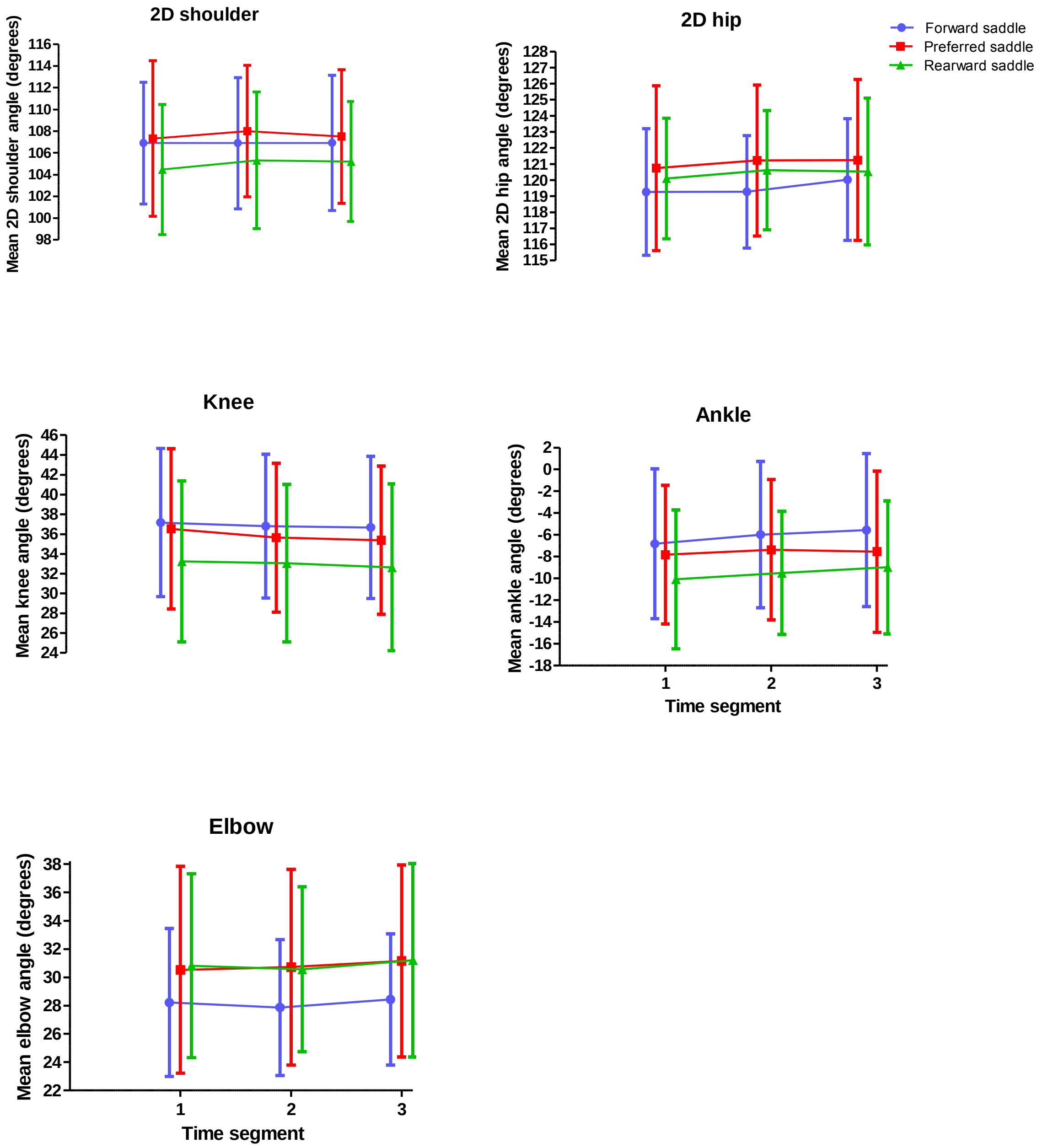

Figure 4.2: Mean joint kinematics between saddle displacements *for the three time segments recorded in each trial.*

The x-axis is degrees of the pedal cycle for all graphs (Shoulder, hip, knee, ankle, and elbow).

The y-axis represents the time segment of the trial for forward saddle (blue), preferred saddle (red), and rearward saddle (green). Each graph shows the mean data ± SD across ten participants. Within each trial and each time segment for each participant, 15 full pedal revolutions were averaged.

Across the three different time segments when the data were captured (20 minutes, 40 minutes and at 60 minutes) during an hour steady state cycling, joint angles did not change, with less than 1^{o} variation throughout the entire cycling session (Table 4.7).

Table 4.7: Shoulder, hip, knee, ankle, and elbow joint kinematics across the three different time segments. P-values for Time x Trial interaction. The joint kinematics values represent each saddle positions and each time segment over fifteen pedals cycle an hour steady state cycling.

2D Shoulder joint	20 minutes	40 Minutes	60 Minutes	p-value
Forward saddle	106.9 ± 5.6 ^{o}	106.9 ± 6.0 ^{o}	106.9 ± 6.2 ^{o}	0.99
Preferred saddle	107.3 ± 7.2 ^{o}	108.0 ± 6.1 ^{o}	107.5 ± 6.2 ^{o}	0.56
Rearward saddle	104.5 ± 6.0 ^{o}	105.3 ± 6.3 ^{o}	105.2 ± 5.5 ^{o}	0.39
2D Hip joint	20 minutes	40 Minutes	60 Minutes	p-value
Forward saddle	119.3 ± 3.9 ^{o}	119.3 ± 3.5 ^{o}	119.0 ± 3.9 ^{o}	0.34
Preferred saddle	120.7 ± 5.1 ^{o}	121.2 ± 4.7 ^{o}	121.2 ± 5.0 ^{o}	0.21
Rearward saddle	120.1 ± 3.8 ^{o}	120.6 ± 3.7 ^{o}	120.5 ± 4.6 ^{o}	0.63
Knee joint	20 minutes	40 Minutes	60 Minutes	p-value
Forward saddle	37.2 ± 7.5 ^{o}	36.8 ± 7.3 ^{o}	36.7 ± 7.2 ^{o}	0.23
Preferred saddle	35.7 ± 7.5 ^{o}	35.6 ± 7.5 ^{o}	35.4 ± 7.5 ^{o}	0.53
Rearward saddle	33.3 ± 8.1 ^{o}	33.1 ± 8.0 ^{o}	32.7 ± 8.4 ^{o}	0.45
Ankle joint	20 minutes	40 Minutes	60 Minutes	p-value
Forward saddle	-6.8 ± 6.9 ^{o}	-6.0 ± 6.7 ^{o}	-5.6 ± 7.0 ^{o}	0.06
Preferred saddle	-7.8 ± 6.4 ^{o}	-7.3 ± 6.4 ^{o}	-7.5 ± 7.4 ^{o}	0.87
Rearward saddle	-10.1 ± 6.4 ^{o}	-9.5 ± 5.7 ^{o}	-9.0 ± 6.1 ^{o}	0.20
Elbow joint	20 minutes	40 Minutes	60 Minutes	p-value
Forward saddle	28.2 ± 5.2 ^{o}	27.9 ± 4.8 ^{o}	28.4 ± 4.6 ^{o}	0.20
Preferred saddle	30.5 ± 7.3 ^{o}	30.7 ± 6.9 ^{o}	31.2 ± 6.8 ^{o}	0.56
Rearward saddle	30.8 ± 6.5 ^{o}	30.6 ± 5.8 ^{o}	31.2 ± 6.8 ^{o}	0.57

The magnitude of change remained constant across the three time segments and different saddle positions for all the five joints measured in this study. A decreasing trend in ankle range of motion at forward saddle was seen and the p-value is closed to statistically significant.

4.3.1. MAGNITUDE-BASED INFERENCES FOR JOINT KINEMATICS

The mean changes in joint kinematic variables and magnitude-based statistics for the differences on the three cycling positions are shown in Table 4.8 and Table 4.9.

Table 4.8: Value differences for kinematics measurement between saddle displacements. Substantial is a change of more than 1.0% for all measures of performance; ± 90%CL: add and subtract this number to the mean effect to obtain the 90% confidence limits for the true difference.

2D shoulder	Mean angle	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	106.91 ± 5.75 °	0.71	2.62	1.91
Preferred saddle	107.61 ± 6.25 °			
Rearward saddle	105.00 ± 5.74 °			
2D hip	**Mean angle**	**PS vs. FS Value Diff**	**PS vs. RS Value Diff**	**FS vs. RS Value Diff**
Forward saddle	119.52 ± 3.64 °	1.55	0.65	-0.90
Preferred saddle	121.07 ± 4.78 °			
Rearward saddle	120.42 ± 3.90 °			
Knee	**Mean angle**	**PS vs. FS Value Diff**	**PS vs. RS Value Diff**	**FS vs. RS Value Diff**
Forward saddle	36.88 ± 7.05 °	-1.03	2.87	3.89
Preferred saddle	35.86 ± 7.46 °			
Rearward saddle	32.99 ± 7.89 °			
Ankle	**Mean angle**	**PS vs. FS Value Diff**	**PS vs. RS Value Diff**	**FS vs. RS Value Diff**
Forward saddle	-6.11 ± 6.66 °	-1.46	1.94	3.40
Preferred saddle	-7.58 ± 6.52 °			
Rearward saddle	-9.52 ± 5.86 °			
Elbow	**Mean angle**	**PS vs. FS Value Diff**	**PS vs. RS Value Diff**	**FS vs. RS Value Diff**
Forward saddle	28.18 ± 4.73 °	2.63	-0.06	-2.69
Preferred saddle	30.80 ± 6.77 °			
Rearward saddle	30.86 ± 6.18 °			

For both knee and ankle joint kinematics at rearward saddle position deferred between 3.9° (58.5%, possibly) and 3.4° (34.0%, possibly) when compared to preferred and forward saddle measured at BDC pedal position respectively. The magnitude of change remained constant for elbow, 2D shoulder and 2D hip, there were very unlikely and most unlikely differences for the various saddle displacements.

Table 4.9: Mean changes in kinematics variables between saddle displacements. Qualitative refers to the likelihood of the difference exceeding the smallest worthwhile change.

	Difference; ± 90% CL	Chances that true differences are substantial	
2D shoulder		%	Qualitative
PS vs. FS	0.71, ± 1.60	0.3	Most unlikely
PS vs. RS	2.62, ± 1.60	9.8	Unlikely
FS vs. RS	1.91, ± 1.10	0.7	Very unlikely
2D hip		%	Qualitative
PS vs. FS	1.55, ± 1.20	0.4	Most unlikely
PS vs. RS	0.65, ± 0.99	0.0	Most unlikely
FS vs. RS	-0.90, ± 1.30	0.0	Most unlikely
Knee		%	Qualitative
PS vs. FS	-1.00, ± 1.00	0.0	Most unlikely
PS vs. RS	2.87, ± 0.84	3.6	Very unlikely
FS vs. RS	3.89, ± 0.77	58.5	Possibly
Ankle		%	Qualitative
PS vs. FS	-1.46, ± 1.00	0.0	Most unlikely
PS vs. RS	1.94, ± 1.60	3.2	Very unlikely
FS vs. RS	3.40, ± 1.70	34.0	Possibly
Elbow		%	Qualitative
PS vs. FS	2.63, ± 1.30	6.5	Unlikely
PS vs. RS	-0.06, ± 2.00	0.3	Most unlikely
FS vs. RS	-2.69, ± 1.90	0.0	Most unlikely

4.4. MUSCLE ACTIVATION

Normalized EMG values over fifteen pedals cycle for each muscle group at different saddle displacements (Mean ± SD and p-values for Time x Trial interaction) are presented in Table 4.10. An ANOVA with repeated measures for the seven monitored leg muscles showed no significant differences in muscle activation between three cycling positions.

Table 4.10:Normalized EMG values for fifteen pedals cycle during submaximal steady state cycling. P-values for Time x Trial interaction. The EMG muscle activation values were an average of fifteen cycle pedals over the three time segments in each saddle position

	Forward saddle (FS)	Preferred saddle (PS)	Rearward saddle (RS)	p-value
Biceps Femoris	0.74 ± 0.17	0.87 ± 0.26	0.88 ± 0.25	0.10
Gluteus Maximus	0.78 ± 0.28	0.92 ± 0.27	0.97 ± 0.36	0.30
Tibialis Anterior	0.81 ± 0.21	0.84 ± 0.20	0.83 ± 0.22	0.35
Vastus Lateralis	0.87 ± 0.20	0.92 ± 0.19	0.83 ± 0.17	0.32
Vastus Medialis	0.86 ± 0.15	0.96 ± 0.18	0.89 ± 0.16	0.12
Rectus Femoris	0.73 ± 0.15	0.79 ± 0.14	0.82 ± 0.21	0.67
Medial Gastrocnemius	0.96 ± 0.29	0.93 ± 0.14	1.04 ± 0.14	0.86

The hip extensor muscle (gluteus maximus (FS 0.78 ± 0.28, PS 0.92 ± 0.27, RS 0.97 ± 0.36, (F(4, 32)=1.08, P=0.30)) demonstrated a 14% and 20% of progressive increases in integrated EMG values with successive movement from forward position to rearward position, however, these differences were not significantly different. The knee flexor muscle (bicep femoris (FS 0.74 ± 0.17, PS 0.87 ± 0.26, RS 0.88 ± 0.25, (F(4, 32)=2.14, P=0.10)) also demonstrated a 13% and 14% progressive increases in integrated EMG values with successive movement from forward position to rearward position, once again, these differences were not significantly different.

