Biomechanical analysis of cycling position in elite cyclist

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Abstract

Winning a track sprint cycling race can often come down to a fraction of a second. In 2016 at the Rio Olympic Games, the Australian men's sprint team lost to Great Britain by 0.102 seconds. Therefore, it is essential that cycling conditions have been optimised to enable the cyclist to output maximum pedal force. The position of the cyclist on the bicycle has proven to have the most significant effect on pedal force production.

Several studies have shown that handlebar type, seat height and power can improve output among road cyclists and triathletes. However, each cycling discipline has a specific focus, training goals and thus, specificity between cycling athletes. Consequently, the results from these studies will not necessarily crossover to track sprint cyclists. Further research is required to identify trends in cyclist position on influencing the biomechanics of pedalling, specific to track sprint cyclists.

The primary objective of this study was to determine if changes in joint kinematics and muscle activations could be detected as a result of adjustments to cyclist seat height and handlebar type at both submaximal and maximal power levels. Eight elite track sprint cyclists from Cycling Australia's High Performance Unit were involved in this study. The kinematic and muscle activation patterns were recorded and analysed during sprints for each subject using 3D motion analysis and electromyography (EMG) electrodes.

The kinematic results confirmed that power level had a significant effect on the joint ranges of motion, while there were no significant differences between handlebar type or between seat heights. On the other hand, the EMG data collected was relatively unreliable due to poor skin-electrode contact. Finally, this project has contributed towards developing a 3D motion analysis protocol for assessing kinematics of track sprint cyclists.

Declaration

I certify that this thesis does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any university, and that to the best of my knowledge and belief it does not contain any material previously published or written by another person, except where due reference is made in the text.

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Timothy Andrew Prins

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1 Introduction

Cycling has a broad scope of applications that can be classified as recreation, a means of transport or a competitive sport. Competitive cycling can range from mountain biking and bicycle motocross (BMX) to triathlons, road cycling and track cycling. Each type of competitive cycling differs with training goal, bike configuration and hence, the muscles recruited in cycling. These differences ultimately result in muscle development and methods of cycling specific to the athlete and the sport.

Track sprint cyclists aim to cycle as fast as possible for a short period of time. There are several track sprint events with duration ranging from 1 km time trials to the flying 200 m sprint, where the current world records are 56.303 seconds and 9.347 seconds, respectively. Athletes are expected to race multiple times throughout the stages of a competition. Therefore, it is essential to optimise their performance and output maximum effort each race.

Various studies have been conducted in an attempt to explore and identify factors involved in optimisation of cycling performance. Positional changes have been linked to changes in muscle activation, force application, reduced energy expenditure, power output, joint force and lower limb kinematics. However, previous studies on positional changes have focussed solely on road and endurance cyclists. Due to the high degree of specificity between different types of cycling, the findings from these studies will not necessarily be applicable to track sprint cyclists.

Therefore, research specific to sprint cyclists is required to optimise the athlete's position on the track. Furthermore, this project aims to develop a method of assessing positional changes made to a sprint cyclist to better understand how these changes influence muscle activation and joint kinematics.

Chapter 2 provides a brief overview of the muscles, muscle types and kinematics involved in cycling.

Chapter 3 presents a detailed analysis and review of previous literature that has focused on kinematics, muscle activations and how cyclist position affects various physiological parameters. This literature review provides the basis and reasoning for undertaking this project.

The methods involved in testing are outlined in chapter 4. This chapter primarily includes a brief description of the 3D motion capture and electromyographic (EMG) equipment used, an overview of the experimental protocol and the process taken to obtain and analyse data.

Chapter 5 presents the main findings and results of the study. Chapter 6 discusses the results and also limitations of this study. Comparisons are made with previous research and trends observed between differences in seat height, power output and handle bar type have been made.

Finally, chapter 7 summarises the main findings and provides suggestions for future work in the area.

2 Biomechanics of Cycling