Progressive differences of 6% and 9% were also seen in rectus femoris (FS 0.73 ± 0.15, PS 0.79 ± 0.14, RS 0.82 ± 0.21, (F(4, 32)=0.59, P=0.67)) but both monoarticular quadriceps muscles (vastus lateralis (FS 0.87 ± 0.20, PS 0.92 ± 0.19, RS 0.83 ± 0.17, (F(4, 32)=1.23, P=0.32)) and vastus medialis (FS 0.86 ± 0.15, PS 0.96 ± 0.18, RS 0.89 ± 0.16, (F(4, 32)=2.00, P=0.12))) were decreased between 9% and 10% in activation in rearward and forward saddle positions as compared to preferred saddle position. However, these changes were once again not statistically significant. Remaining muscle groups (tibialis anterior (FS 0.81 ± 0.21, PS 0.84 ± 0.20, RS 0.83 ± 0.22, (F(4, 32)=1.44, P=0.35)) and medial gastrocnemius (FS 0.96 ± 0.29, PS 0.93 ± 0.14, RS 1.04 ± 0.14, (F(4, 32)=0.32, P=0.86))) did not follow any trend with respect to integrated EMG signal in relation to position.

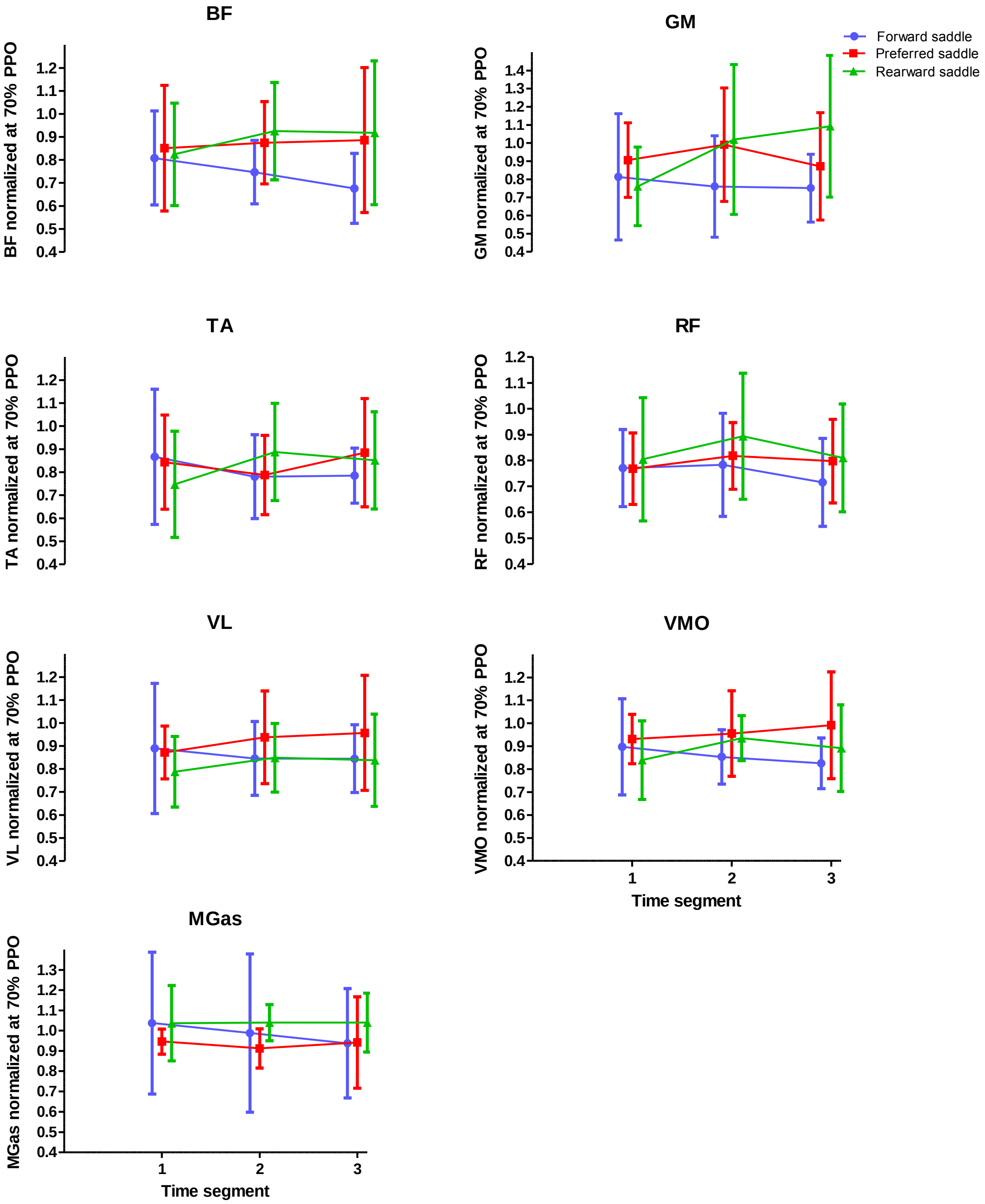

Figure 4.3: Normalized EMG amplitude for Biceps femoris (BF), Gluteus Maximus (GM), Tibialis Anterior (TA), Vastus Lateralis (VL), Vastus Medialis (VM), Rectus Femoris (RF) and Medial Gastrocnemius (MGas) at 70% of PPO.

The x-axis is the muscle activation values that normalized at 70% peak power output. The y-axis represents the time segment of the trial for forward saddle (blue), preferred saddle (red), and rearward saddle (green). Each graph shows the mean data ± SD across ten participants. Within each trial and each time segment for each participant, 15 full pedal revolutions were averaged.

4.4.1. MAGNITUDE-BASED INFERENCES FOR EMG

The mean changes in EMG of the seven monitored leg muscles variables and magnitude-based statistics for the differences on the three cycling positions are shown in Table 4.11 and Table 4.12.

Table 4.11: Value differences for EMG measurement between saddle displacements. Substantial is a change of more than 1.0% for all measures of performance; ± 90%CL: add and subtract this number to the mean effect to obtain the 90% confidence limits for the true difference.

Biceps Femoris	Mean normalized EMG signals	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	0.74 ± 0.17	0.13	-0.01	-0.14
Preferred saddle	0.87 ± 0.26			
Rearward saddle	0.88 ± 0.25			
Gluteus Maximus	Mean normalized EMG signals	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	0.78 ± 0.28	0.14	-0.05	-0.20
Preferred saddle	0.92 ± 0.27			
Rearward saddle	0.97 ± 0.36			
Tibialis Anterior	Mean normalized EMG signals	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	0.81 ± 0.21	0.03	0.01	-0.01
Preferred saddle	0.84 ± 0.20			
Rearward saddle	0.83 ± 0.22			
Vastus Lateralis	Mean normalized EMG signals	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	0.87 ± 0.20	0.05	0.09	0.04
Preferred saddle	0.92 ± 0.19			
Rearward saddle	0.83 ± 0.17			
Vastus Medialis	Mean normalized EMG signals	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	0.86 ± 0.15	0.10	0.07	-0.02
Preferred saddle	0.96 ± 0.18			
Rearward saddle	0.89 ± 0.16			
Rectus Femoris	Mean normalized EMG signals	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	0.73 ± 0.15	0.06	-0.03	-0.09
Preferred saddle	0.79 ± 0.14			
Rearward saddle	0.82 ± 0.21			
Medial Gastrocnemius	Mean normalized EMG signals	PS vs. FS Value Diff	PS vs. RS Value Diff	FS vs. RS Value Diff
Forward saddle	0.96 ± 0.29	-0.02	-0.10	-0.08
Preferred saddle	0.93 ± 0.14			
Rearward saddle	1.04 ± 0.14			

All muscle demonstrated a very unlikely or a most unlikely difference for the various saddle displacements. Biceps femoris and gluteus maximus decrease between 3% and 3.1% of muscle activations when compared between preferred and forward saddle position. Medial gastrocnemius demonstrated an 8.1% decrease when compared to preferred and rearward saddle position.

Table 4.12: Mean changes in EMG variables between saddle displacements. Qualitative refers to the likelihood of the difference exceeding the smallest worthwhile change.

	Difference; ± 90% CL	Chances that true differences are substantial	
Biceps Femoris		%	Qualitative
PS vs. FS	0.13, ± 0.10	3.0	Very unlikely
PS vs. RS	-0.01, ± 0.08	0.0	Most unlikely
FS vs. RS	-0.14, ± 0.08	0.0	Most unlikely
Gluteus Maximus		%	Qualitative
PS vs. FS	0.14, ± 0.09	3.1	Very unlikely
PS vs. RS	-0.05, ± 0.13	0.1	Most unlikely
FS vs. RS	-0.20, ± 0.14	0.0	Most unlikely
Tibialis Anterior		%	Qualitative
PS vs. FS	0.03, ± 0.11	0.2	Most unlikely
PS vs. RS	0.01, ± 0.08	0.3	Most unlikely
FS vs. RS	-0.01, ± 0.06	0.0	Most unlikely
Vastus Lateralis		%	Qualitative
PS vs. FS	0.05, ± 0.07	0.0	Most unlikely
PS vs. RS	0.09, ± 0.07	0.1	Most unlikely
FS vs. RS	0.04, ± 0.09	0.1	Most unlikely
Vastus Medialis		%	Qualitative
PS vs. FS	0.10, ± 0.06	0.1	Most unlikely
PS vs. RS	0.07, ± 0.06	0.0	Most unlikely
FS vs. RS	-0.02, ± 0.05	0.0	Most unlikely
Rectus Femoris		%	Qualitative
PS vs. FS	0.06, ± 0.05	0.0	Most unlikely
PS vs. RS	-0.03, ± 0.07	0.0	Most unlikely
FS vs. RS	-0.09, ± 0.06	0.0	Most unlikely
Medial Gastrocnemius		%	Qualitative
PS vs. FS	-0.02, ± 0.09	0.0	Most unlikely
PS vs. RS	-0.10, ± 0.05	8.1	Very unlikely
FS vs. RS	-0.08, ± 0.16	0.2	Most unlikely

Chapter 5

5.1 DISCUSSION

The aim of this study was to examine the influence of saddle fore-aft displacement on gross muscle activation patterns, oxygen consumption, respiratory exchange ratios and joint kinematics during prolonged steady state submaximal cycling. Moving the saddle forward or rearward changes the seat's relative position to the crank axis in the sagittal plane (otherwise referred to as the effective seat tube angle (ESTA)), which may affect multiple dependent variables such as pedalling efficiency and gross economy. However, the current literature investigating the effect of saddle displacement on these and other variables is limited by both the quantity of published studies and the methodology which has been implemented in the published data. Most often the methodological flaws relate to having made changes to both ESTA and other variables concurrently; a prime example being the hip joint angle, which is known to affect gross economy and muscle recruitment (Brown et al., 1996; Hayot et al., 2013; Heil et al., 1997; Heil et al., 1995; Ricard et al., 2006; Savelberg, Port, Willems, et al., 2003). Therefore, in this study, dependent variables were assessed for preferred, forward and rearward saddle positions while specifically attempting to control for joint kinematics, which were also measured to assess whether these affected other variables. Joint kinematics, metabolic cost and muscles activation variables that could be influenced by the seat positions were collected during this study.

5.2 JOINT KINEMATICS

Previous studies did not clearly indicate control of the handlebar position in relation to the changes made to the STA (Bisi et al, 2012; Garside & Doran, 2000; Ricard et al., 2006). This may have affected the hip angle, torso angle, and shoulder angle. For example, a more vertical sitting position associated with an increase of the STA could result in rotating the pelvis backward; opening the hip joint angle. In order to maintain the same reach length (distance between the saddle and the handlebar), we increased or decreased the horizontal distance to the handlebar concurrent with changes made for the saddle setback while maintaining other geometrical measurements of the cycle ergometer so as to not affect the joint kinematics during steady state cycling.

Bini and colleagues (2013) found a 5-6^{o} increased in knee flexion when compared preferred, forward and rearward saddle positions (Bini et al., 2013). In this study, the cyclists simulate a lower body position similar to time-trial and hill-climb cycling without substantial changes in the upper body lean position (Bini et al., 2013). In our current study, changing the cycle ergometer saddle and handlebar either forward or rearward did result in small progressive changes in the knee and the ankle joint kinematics. The results of this study showed that the knee angle increase by 1^{o} and decrease by 3^{o} when the saddle position was moved by three centimetres forward or rearward respectively from the preferred position. These changes also influenced the ankle joint angle, which decreases by 1.5^{o} and increases by 2^{o} when the saddle positions were moved forward or rearward respectively from the preferred position. This indicates that the changes in setback may have selectively affected the knee and ankle flexion angle without affecting other joint angles such as the hip, shoulder and elbow angle. The changed in knee and ankle joint kinematic was an unexpected finding as previous studies have shown that the knee angle and range of motion are minimally affected as long as the seat height remains unchanged (Chapman et al., 2008; Savelberg, Port, Willems, et al., 2003). This finding may imply that the positive association between saddle displacements and changes in knee joint kinematics is present in the dynamic cycling situation.

The changes in the knee and the ankle flexion angle may be explained as a result of the effective distance from the seat contact point to the crank axis having increased by a small but not insignificant total distance. This can be reduced to simple trigonometric evaluation where the change in the setback equates to the “opposite” length where the “hypotenuse” reflects the most linear distance from the center of the crank axis to the saddle contact point under the ischial tuberosities and is the distance used to measure saddle height. Although the vertical distance, (the “adjacent”) and the “hypotenuse” are on average a 10 fold greater magnitude than the “opposite” with respect to these variables being used when describing the bicycle saddle position this way, the effect of the six centimetres change from forward to rearward position may well have affected the joint kinematics of the knee and ankle joint which are typically influenced by the saddle height. As a result, clinical practitioners and researchers should be aware that large changes of the saddle position in the sagittal plane may result in kinematic changes. These should, therefore, be controlled in future studies by altering the saddle height to maintain the joint kinematics of the knee and ankle joint when large changes in setback are used as an intervention.

Another finding from this study suggests that maintaining the same reach length (distance between the saddle and the handlebar) minimally affected the orientation between the pelvis and the thigh. Previous studies have shown that the thigh will be more vertically orientated with an increase in STA (Price & Donne, 1997; Savelberg, Port, & Willems, 2003), which would theoretically reduce the hip flexion angle. This was probably due to the orientation change that occurred with the pelvis. Future studies, following the acute findings reported within this study, should consider controlling the reach, as per out methodology, when investigating joint kinematics during cycling.

5.3 METABOLIC COSTS DURING STEADY STATE CYCLING

During the hour-long steady state, metabolic costs performing the set workload were not significantly different in the forward, preferred and rearward saddle displacements. However, magnitude-based inference statistics did indicate a “likely” and a “possible effect” for higher oxygen cost for preferred and forward saddle positions when compared to the rearward saddle position. The current observation in the literature suggests that steeper STA contribute to lower $\dot{V}O_2$ values and heart rate with higher work done compared to shallow STA (Fintelman et al., 2015; Heil, Derrick, & Whittlesey, 1997; Heil, Wilcox, & Quinn, 1995). This was not supported by this study. It may be that previous studies were affected by the lack of control for variables such as hip and shoulder angle, which could be related to the reach length discrepancy.

In this study, the joint kinematics was remained constant during an hour-long steady state cycling and in the forward, preferred and rearward saddle displacements. There were two variables, the knee, and ankle joint angles were different when the saddle was moved from forward to rearward, but the difference in angle was small enough (1-3°) to be considered a flaw in study methodology. Therefore, controlling of the joint kinematic variables is associated with metabolic cost when STA and external power output is kept constant. The $\dot{V}O_2$ values were decreased by 1.56±0.65 ml/kg/min and 1.02±0.86 ml/kg/min at rearward saddle position when compared to the preferred saddle and forward saddles positions respectively. The $\dot{V}O_2$ value changed 0.54±0.75 ml/kg/min when the preferred saddle was compared to forward saddle positions. The magnitude of change remained constant for RER, heart rate, power output, and cadences, which keeping with the method of steady state submaximal workload.

The lower $\dot{V}O_2$ value at rearward saddle position could be related to the changes which were observed in the knee and ankle joint flexion that was discussed previously. The mean knee flexion angle in the preferred saddle and forward saddle positions of (36.9° ± 7.1°, 35.9° ± 7.5°) compared to the mean values for the rearward saddle position (33.0° ± 7.9°) closely equate to the study by Peveler and colleague (2011) who demonstrated lower oxygen costs for statically measured knee flexion angles of 25° in comparison to 35°. Two studies have demonstrated a change in knee flexion angle of approximately 8° when transitioning from static to dynamic measurements (Peveler & Green, 2011; Peveler et al., 2012). The mean knee flexion of 33.0° which we recorded for dynamic measurement in the rearward saddle position equates closely to the 25° static angle reported by Peveler and colleague (2011) to be the most economical.

The changes in STA will alter the reach length (distance between the saddle and the handlebar), and, in turn, increase shoulders flexion and hip flexion angles during cycling. In the present study, the reach length was maintained by moving the handlebar in the same direction and distance as the saddle displacement. Therefore, the shoulders and hip flexion angles were kept constant during the study, which these two angles were showed in joint kinematics data. Heil and colleagues (1995; 1997) reported that changing STA and hip flexion angles contributed to change in cardiorespiratory measures. Thus, it is possible that hip flexion angles could be an independent variable that is associated with metabolic cost when STA and external power output is kept constant. This finding can assist the analysis and development of future research designs to fill gaps in the current understanding.

Studies investigating the effects of different bicycle conformation changes on the economy should, therefore, control for reach (as we did) and in addition, ensure than knee flexion angle remains constant for different positions.

5.4 MUSCLE ACTIVATIONS

Surface EMG was used to monitor the seven lower limb muscles during an hour steady state cycling but these were not significantly different in forward, preferred and rearward saddle position. In addition, magnitude type statistics indicate most unlikely or very unlikely benefits for all the EMG variables between saddle displacements. This is most likely due to the high degree of variability in EMG data, resulting in large standard deviations for each of the means. It is however of some interest to discuss changes in mean EMG values which we noted when changes in saddle displacement were implemented. The tibialis anterior produced similar muscle activity means between all three saddle positions. The medial gastrocnemius was more active in the rearward saddle positions when compared to preferred saddle position. This change could be related to the decrease in the knee joint angle and increase in the ankle joint angle during the rearward saddle displacement. The evidence from previous studies showed that changes in trunk orientation have effects on the tibialis anterior and the gastrocnemius muscle activity during cycling (Savelberg, Port, & Willems, 2003). This effect was trivial if only upper body orientations were altered (Bini & Diefenthaeler, 2009; Dorel, Couturier, & Hug, 2009). This is because the distal leg muscles regulate the stiffness for effective transmission of muscle energy to the cranks (Bini & Diefenthaeler, 2009; Raasch & Zajac, 1999; Raasch et al., 1997). The biceps femoris mean values were lower in the forward position, which is similar findings in previous studies (Hayot et al., 2013; Ricard et al., 2006). However, the vastus lateralis and vastus medialis mean values were lower in forward and rearward positions compared to preferred saddle position. Raasch and Zajac (1999) had shown that vastus lateralis and vastus medialis were the muscles contributing to power generation and control of cadence. These two variables were controlled in this study, and therefore, no changes were expected with the saddle displacement. It is therefore not readily evident why these means differed in this study. The rectus femoris and gluteus maximus mean values were lower in forward saddle position and greater in the rearward position. A hip position which is further away from the crank axle requires either more knee extension or more ankle plantar flexion at the early propulsion phase. This, in turn, may lead to increase in hip extension before the recovery phase during cycling. A previous study stated that gluteus maximus worked alternately with iliacus psoas and biceps femoris during cycling (Raasch & Zajac, 1999). However, this study showed that the rectus femoris and gluteus maximus muscle increased in activation when the saddle was moved rearward which was in keeping with our findings. Future research designs aimed at understanding the coordination of agonist and antagonist muscles at different ESTA during cycling should utilize greater numbers of participants in keeping with the high degree of variability in EMG signal.

5.5 CONCLUSION

In conclusion, this study has shown that preserving the joint kinematics of the elbow, shoulder, hip, knee, and ankle joint of the cyclist when changing the effective seat tube angle effectively negate any change in physiological parameters such as heart rate, oxygen consumption, and respiratory exchange ratios.

Minor changes in economy, and knee flexion angle and ankle flexion angle which were detected using magnitude-based inferences may be causal and reflect a methodological flaw in our study design which should not be overlooked in future studies. Specifically, knee flexion angle and ankle flexion angle should be controlled for when manipulating saddle setback.

Lastly, although there were differences in the means of muscle EMG signal data, the high degree of variability in EMG signals negated the ability to interpret these changes to any meaningful degree. The effects of saddle setback on muscle recruitment patterns, therefore, require further assessment using greater numbers of participants.

References

Abbiss, C. R., & Laursen, P. B. (2005). Models to explain fatigue during prolonged endurance cycling. *Sports Medicine (Auckland, N.Z.), 35*(10), 865–98. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16180946

Abt, J. P., Smoliga, J. M., Brick, M. J., Jolly, J. T., Lephart, S. M., & Fu, F. H. (2007). Relationship between cycling mechanics and core stability. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *21*(4), 1300–4. https://doi.org/10.1519/R-21846.1

Albertus-Kajee, Y., Tucker, R., Derman, W., & Lambert, M. (2010). Alternative methods of normalising EMG during cycling. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology, 20*(6), 1036–43. https://doi.org/10.1016/j.jelekin.2010.07.011

American College of Sports Medicine. (2009). *ACSM's Guidelines for Exercise Testing and Prescription* (Eighth edi). Lippincott Williams & Wilkins, Baltimore, MD, USA.

Batterham, A. M., & Hopkins, W. G. (2006). Making Meaningful Inferences About Magnitudes. *International Journal of Sports Physiology and Performance*, *1*(April 2006), 50–57. https://doi.org/10.1123/ijspp.1.1.50

Baum, B. S., & Li, L. (2003). Lower extremity muscle activities during cycling are influenced by load and frequency. *Journal of Electromyography and Kinesiology*, *13*(2), 181–190. https://doi.org/10.1016/S1050-6411(02)00110-4

Bini, R., Carpes, F., Diefenthaeler, F., Mota, C., & Guimaraes, A. (2008). Physiological and electromyographic responses during 40-km cycling ... *Journal of Science and Medicine in Sport*, *11*(4), 363–370.

Bini, R., Hume, P. A., & Croft, J. L. (2011). Effects of bicycle saddle height on knee injury risk and cycling performance. *Sports Medicine (Auckland, N.Z.), 41*(6), 463–476. https://doi.org/10.2165/11588740-000000000-00000

Bini, R. R., & Diefenthaeler, F. (2009). Mechanical work and coordinative pattern of cycling.pdf. *Kinesiology*, *41*(1), 25–39.

Bini, R. R., & Diefenthaeler, F. (2010). Kinetics and kinematics analysis of incremental cycling to exhaustion. *Sports Biomechanics / International Society of Biomechanics in Sports*, *9*(4), 223–35. https://doi.org/10.1080/14763141.2010.540672

Bini, R. R., Diefenthaeler, F., & Mota, C. B. (2010). Fatigue effects on the coordinative pattern during cycling: kinetics and kinematics evaluation. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *20*(1), 102–7. https://doi.org/10.1016/j.jelekin.2008.10.003

Bini, R. R., Hume, P. A., Lanferdini, F. J., & Vaz, M. A. (2013). Effects of moving forward or backward on the saddle on knee joint forces during cycling. *Physical Therapy in Sport : Official Journal of the Association of Chartered Physiotherapists in Sports Medicine*, *14*(1), 23–7. https://doi.org/10.1016/j.ptsp.2012.02.003

Bini, R. R., Tamborindeguy, A. C., & Mota, C. B. (2010). Effects of saddle height, pedaling cadence, and workload on joint kinetics and kinematics during cycling. *Journal of Sport Rehabilitation*, *19*(3), 301–14. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/20811079

Bisi, M. C., Ceccarelli, M., Riva, F., & Stagni, R. (2012). Biomechanical and metabolic responses to seat-tube angle variation during cycling in tri-athletes. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *22*(6), 845–51. https://doi.org/10.1016/j.jelekin.2012.04.013

Bisi, M. C., Stagni, R., & Gnudi, G. (2012). Sensitivity analysis of an energetic muscle model applied at whole body level in recumbent pedalling. *Computer Methods in Biomechanics and Biomedical Engineering*, *15*(5), 527–38. https://doi.org/10.1080/10255842.2010.545950

Brisswalter, J., Hausswirth, C., Smith, D., Vercruyssen, F., & Vallier, J. M. (2000). Energetically optimal cadence vs. freely-chosen cadence during cycling: Effect of exercise duration. *International Journal of Sports Medicine*, *21*(1), 60–64. https://doi.org/10.1055/s-2000-8857

Brown, D. a, Kautz, S. a, & Dairaghi, C. a. (1996). Muscle activity patterns altered during pedaling at different body orientations. *Journal of Biomechanics*, *29*(10), 1349–56. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/8884480

Browning, R., Gregor, R., & Broker, J. (1992). Lower extremity kinetics in elite athletes in cycing positions. *Medicine and Science in Sports and Exercise*, *224*, S186.

Burke, E., & Pruitt, A. (2003). Body positioing for cycling. In *High-Tech Cycling* (p. 70). Human Kinetics, Champaign, IL.

Callaghan, M. J. (2005). Lower body problems and injury in cycling. *Journal of Bodywork and Movement Therapies*, *9*(3), 226–236. https://doi.org/10.1016/j.jbmt.2005.01.007

Chapman, A., Vicenzino, B., Blanch, P., & Hodges, P. (2009). Do differences in muscle recruitment between novice and elite cyclists reflect different movement patterns or less skilled muscle recruitment? *Journal of Science and Medicine in Sport / Sports Medicine Australia*, *12*(1), 31–4. https://doi.org/10.1016/j.jsams.2007.08.012

Chapman, A., Vicenzino, B., Blanch, P., Knox, J., Dowlan, S., & Hodges, P. (2008). The influence of body position on leg kinematics and muscle recruitment during cycling. *Journal of Science and Medicine in Sport*, *11*(6), 519–526.

Chung, K. R., Hyeong, J. H., Kim, S. Y., Senner, V., & Hoechtl, F. (2011). The effects of seat tube angle on the metabolic cost during cycling at low intensity workload. *Procedia Engineering*, *13*, 334–337. https://doi.org/10.1016/j.proeng.2011.05.094

De Pauw, K., Roelands, B., Cheung, S., de Geus, B., Rietjens, G., & Meeusen, R. (2013). Guidelines to classify subject groups in sport-science research. *International Journal of Sports Physiology and Performance, 8*(2), 111–122. https://doi.org/10.1123/ijspp.2015-0153

Dorel, S., Couturier, a, & Hug, F. (2009). Influence of different racing positions on mechanical and electromyographic patterns during pedalling. *Scandinavian Journal of Medicine & Science in Sports*, *19*(1), 44–54. https://doi.org/10.1111/j.1600-0838.2007.00765.x

Dorel, S., Drouet, J.-M., Couturier, A., Champoux, Y., & Hug, F. (2009a). Changes of pedaling technique and muscle coordination during an exhaustive exercise. *Medicine and Science in Sports and Exercise*, *41*(6), 1277–86. https://doi.org/10.1249/MSS.0b013e31819825f8

Dorel, S., Drouet, J.-M., Couturier, A., Champoux, Y., & Hug, F. (2009b). Changes of pedaling technique and muscle coordination during an exhaustive exercise. *Medicine and Science in Sports and Exercise*, *41*(6), 1277–86. https://doi.org/10.1249/MSS.0b013e31819825f8

Duc, S., Bertucci, W., Pernin, J. N., & Grappe, F. (2008). Muscular activity during uphill cycling: effect of slope, posture, hand grip position and constrained bicycle lateral sways. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *18*(1), 116–27. https://doi.org/10.1016/j.jelekin.2006.09.007

Ericson, M., Ekholm, J., Svensson, O., & R Nisell. (1985). The forces on ankle joint structures during ergometer cycling. *Foot Ankle International*, *6*, 135–142.

Ericson, M. O., Nisell, R., & Nemeth, G. (1988). Joint Motions of the Lower Limb during Ergometer Cycling. *The Journal of Orthopaedic and Sports Physical Therapy*, *9*(8), 273–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/18796995

Faria, E. W., Parker, D. L., & Faria, I. E. (2005). The science of cycling: physiology and training - part 1. *Sports Medicine (Auckland, N.Z.)*, *35*(4), 285–312. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15831059

Faria, I., & Cavanagh, P. (1978). *The physiology and biomechanics of cycling*. (Illustrated, Ed.). Wiley, 1978.

Ferrer-Roca, V., Bescos, R., Roig, A., Galilea, P., Valero, O., Garcia-Lopez, J., … García-López, J. (2014). Acute effects of small changes in bicycle saddle height on gross efficiency and lower limb kinematics. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *28*(3), 784–91. https://doi.org/10.1519/JSC.0b013e3182a1f1a9

Ferrer-Roca, V., Roig, A., Galilea, P., & Garcia-Lopez, J. (2012). INFLUENCE OF SADDLE HEIGHT ON LOWER LIMB KINEMATICS INWELL-TRAINED CYCLISTS: STATIC VS. DYNAMIC EVALUATION IN BIKE FITTING. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *26*(11), 3025–3029.

Fintelman, D. M., Sterling, M., Hemida, H., & Li, F.-X. (2014). Optimal cycling time trial position models: aerodynamics versus power output and metabolic energy. *Journal of Biomechanics*, *47*(8), 1894–8. https://doi.org/10.1016/j.jbiomech.2014.02.029

Fintelman, D. M., Sterling, M., Hemida, H., & Li, F.-X. (2015). The effect of time trial cycling position on physiological and aerodynamic variables. *Journal of Sports Sciences*, *33*(16), 1730–7. https://doi.org/10.1080/02640414.2015.1009936

Fonda, B., Panjan, A., Markovic, G., & Sarabon, N. (2011). Adjusted saddle position counteracts the modified muscle activation patterns during uphill cycling. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *21*(5), 854–60. https://doi.org/10.1016/j.jelekin.2011.05.010

Garside, I., & Doran, D. a. (2000). Effects of bicycle frame ergonomics on triathlon 10-km running performance. *Journal of Sports Sciences*, *18*(10), 825–33. https://doi.org/10.1080/026404100419883

Gnehm, P., Stephen, R., Ekkehardt, A., Hans, W., & Hans, H. (1997). Influence of different racing positions on metabolic cost in elite cyclists. *Medicine & Science in Sports & Exercise*, *29*(6), 818–823.

Gonzalez, H., & Hull, M. L. (1989). Multivariable optimization of cycling biomechanics. *Journal of Biomechanics*, *22*(11), 1151–1161.

Grappe, F; Candau, R; Belli, A. J. R. (1997). Aerodynamic drag in field cycling with special reference to the Obree’s position. *Ergonomics*, *40*(12), 1299–1311. https://doi.org/10.1080/001401397187388

Hamley, E. J., & Thomas, V. (1967). Physiological and postural factors in the caliration of the bicycle ergometer. *Journal of Physiology*, (191), 55–57P.

Hautier, C. a, Arsac, L. M., Deghdegh, K., Souquet, J., Belli, a, & Lacour, J. R. (2000). Influence of fatigue on EMG/force ratio and cocontraction in cycling. *Medicine and Science in Sports and Exercise*, *32*(4), 839–43. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/10776904

Hayot, C., Domalain, M., Bernard, J., Decatoire, a, & Lacouture, P. (2013). Muscle force strategies in relation to saddle setback management in cycling. *Computer Methods in Biomechanics and Biomedical Engineering*, *16 Suppl 1*(July 2014), 106–8. https://doi.org/10.1080/10255842.2013.815937

Heil, D., Derrick, T., & Whittlesey, S. (1997). The relationship between preferred and optimal positioning during submaximal cycle ergometry. *European Journal of Applied Physiology*, *75*, 160–165.

Heil, D. P., Derrick, T. R., & Whittlesey, S. (1997). The relationship between preferred and optimal positioning during submaximal cycle ergometry. *European Journal of Applied Physiology and Occupational Physiology*, *75*(2), 160–5. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9118982

Heil, D., Wilcox, A., & Quinn, C. (1995). Cardiorespiratory responses to seat tube.pdf. *Medicine and Science in Sports and Exercise*, *27*(5), 730–735.

Holliday, W., Fisher, J., Theo, R., & Swart, J. (2017). Static versus dynamic kinematics in cyclists: A comparison of goniometer, inclinometer and 3D motion capture. *European Journal of Sport Science*, *0*(0), 1–14. https://doi.org/10.1080/17461391.2017.1351580

Houtz, S., & Fischer, F. (1959). An analysis of muscle action and joint excursion during exercise on a stationary bicycle. *Journal of Bone and Joint Surgery*, *41*(1), 123–131.

Hug, F., Bendahan, D., Le Fur, Y., Cozzone, P. J., & Grélot, L. (2004). Heterogeneity of muscle recruitment pattern during pedaling in professional road cyclists: a magnetic resonance imaging and electromyography study. *European Journal of Applied Physiology*, *92*(3), 334–42. https://doi.org/10.1007/s00421-004-1096-3

Hug, F., Drouet, J. M., Champoux, Y., Couturier, A., & Dorel, S. (2008). Interindividual variability of electromyographic patterns and pedal force profiles in trained cyclists. *European Journal of Applied Physiology*, *104*(4), 667–78. https://doi.org/10.1007/s00421-008-0810-y

Hunter, a M., St Clair Gibson, a, Lambert, M. I., Nobbs, L., & Noakes, T. D. (2003). Effects of supramaximal exercise on the electromyographic signal. *British Journal of Sports Medicine*, *37*(4), 296–9. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=1724671&tool=pmcentrez&rendertype=abstract

Jobson, S. a, Nevill, a M., George, S. R., Jeukendrup, a E., & Passfield, L. (2008). Influence of body position when considering the ecological validity of laboratory time-trial cycling performance. *Journal of Sports Sciences*, *26*(12), 1269–78. https://doi.org/10.1080/02640410802183585

Jorge, M., & Hull, M. L. (1986). Analysis of EMG measurements during bicycle pedalling. *Journal of Biomechanics*, *19*(9), 683–694. https://doi.org/10.1016/0021-9290(86)90192-2

Juker, D., McGill, S., Kroff, P., & Steffen, T. (1998). Quantitative intramuscular myoelectric activity of lumbar portions of psoas and the abdominal wall during a wide variety of tasks.pdf. *Medicine & Science in Sports & Exercise*, *30*(2), 301–310.

Lamberts, R. P., Swart, J., Noakes, T. D., & Lambert, M. I. (2011). A novel submaximal cycle test to monitor fatigue and predict cycling performance. *British Journal of Sports Medicine*, *45*(10), 797–804. https://doi.org/10.1136/bjsm.2009.061325

Laplaud, D., Hug, F., & Grelot, L. (2006). Reproducibility of eight lower limb muscles activity level in the course of an incremental pedaling exercise. *Journal of Electromyography and Kinesiology*, *16*(2), 158–166. https://doi.org/10.1016/j.jelekin.2005.04.002

Madsen, K., Maclean, D. A., Kiens, B., Christensen, D., Temesi, J., Johnson, N. A., … Gleeson, M. (2012). Effects of glucose , glucose plus branched-chain amino acids , or placebo on bike performance over 100 km Effects of glucose , glucose plus branched-chain amino acids , or placebo on bike performance over 100 km, 2644–2650.

Marfell-jones, M., Olds, Ti., Stewart, A. D., & Carter, L. (2006). International stardards for anthropometric assessement. *Potchefsroom*, 1–30.

McDaniel, J., Subudhi, A., & Martin, J. C. (2005, August). Torso stabilization reduces the metabolic cost of producing cycling power. *Canadian Journal of Applied Physiology = Revue Canadienne de Physiologie Appliquée*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/16258182

Mestdagh, K. D. V. (1998). Personal perspective : in search of an optimum cycling posture. *Applied Ergonomics*, *29*(5), 325–334.

Mornieux, G., Guenette, J. a, Sheel, a W., & Sanderson, D. J. (2007). Influence of cadence, power output and hypoxia on the joint moment distribution during cycling. *European Journal of Applied Physiology*, *102*(1), 11–8. https://doi.org/10.1007/s00421-007-0555-z

Neptune, R. R., & Hull, M. L. (1995). Accuracy assessment of methods for Determining hip movement in seated cycling. *Journal of Biomechanics*, *28*(4), 423–437.

Nordeen-Snyder, K. S. (1977, January). The effect of bicycle seat height variation upon oxygen consumption and lower limb kinematics. *Medicine and Science in Sports*. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/895427

Origenes, M., Blank, S., & Schoene, R. (1993). Exercise ventilatory response to upright and aero-posture cycling. *Medicin*, *25*(5), 608–612.

Paton, C. D., & Hopkins, Wi. G. (2005). Combining explosive and high-resistance training improves performance in competitive cyclists. *Journal of Strength and Conditioning Research*, *19*(4), 826–830.

Peveler, W., Bishop, P., Smith, J., & Richardson, M. (2005). Effects of training in an aero position on metabolic economy. *Journal of Exercise Physiology Online*, *8*(1), 44–50.

Peveler, W., Pounders, J., & Bishop, P. (2007). Effects of saddle height on anaerobic power production in cycling. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *21*(4), 1023–1027.

Peveler, W. W. (2008). Effects of saddle height on economy in cycling. *Journal of Strength and Conditioning Research*, *22*(4), 1355–1359.

Peveler, W. W., & Green, J. M. (2011a). Effects of Saddle Height on Economy and Anaerobic Power in well-trained cyclists. *Journal of Strength and Conditioning Research*, *25*(3), 629–633.

Peveler, W. W., & Green, J. M. (2011b). Effects of saddle height on economy and anaerobic power in well-trained cyclists. *Journal of Strength and Conditioning Research / National Strength & Conditioning Association*, *25*(3), 629–33. https://doi.org/10.1519/JSC.0b013e3181d09e60

Peveler, W. W., Shew, B., Johnson, S., & Palmer, T. G. (2012). A kinematic comaprison of alternations to knee and ankle angles from resting measures to active pedaling during a graded exercise protocol. *Journal of Streng*, *26*(11), 3004–3009.

Price, D., & Donne, B. (1997). Effect of variation in seat tube angle at different seat heights on submaximal cycling performance in man. *Journal of Sports Sciences*, *15*(4), 395–402. https://doi.org/10.1080/026404197367182

Psek, J. A., & Cafarelli, E. (1993). Behavior of coactive muscles during fatigue. *Journal of Applied Physiology*, *74*(1), 170–175.

Raasch, C. C., & Zajac, F. E. (1999). Locomotor Strategy for Pedaling : Muscle Groups and Biomechanical Functions Locomotor Strategy for Pedaling : Muscle Groups and Biomechanical Functions. *Journal of Neurophysiology*, *82*, 515–525.

Raasch, C., Zajac, F., Mas, B., & Levine, W. (1997). MUSCLE COORDINATION OF MAXIMUM-SPEED. *Journal of Biomechanics*, *30*(6), 595–602.

Ricard, M. D., Hills-Meyer, P., Miller, M. G., & Michael, T. J. (2006). The effects of bicycle frame geometry on muscle activation and power during a wingate anaerobic test. *Journal of Sports Science & Medicine*, *5*(1), 25–32. Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3818671&tool=pmcentrez&rendertype=abstract

Ryan, M., & RJ Gregor. (1992). EMG profiles of lower extremity muscles during cycling at constant workload and cadence. *Journal of Electromyography and Kinesiology*, *2*, 69–80.

Sanderson, D. J., & Amoroso, A. T. (2009). The influence of seat height on the mechanical function of the triceps surae muscles during steady-rate cycling. *Journal of Electromyography and Kinesiology : Official Journal of the International Society of Electrophysiological Kinesiology*, *19*(6), e465-71. https://doi.org/10.1016/j.jelekin.2008.09.011

Sanderson, D. J., & Black, A. (2003). The effect of prolonged cycling on pedal forces. *Journal of Sports Sciences*, *21*(3), 191–9. https://doi.org/10.1080/0264041031000071010

Sarabon, N., Fonda, B., & Markovic, G. (2012). Change of muscle activation patterns in uphill cycling of varying slope. *European Journal of Applied Physiology*, *112*(7), 2615–23. https://doi.org/10.1007/s00421-011-2236-1

Savelberg, H., Port, I., & Willems, P. (2003). Body Configuration in Cycling Affects Muscle Recruitment and Movement Pattern. *Journal of Applied Biomechanics*, *19*, 310–324.

Savelberg, H., Port, I., Willems, P., Hans H C M Savelberg, Ingrid G L Van de Port, & Paul J B Willems. (2003). Body Configuration in Cycling Affects Muscle Recruitment and Movement Pattern. *Journal of Applied Biomechanics*, *19*, 310–324.

Silder, A., Gleason, K., & Thelen, D. G. (2011). Influence of bicycle seat tube angle and hand position on lower extremity kinematics and neuromuscular control: implications for triathlon running performance. *Journal of Applied Biomechanics*, *27*(4), 297–305. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/21896955

So, R. C. H., Ng, J. K.-F., & Ng, G. Y. F. (2005). Muscle recruitment pattern in cycling: a review. *Physical Therapy in Sport*, *6*(2), 89–96. https://doi.org/10.1016/j.ptsp.2005.02.004

Swart, J., Lamberts, R. P., Derman, W., & Lambert, M. I. (2009). Effects of high-intensity training by heart rate or power in well-trained cyclists. *Journal of Strength and Conditioning Research*, *23*(2), 619–625.

Too, D. (1989). The Effect of Body Orientation on Cycling Performance. *Kinesiology, Sport Studies and Physical Education*, *97*, 51–58.

Too, D. (1990). Biomechanics of cycling and factors affecting performance. *Sports Medicine (Auckland, N.Z.)*, *10*(5), 286–302. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/2263797

Too, D. (1991). The Effect of Hip Position / Configuration on Anaerobic Power and Capacity in Cycling The Effect of Hip Position / Configuration on Anaerobic Power and Capacity I-. *International Journal of Sport Biomechanics*, *7*, 359–370.

Too, D. (1994). The effect of trunk angle on power production in cycling. *Research Quarterly for Exercise & Sport*, *65*(4), 308–315. Retrieved from http://search.proquest.com/docview/218540010?accountid=14681

Umberger, B. R., Scheuchenzuber, H. J., & T M Manos. (1998). differences in power output during cycling at different seat tube angles.pdf. *Journal of Human Movement studies1*, *35*, 21–36.

Underwood, L., Schumacher, J., Burette-Pommay, J., & Jermy, M. (2011). Aerodynamic drag and biomechanical power of a track cyclist as a function of shoulder and torso angles. *Sports Engineering*, *14*(2–4), 147–154. https://doi.org/10.1007/s12283-011-0078-z

Vrints, J., Koninckx, E., Van Leemputte, M., & Jonkers, I. (2011). The effect of saddle position on maximal power output and moment generating capacity of lower limb muscles during isokinetic cycling. *Journal of Applied Biomechanics*, *27*(1), 1–7. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/21451176

Wozniak-Timmer, C. (1991). Cycling Biomechanics: A Literature Review. *Journal Orthopaedic & Sport Physical Therapy*, *14*(3), 106–113.

Zlowodzki, M., & Bhandari, M. (2009). Outcome measures and implications for sample-size calculations. *The Journal of Bone and Joint Surgery. American Volume, 91 Suppl 3*, 35–40. https://doi.org/10.2106/JBJS.H.01602

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1. Advertisement for recruitment

MALE CYCLISTS WANTED FOR UCT RESEARCH

We would like to monitor a group of well-trained cyclists as the change their bicycle set-up

INCLUDES ONE FREE $\dot{V}O_2$ MAX TEST, ELECTROMYOGRAPHY AND THREE-DIMENSIONAL CAMERA ANALYSIS

What type of participants are we looking?

- Males aged 18 to 45 years of age.
- Recent Argus time of no longer than 4hrs30min.
- Minimum training load of at least 4 hours per week on average in the three months preceding the trial.
- No change to bicycle set-up in last three months, and be comfortable in current set-up.

What will be required of you?

- One $\dot{V}O_2$ max test and three 1-hour steady-state cycling
- Keeping a daily log of all your training
- Maintain current training program for 4 weeks

What are the benefits?

- Full analysis of your performance tests
- An opportunity to monitor how changing bicycle set-up affects your training

Who is conducting this research?

- UCT/MRC Research Unit for Exercise Science and Sports Medicine.
  At the Sports Science Institute of South Africa, Boundary Rd, Newlands
  Department of Human Biology, Faculty of Health Science, University of Cape Town

Who should I contact?

- **Raymond Teo** via email: raymond74@gmail.com or phone: **071 528 5426**

PLEASE APPLY BEFORE January 2015

2. Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire

Name:

1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor? Yes ☐ No ☐

2. Do you feel pain in your chest when you do physical activity? Yes ☐ No ☐

3. In the past month, have you had chest pain when you were not doing physical activity? Yes ☐ No ☐

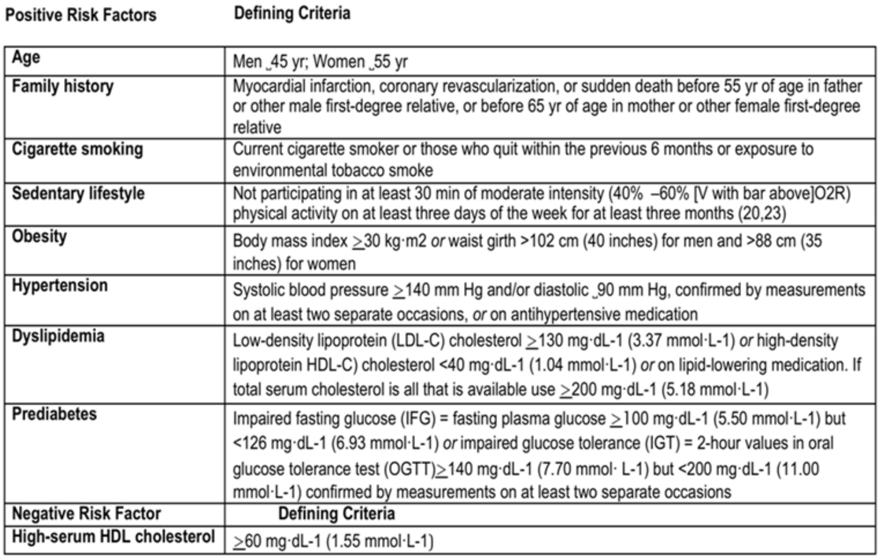
4. Do you lose your balance because of dizziness or do you ever lose consciousness? Yes ☐ No ☐

5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity? Yes ☐ No ☐

6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition? Yes ☐ No ☐

7. Do you know of any other reason why you should not do physical activity? Yes ☐ No ☐

8. Do you have any of the risk factors indicated in the following chart? Yes ☐ No ☐



Positive Risk Factors	**Defining Criteria**
Age	Men ¸45 yr; Women ¸55 yr
Family history	Myocardial infarction, coronary revascularization, or sudden death before 55 yr of age in father or other male first-degree relative, or before 65 yr of age in mother or other female first-degree relative
Cigarette smoking	Current cigarette smoker or those who quit within the previous 6 months or exposure to environmental tobacco smoke
Sedentary lifestyle	Not participating in at least 30 min of moderate intensity (40% –60% [V with bar above]O2R) physical activity on at least three days of the week for at least three months (20,23)
Obesity	Body mass index ≥30 kg·m2 *or* waist girth >102 cm (40 inches) for men and >88 cm (35 inches) for women
Hypertension	Systolic blood pressure ≥140 mm Hg and/or diastolic ¸90 mm Hg, confirmed by measurements on at least two separate occasions, *or* on antihypertensive medication
Dyslipidemia	Low-density lipoprotein (LDL-C) cholesterol ≥130 mg·dL-1 (3.37 mmol·L-1) *or* high-density lipoprotein HDL-C) cholesterol <40 mg·dL-1 (1.04 mmol·L-1) *or* on lipid-lowering medication. If total serum cholesterol is all that is available use ≥200 mg·dL-1 (5.18 mmol·L-1)
Prediabetes	Impaired fasting glucose (IFG) = fasting plasma glucose ≥100 mg·dL-1 (5.50 mmol·L-1) but <126 mg·dL-1 (6.93 mmol·L-1) *or* impaired glucose tolerance (IGT) = 2-hour values in oral glucose tolerance test (OGTT)≥140 mg·dL-1 (7.70 mmol· L-1) but <200 mg·dL-1 (11.00 mmol·L-1) confirmed by measurements on at least two separate occasions
Negative Risk Factor	**Defining Criteria**
High-serum HDL cholesterol	≥60 mg·dL-1 (1.55 mmol·L-1)

Participant Signature	**Date**

3. Informed consent form

INFORMED CONSENT FORM

Dear Participant

I am a Masters student in Exercise Science and Sports Medicine at the University of Cape Town. I will be conducting a study to understand the different seat tube angles contributed to the effects of muscle recruitment patterns related to optimal metabolic economy in the hip, knee, ankle, shoulder and elbow during steady-state cycling tests.

Your training and competition information will be obtained as well as flexibility, $\dot{V}O_2$ max, EMG measures, oxygen consumption and joint angle range of motion measures will be conducted. Information obtained within the study will be used to complete my dissertation in fulfilment of the MSc Exercise Science and Sports Medicine course. This study has been given ethical approval by the Faculty of Health Sciences Human Research Ethics Committee, University of Cape Town (HREC REF: 649/2014).

Early research identified four geometry variables (crank arm length, seat height, seat tube angle and longitudinal foot position) that influence these biomechanical functions, which in turn, affect the cycling biomechanics. Within these four variables, little focus on research by manipulating the seat tube angle induce changes in metabolic economy and mechanical efficiency. Hence, to understand the effects on alterations effective seat tube angles influence cycle performance, economy and comfort will contribute to further research and enhance cycling performance.

You will be invited to attend a total of four appointments, lasting approximately two hours each, one week apart at the Sports Science Institute of South Africa, testing laboratory.

This study will be supervised by Dr Jeroen Swart from the University of Cape Town. Please take time to read this form thoroughly before signing.

What will happen to me if I take part?

If you agree to take part in this study, the investigator will brief you on the study and you will need to sign a written consent. You will need to fill up the past 4 weeks training dairy then the investigator will be measuring your anthropometry and schedule for familiarization tests on CycleOps 400 Indoor Pro Cycle. Brief outlines for each session are listed as follows.

On the first appointment:

The first appointment will last approximately two hours. You will be asked to bring your own road bicycle and riding shorts and shoes. The first session will be divided into four activities.

In the first activity you will be asked to complete a questionnaire regarding your bicycle configuration, training, competition and injury history. There will be questions included to assess your readiness to complete the necessary physical tests which will screen for any medical conditions that may exclude you from the study. Should any medical conditions be detected, you will be referred to the appropriate medical facility.

The second activity will include anthropometry measurements such as weight, height, and skinfold thickness at seven sites (biceps, triceps, subscapular, abdomen, suprailiac, thigh and calf). After which, the measurements will be taken to determine the configuration of your bicycle and this will include saddle height, saddle set-back, reach and drop.

Finally, after a warm-up period, you will undergo peak oxygen consumption and peak power output test on an electronically braked cycle ergometer (CycleOps 400 Indoor Pro Cycle). This will be used to determine the rate at which you will cycle for the next three sessions.

You will be familiarised with all testing procedures that will be used during the study and have the opportunity to practice any of the tests that will be completed in the next three sessions. The testing procedure will be explained and any questions will be answered to your satisfactory.

On the second appointment:

The second appointment will be approximately two hours to complete the trials. At the second meeting (approximately one week later), you will be performing a Sit-and-Reach test, where a measure will be taken of how far you can reach towards or beyond your toes. You will also be performs reaching the fingertips to the floor, where spinal flexibility will be measured with a tape measure. To determine the flexibility of your hip flexors and Iliotibial band, a Thomas test will be conducted, which require you to hold one knee to your chest and gently roll your back onto the plinth with the other leg gently lowered onto the plinth and assessed for tightness in the hip flexors or Iliotibial band. Hamstring length will be measured with your back on a plinth. Each leg will be raised and the knee will be straightened until a deep stretch is felt to determine the angle it forms at your knee.

The CycleOps Trainer will be configured according to the exact measurements of your bicycle taken during the first session. Your hip, knee, ankle, shoulder and elbow static joint angles will be measured with a goniometer and three-dimensional (3D) Vicon system, with you on your bicycle.

Electromyography (EMG) electrodes will be fitted onto your skin. The site of the electrode will be shaved and cleaned with ethanol and the electrodes will be secured with tape.

Reflective markers will be placed on the pelvis and lower limb for 3D Vicon system recording of the joint range of motion. You will be fitted with a pneumotach face mask to measure oxygen consumption during three short intervals of the hour-long steady state cycle.

During this session you will follow a warm-up protocol lasting 16:30 minutes and a 5 minute EMG normalization cycle. After a brief rest, you will be requested to cycle at 60% of the peak power output for an hour.

The 3D Vicon camera system and EMG data will be recorded during an hour long steady state cycle. Distance cycled and oxygen consumption will also be measured. All recordings will be stored on a secure computer for the duration of the data analysis.

On the third, fourth and fifth appointment:

The third appointment will be one week after the second appointment and will be approximately two hours to complete the trial. The CycleOps trainer will be configured according to the exact measurements of your bicycle taken during the second appointment. Your saddle setback will be adjusted to your original bicycle configuration after third appointment for seven days “washout” period training.

Your bicycle saddle setback will be adjusted 3cm forward or backward (opposite from the second appointment configuration) on the fourth appointment. You will need to return to the laboratory for the final session testing.

All the measurements and testing procedures will be the same as second session except your bicycle configuration and the CycleOPs 400 Indoor Trainer will be adjusted for your own training and testing in the laboratory. Your bicycle configuration will be adjusted to your original setting during the fifth appointment in the laboratory.

Are there any disadvantages / risks in taking part?

Data collection involves a series of laboratory based physiological and biomechanical tests with no invasive measurements. While the physiological tests are of maximal effort, only physically active, healthy cyclists, who train regularly, will be recruited for this study. It has been well-documented that overall risk of maximal exercise testing in healthy individuals (without known diseases) is very low, with complications rate of 0.8 per 10 000 tests (Gibbons et al., 1989). Hence, the testing protocols you are undergone does not expose you to any additional risks over and above that to which you normally exposed during maximal testing and training. However, changing the saddle setback positions during the trial may increase discomfort and the normal “risk’ associated with the routinely adjusted bicycle set-up.

The investigators are trained with the curriculum of the American Heart Association basic life support for healthcare provider (cardiopulmonary resuscitation and automated external defibrillator) program with the equipment and medical supports in the building in case of any emergency.

Will I be compensated for participation?

You will be given feedback on all the anthropometrical and maximal aerobic capacity measurements taken. Unfortunately no financial compensation is available for participation in this study.

What if something goes wrong?

There will not be any expected adverse effects as all exercises will be according to your exercise parameters.

However, if you experience any signs or symptoms such as shortness of breath, pain or giddiness during the exercise, you must inform the investigator immediately. The investigator may ask you to stop the exercise and ask you to rest. No compensation is available for lost wages and/or pain.

Please note that UCT does offer a no-fault insurance that will cover all participants in the event that something may go wrong. This insurance will provide prompt payment of compensation for any trial-related injury according to the Association of the British Pharmaceutical Industry (ABPI) guidelines (1991). These guidelines recommend that UCT, without any legal commitment, should compensate you without you having to prove that UCT is at fault. An injury is considered trial-related if, and to the extent that, it is caused by study activities. You must notify the study investigators immediately of any injuries during the trial, whether they are research-related or other related complications. UCT reserves the right not to provide compensation if, and to the extent that, your injury came about because you chose not to follow the instructions that you were given while taking part in the study. Your right in law to claim compensation for injury where you prove negligence is not affected.

The UCT FHS Human Research Ethics Committee can be contacted on 021 406 6338 or any of the individuals listed below in case you have any questions regarding your rights and welfare as research paarticipants on the study. You are assured that all inquiries will remain confidential.

Confidentiality – Who will know my results?

All information collected about you will be kept confidential. Only the investigator and the co-investigators will have access to the information and any information about you will be coded. Data that may be reported in scientific journals will not include any information identifying you as a participant in the study.

What happens if I refuse to take part?

You are under no obligation to take part. If you decide not to take part, you will not be penalised.

If you have any questions about the study, you may contact Mr Raymond Teo 0715285426.

Raymond Teo

Physical Address: Sports Science Institute South Africa
Boundary Road, Newlands
Tel number: 0715285426

Email: raymond74@gmail.com

Dr. Jeroen Swart

Physical Address: Sports Science Institute South Africa
Boundary Road, Newlands
Tel number/Fax: (021) 6595644/(021) 6595633
Email: jeroen@sciencetosport.com

Professor Marc Blockman

Chairperson, Faculty of Health Sciences Human Research Ethics Committee

Tel number: (021) 4066492

E-mail: marc.blockman@uct.ac.za

By placing your signature below, it serves as confirmation that you have had adequate time to read through the study information, that you have understood the consent form and that you are willing to participate in this study. You have the right to withdraw at any time and you may ask questions at any time during the study. All information recorded during this study will remain confidential, and no participants will be identified in the event of future publication. Your signature is further confirmation that you are aware of the possible risks involved in this study.

______________________	______________________	____________
Signature of Participant	Name (Please Print)	Date
______________________	______________________	____________
Signature of Investigator	Name (Please Print)	Date

4. De Pauw’s Guidelines to classify subject groups in sport-science research

	PL 1	**PL 2**	**PL 3**	**PL 4**	**PL 5**
Physiological performance indicators					
1° relative $\dot{V}O_2$ max, mL · min^{-1} · kg^{-1}	<45	45-54.9	55-64.9	65-71	>71
2° absolute PPO, W	<280	280-319	320-379	380-440	>350
Absolute $\dot{V}O_2$ max, L/min	<3.7	3.4-4.2	4.2-4.9	4.5-5.3	>5.0
Relative PPO, W/kg	<4.0	3.6-4.5	4.6-5.5	4.9-6.4	>5.5
Cycling status					
Training frequency/week			≥3	>3	>5
Training h/wk	<2-3	3-4	≥5	≥10	>10
Training distance, km/wk		<60	60-290	>250	>500
Cycling experience, years				≥3	≥5

5. Physical Activity and training Questionnaire

MSc Exercise Science and Sports Medicine

The effect of alterations in effective seat tube angle on cycling performance, economy and discomfort

The information collected in this questionnaire will only be used for research purposes within the scope of this study. All information will be kept strictly confidential and anonymous.

Instructions

The questionnaire must be completed during the first session of the testing procedure. Please answer each question by filling in the details in the allocated space or checking one or more of the option boxes.

Informed consent must be signed prior to completing the questionnaire online, and handed in to the investigator.

Investigator: Raymond Teo
Tel number: 0715285426
E-mail: raymond74@gmail.com

Supervisor: Dr Jeroen Swart
Tel number: (021) 6595644
E-mail: jeroen@sciencetosport.com

Please complete the following sections:

Section A	Personal Details
Section B	Cycling Information
Section C	Cycling Training
Section D	Competition History
Section E	General Training
Section F	Injury History
Section G	Cycling Training Dairy

Section A: Personal details

Name: ______________________________
Email address: ______________________________
Date of birth: ______________________________
Cell number: ______________________________
Home number: ______________________________
Height: ______________________________
Weight: ______________________________
Age: ______________________________
Occupation: ______________________________

Section B: Cycling information

1. Bicycle model
2. In which cycling disciplines do you currently take part:

Road	☐
Mountain Bike	☐
Cross Country	☐
Indoor spinning	☐

3a. Have you ever had your bicycle set-up done by a professional? ☐Yes ☐ No
3b. If YES, who did your bicycle set-up? ________________________
3c. if YES, when did you have it done? ________________________
3d.1. if YES, where you happy with the set-up? ☐ Yes ☐ No
3d.2 if NO, you were not happy, did you change the set-up? ☐ Yes ☐ No
3d.3 if you did change the set-up, what did you change?
____
____
____

Section C: Cycling Training

1a. What is the length of your average training ride per week in the last 3 months? ____hours
1b.What is your maximum training ride time per week in the last 3 months? ____hours
1c. What is your minimum training ride time per week in the last 3 months? ____hours

2a. How many cycling training sessions do you complete each week? ______________
2b. How many days do you rest from cycling training each week? ________________
3a. Have you stopped cycling for a particular period of time in the last 12 months (rest period)? ☐Yes ☐ No
3b. If YES, how long was this rest period? ______________
3c. If YES, what was the reason for this rest period?

Injury	☐
Illness	☐
Work commitments	☐
Family commitments	☐
Other	Please specify: ______________________________

4. Do you include the following in your cycling training? On average, how often per week do you include them? Please see Appendix 1. For the Rate of Perceived Exertion Scale (RPE).

Long slow cycles ☐ Yes ☐No How often/wk? _____ Rate your RPE ___
Speed/Interval sessions ☐ Yes ☐No How often/wk? _____ Rate your RPE ___
Hill training ☐ Yes ☐No How often/wk? _____ Rate your RPE ___

Section D: Competition History

1a.What was your Argus 2014 completion time? ____________
1b.How many Argus Cycle Tours have you completed? ___________
2.What other races have you competed in, in the last 12 months?

Road
PPA one tonner 2013 ☐
Coronation Double Century 2013 ☐
The Herald Port Elizabeth 2014 ☐
Momentun 94.7 Cycle Challenge ☐
Die Burger 2014 ☐
99er Cycle tour 2014 ☐

Mountain bike
Tru-Cape 2013 ☐
Cape Country MTB tour 2013 ☐
Pick n Pay Weekend Argus Rotary Knysna Cycle Tour 2013 ☐
ABSA Cape Epic 2013 ☐
ABSA Cape Epic 2014 ☐
99er MTB Challenge 2014 ☐

Please lists the races you have done for the past 1 year if are not listed above:

Section E: General Training

1. Do you do any other forms of training on a regular basis? ☐ Yes ☐ No
2. Which type of training, how often per week and for how many months of the year do you participate in this training?

Running ____________hrs/wk _____________months/year
Swimming ____________hrs/wk _____________months/year
Rugby ____________hrs/wk _____________months/year
Touch Rugby ____________hrs/wk _____________months/year
Cricket ____________hrs/wk _____________months/year
Martial arts ____________hrs/wk _____________months/year
Pilates ____________hrs/wk _____________months/year
Yoga ____________hrs/wk _____________months/year
Resistance training ____________hrs/wk _____________months/year
Hockey ____________hrs/wk _____________months/year
Canoeing ____________hrs/wk _____________months/year
Horse riding ____________hrs/wk _____________months/year
Volleyball ____________hrs/wk _____________months/year

Walking ____________hrs/wk ____________months/year
Squash ____________hrs/wk ____________months/year
Basketball ____________hrs/wk ____________months/year
Hiking ____________hrs/wk ____________months/year
Tennis ____________hrs/wk ____________months/year
Soccer ____________hrs/wk ____________months/year
Golf ____________hrs/wk ____________months/year
Badminton ____________hrs/wk ____________months/year
Other: Please specify:____

3a. Do you do any flexibility/stretch exercises regularly? ☐ Yes ☐ No
3b. If YES, on average, how many days a week do you perform a stretching session?
3c. Do you stretch: Before exercise ☐
During exercise ☐
After exercise ☐
3d. Which muscle groups do you include in your stretches? ☐ Hamstrings
☐ Quadriceps
☐ Calves
☐ Groin
☐ Other: Please specify
3e. When you stretch the above muscle groups, how long, on average, do you hold each stretch for? ______Seconds
3f. On each occasion, when you stretch the above muscle groups, how often, on average do you repeat each stretch?
☐ Once
☐ Twice
☐ 3 times
☐ 4 times
☐ 5± times

Section F: Injury History

1a. Have you sustained any injuries while cycling in the last year, that have interrupted your cycling training? ☐Yes ☐No

1b. If NO, thank you for completing this questionnaire.

If YES: On the right side? ☐
On the left side? ☐
Both sides? ☐

1c. Were you diagnosed by a medical professional? ☐Yes ☐No

1d. If yes, what was your diagnosis? ______________________________

1e. Did you receive any treatment for this injury? ☐Yes ☐No

1f. If YES, what type of treatment did you receive (Tick all appropriate answers)?

Tablets ☐
Stretches ☐
Cortisone injection ☐
Physiotherapy ☐
Orthotics ☐
Strengthening exercises ☐
Equipment change ☐
Surgery ☐
Other: Please specify:___________

1g. Does this injury still interfere with your cycling training? ☐Yes ☐No

1h. How long did it take to recover? _____________________________________

2a. Have you sustained any other injuries while cycling in the last year that have resulted in time off training? ☐Yes ☐No

2b. If NO, thank you for completing this questionnaire.

If yes, please complete the questions for each additional injury.

Additional Injury 1: What did you injure? ___________________________________

On the right side? ☐
On the left side? ☐
Both sides? ☐

2c. Were you diagnosed by a medical professional? ☐ Yes ☐ No

2d. If yes, what was your diagnosis? ______________________________

2e. Did you receive any treatment for this injury? ☐Yes ☐ No

2f. If YES, what type of treatment did you receive (Tick all appropriate answers)?

Tablets ☐
Stretches ☐
Cortisone injection ☐
Physiotherapy ☐
Orthotics ☐
Strengthening exercises ☐
Equipment change ☐
Surgery ☐
Other: Please specify:___________

2g. Does this injury still interfere with your cycling training? ☐ Yes ☐ No

2h. How long did it take to recover? _____________________________________

Additional Injury 2: What did you injure? ____________________________________

On the right side? ☐
On the left side? ☐
Both sides? ☐

2j. Were you diagnosed by a medical professional? ☐ Yes ☐ No
2k. If yes, what was your diagnosis? _______________________________
2l. Did you receive any treatment for this injury? ☐ Yes ☐ No

2m. If YES, what type of treatment did you receive (Tick all appropriate answers)?

Tablets ☐
Stretches ☐
Cortisone injection ☐
Physiotherapy ☐
Orthotics ☐
Strengthening exercises ☐
Equipment change ☐
Surgery ☐
Other: Please specify:___________

2n. Does this injury still interfere with your cycling training? ☐ Yes ☐ No
2o. How long did it take to recover? ______________________________________

Section G: Cycling Training Dairy

Cyclist:	**Day:**	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**	**Saturday**	**Sunday**
Maximum Heart Rate:	**Date:**							
Session RPE	**Morning**							
0 - Rest	Resting heart rate:							
1 - Very, very easy	**Training information**							
2 - Easy	Training duration (minutes):							
3 - Moderate	Session RPE:							
4 - Somewhat hard	Distance:							
5 - Hard	Average heart rate during training:							
6 -	Maximum heart rate during training:							
7 - Very hard	**Training load**							
8 -	Session RPE method:							
9 - Extremely hard	TRIMPs:							
10 - Maximal								

THANK YOU FOR COMPLETING THIS QUESTIONNAIRE

6. Bicycle configuration measurements.

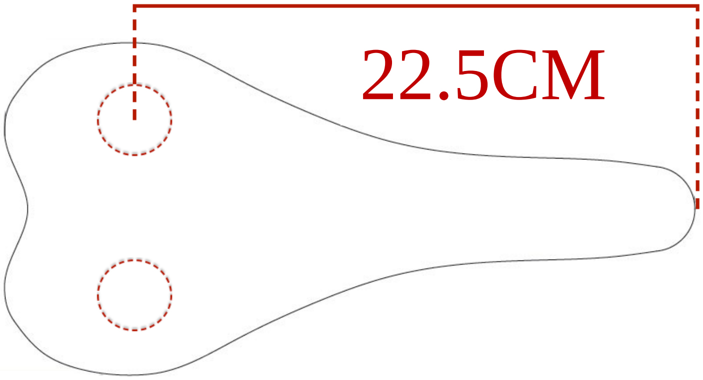
6.1 Saddle height:

The saddle height is measured from the center of the crank axle to the top of the saddle, passing through the center of the bicycle seat tube and seat post.

6.2 Saddle setback:

Saddle setback is measured as the horizontal distance from the front of the saddle to the center of the crank axle.

6.3 The saddle needs to be measured, a standard saddle is 22.5cm in length*, from the center of the ischial tuberosity padding to the front of the saddle.



6.4 Reach:

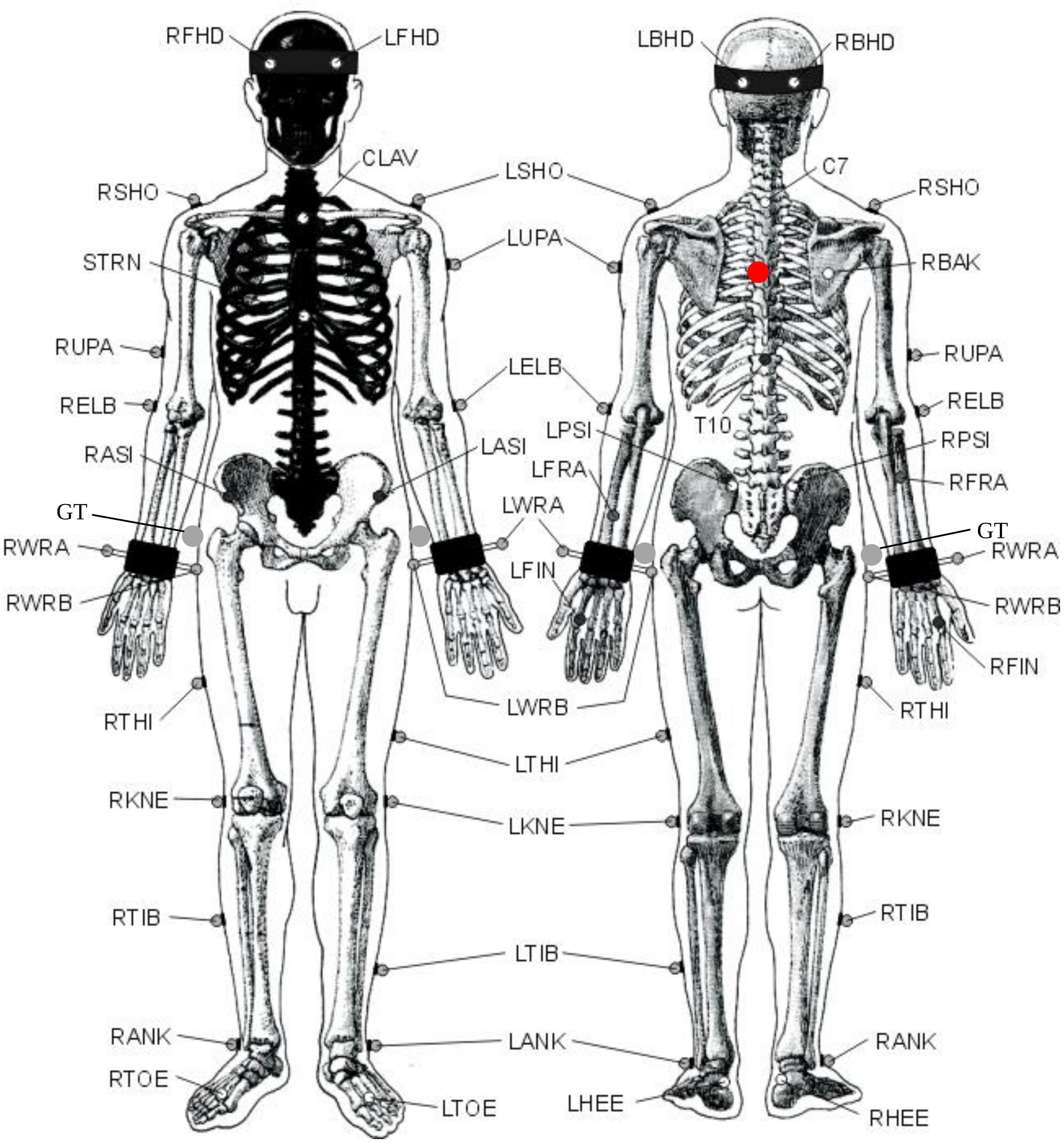
The reach will be measured horizontally, from the center of the handlebar clamping point to the center of the seatpost or seat tube. This measurement is for bicycle frames with a 74° seat tube angle.

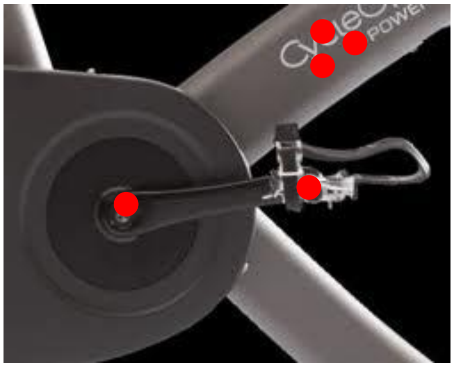
6.5 For bicycle frames that do not have a 74°, the reach will be measured as the horizontal distance from the center of the crank axle to the center of the handlebar clamping point.

6.6 Drop:

Drop values will be measured as the vertical distance from the top of the saddle surface to the center of the handlebar clamping joint.

7. VICON markers





8. EMG Placement

Muscle Name	Medialis Gastrocnemius
Origin	Proximal and posterior part of medial condyle and adjacent part of the femur, capsule of the knee joint.
Insertion	Middle part of posterior surface of calcaneus.
Function	Flexion of the ankle joint and assist in flexion of the knee joint.
Recommended sensory placement procedure	
Starting posture	Lying on the belly with the face down, the knee extended and the foot projecting over the end of the table.
Electrode size	Maximum size in the direction of the muscle fibres: 10 mm.
Electrode distance	20 mm.
Electrode placement	
- location	Electrodes need to be placed on the most prominent bulge of the muscle.
- orientation	In the direction of the leg (see picture).
- fixation on the skin	(Double sided) tape / rings or elastic band.
- reference electrode	On / around the ankle or the proc. spin. of C7.
Clinical test	Plantar flexion of the foot with emphasis on pulling the heel upward more than pushing the forefoot downward. For maximum pressure in this position it is necessary to apply pressure against the forefoot as well as against the calcaneus.

Muscle Name	Gluteus Maximus
Origin	Posterior gluteal line of ilium ad portion of bone superior and posterior to t, posterior surface of lower part of sacrum, side of coccyx, aponeurosis of erector spinea, sacrotuberous ligament and gluteal aponeurosis.
Insertion	Larger proximal portion and superficial fibres of distal portion of muscle into iliotibial tract of fascia lata. Deeper fibres of distal portion into gluteal tuberosity of femur.
Function	Extends, laterally rotates and lower fibres assist in adduction of the hip joint. The upper fibres assist in adduction. Through its insertion into the iliotibial tract, helps to stabilise the knee in extension.
Recommended sensory placement procedure	
Starting posture	Prone position, lying down on a table.
Electrode size	Maximum size in the direction of the muscle fibres: 10 mm.
Electrode distance	20 mm.
Electrode placement	
- location	The electrodes need to be placed at 50% on the line between the sacral

	vertebrae and the greater trochanter. This position corresponds with the greatest prominence of the middle of the buttocks well above the visible bulge of the greater trochanter.
- orientation	In the direction of the line from the posterior superior iliac spine to the middle of the posterior aspect of the thigh
- fixation on the skin	(Double sided) tape / rings or elastic band.
- reference electrode	On the proc. spin. of C7 or on / around the wrist or on / around the ankle.
Clinical test	Lifting the complete leg against manual resistance.

Muscle Name	Tibialis anterior
Origin	Lateral condyle and proximal 1/2 of lateral surface of tibia, interosseus membrane, deep fascia and lateral intermuscular septum.
Insertion	Medial and plantar surface of medial cuneiform bone, base of first metatarsal bone.
Function	Dorsiflexion of the ankle joint and assistance in inversion of the foot.
Recommended sensory placement procedure	
Starting posture	Supine or sitting.
Electrode size	Maximum size in the direction of the muscle fibres: 10 mm.
Electrode distance	20 mm.
Electrode placement	
- location	The electrodes need to be placed at 1/3 on the line between the tip of the fibula and the tip of the medial malleolus.
- orientation	In the direction of the line between the tip of the fibula and the tip of the medial malleolus.
- fixation on the skin	(Double sided) tape / rings or elastic band.
- reference electrode	On / around the ankle or the proc. spin. of C7.
Clinical test	Support the leg just above the ankle joint with the ankle joint in dorsiflexion and the foot in inversion without extension of the great toe. Apply pressure against the medial side, dorsal surface of the foot in the direction of plantar flexion of the ankle joint and eversion of the foot.

Muscle Name	Quadriceps Rectus Femoris
Origin	Straight head from anterior inferior iliac spine. Reflected head from groove above rim of acetabulum.
Insertion	Proximal border of the patella and through patellar ligament.
Function	Extension of the knee joint and flexion of the hip joint.
Recommended sensory placement procedure	

Starting posture	Sitting on a table with the knees in slight flexion and the upper body slightly bend backward.
Electrode size	Maximum size in the direction of the muscle fibres: 10 mm.
Electrode distance	20 mm.
Electrode placement	
- location	The electrodes need to be placed at 50% on the line from the anterior spina iliaca superior to the superior part of the patella
- orientation	In the direction of the line from the anterior spina iliaca superior to the superior part of the patella.
- fixation on the skin	(Double sided) tape / rings or elastic band.
- reference electrode	On / around the ankle or the proc. spin. of C7.
Clinical test	Extend the knee without rotating the thigh while applying pressure against the leg above the ankle in the direction of flexion.

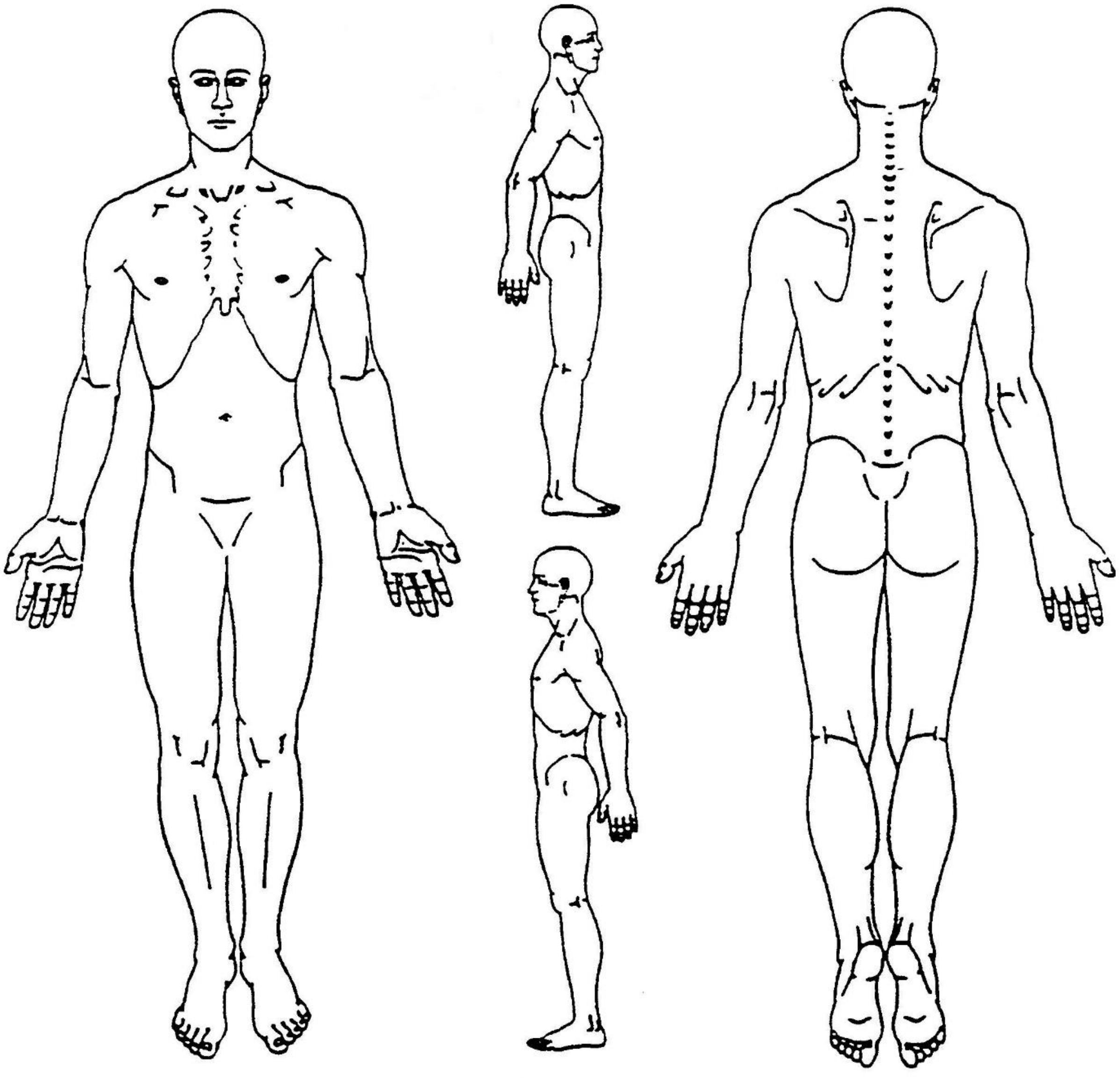
Muscle Name	Quadriceps (vastus medialis)
Origin	Distal half of the intertrochanteric line, medial lip of line aspera, proximal part of medial supracondylar line, tendons of adductor longus and adductor magnus and medial intermuscular septum.
Insertion	Proximal border of the patella and through patellar ligament.
Function	Extension of the knee joint.
Recommended sensory placement procedure	
Starting posture	Sitting on a table with the knees in slight flexion and the upper body slightly bend backward.
Electrode size	Maximum size in the direction of the muscle fibres: 10 mm.
Electrode distance	20 mm.
Electrode placement	
- location	Electrodes need to be placed at 80% on the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament.
- orientation	Almost perpendicular to the line between the anterior spina iliaca superior and the joint space in front of the anterior border of the medial ligament.
- fixation on the skin	(Double sided) tape / rings or elastic band.
- reference electrode	On / around the ankle or the proc. spin. of C7.
Clinical test	Extend the knee without rotating the thigh while applying pressure against the leg above the ankle in the direction of flexion.

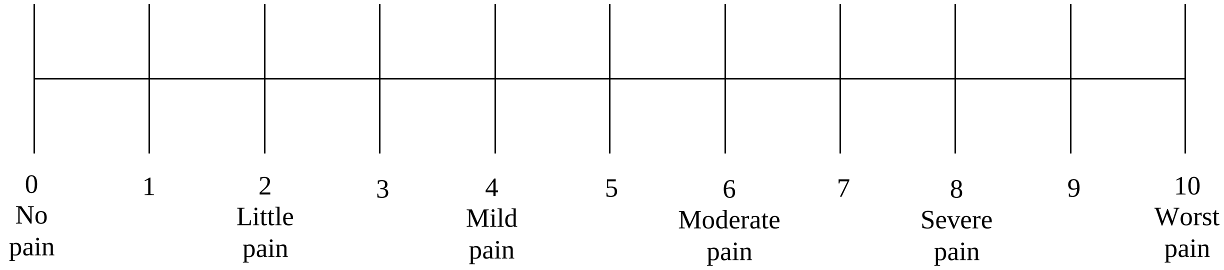
Muscle Name	Quadriceps (vastus lateralis)
Origin	Proximal parts of intertrochanteric line, anterior and inferior borders of greater trochanter, lateral lip of gluteal tuberosity, proximal half of lateral lip of linea aspera, and lateral intermuscular septum.
Insertion	Proximal border of the patella and through patellar ligament.
Function	Extension of the knee joint.
Recommended sensory placement procedure	
Starting posture	Sitting on a table with the knees in slight flexion and the upper body slightly bend backward.
Electrode size	Maximum size in the direction of the muscle fibres: 10 mm.
Electrode distance	20 mm.
Electrode placement	
- location	Electrodes need to be placed at 2/3 on the line from the anterior spina iliaca superior to the lateral side of the patella.
- orientation	In the direction of the muscle fibres
- fixation on the skin	(Double sided) tape / rings or elastic band.
- reference electrode	On / around the ankle or the proc. spin. of C7.
Clinical test	Extend the knee without rotating the thigh while applying pressure against the leg above the ankle in the direction of flexion.

Muscle Name	Biceps femoris
Origin	Long head: distal part of sacrotuberous ligament and posterior part of tuberosity Short head: lateral lip of linea aspera, proximal 2/3 of supracondylar line and lateral intermuscular septum.
Insertion	Lateral side of head of fibula, lateral condyle of tibia, deep fascial on lateral side of leg.
Function	Flexion and lateral rotation of the knee joint. The long head also extends and assists in lateral rotation of the hip joint.
Recommended sensory placement procedure	
Starting posture	Lying on the belly with the face down with the thigh down on the table and the knees flexed (to less than 90 degrees) with the thigh in slight lateral rotation and the leg in slight lateral rotation with respect to the thigh.
Electrode size	Maximum size in the direction of the muscle fibres: 10 mm.
Electrode distance	20 mm.
Electrode placement	
- location	The electrodes need to be placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia.

- orientation	In the direction of the line between the ischial tuberosity and the lateral epicondyle of the tibia.
- fixation on the skin	(Double sided) tape / rings or elastic band.
- reference electrode	On / around the ankle or the proc. spin. of C7.
Clinical test	Press against the leg proximal to the ankle in the direction of knee extension.

9. Body chart for Numerical Pain Scale





10. Borg Scale for Rate of Perceived Exertion

Borg scale: Rate of Perceived Exertion

Choose the number from below that best describes your level of exertion. It should reflect how heavy and strenuous the exercise feels to you, combining all factors of physical stress, effort, and fatigue.

6	
7	Very, very light (rest)
8	
9	Very light (gentle walking)
10	
11	Fairly light
12	
13	Somewhat hard (steady pace)
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	Exhaustion

11. Data collection sheet

Personal details					
Age			years		
Weight			kg		
Height			cm		
Arm length		Left		Right	
Leg length		Left		Right	
Knee extension angle		Left		Right	
Thomas: Rectus femoris		Left		Right	
Thomas: iliotibial band		Left		Right	
Sit and reach			cm		
Lumbar Flexion measure			cm		
Fingertip to floor			cm		
Bicycle components					
Saddle height			mm		
Reach			mm		
Saddle setback			mm		
Drop			mm		
Crank Length			mm		
Saddle length			mm		
On the bike, 6 o'clock position					
Shoulder angle		Left		Right	
Elbow angle		Left		Right	
Hip angle		Left		Right	
Knee angle		Left		Right	
Ankle angle		Left		Right	

$\dot{V}O_2$ max and Peak power output

Raymond Teo

(Assessment form)

essm EXERCISE SCIENCE AND SPORTS MEDICINE	**Date:** ______ - _______ - 2014
Name:	**Date of birth:**
Address: **email:**	**Cell phone:** **Home Phone:**

Physical examination

Height (cm)	**Weight (kg)**

General questionnaire

Sport injuries?	**Yes**	**No**	**Muscle soreness?**	**Yes**	**No**
Slept well?	**Yes**	**No**	**Any coffee the last 3 hours?**	**Yes**	**No**
Using medication?	**Yes**	**No**	**Using performance enhancing supplements?**	**Yes**	**No**

Bike related questionnaire

Same bike	**Yes**	**No**	**Fan 2M from the axle?**	**Yes**	**No**
same outfit	**Yes**	**No**	**Did you change any setting?**	**Yes**	**No**

Results

$\dot{V}O_2$ max: _____ ml/min/kg	**PPO: _____ Watts**
AT: ____ Watts/ ____ bpm	**RER: _____**
Max. heart rate: ____ bpm	**Gear settings: __ x __**

Skinfold Thickness

	1st	2nd	3rd
Biceps			
Triceps			
Subscapular			
Abdomen			
Suprailiac			
Thigh			
Calf			

Comments

Steady-state trial

Raymond Teo
(Assessment form)

	Date: **______ - ______ - 2014**
Name:	**Date of birth:**
Address: **email:**	**Cell phone:** **Home Phone:**

Physical examination

Height (cm)	**Weight (kg)**

General questionnaire

Sport injuries?	**Yes**	**No**	**Muscle soreness?**	**Yes**	**No**
Slept well?	**Yes**	**No**	**Any coffee the last 3 hours?**	**Yes**	**No**
Using medication?	**Yes**	**No**	**Using performance enhancing supplements?**	**Yes**	**No**

Bike related questionnaire

Same bike	**Yes**	**No**	**Fan 2M from the axle?**	**Yes**	**No**
same outfit	**Yes**	**No**	**Did you change any setting?**	**Yes**	**No**

Results

20 minutes: $\dot{V}O_2$ values: RPE: Pain:

40 minutes: $\dot{V}O_2$ values: RPE: Pain:

60 minutes: $\dot{V}O_2$ values: RPE: Pain:

Skinfold Thickness

	1st	2nd	3rd
Biceps			
Triceps			
Subscapular			
Abdomen			
Suprailiac			
Thigh			
Calf			

Comments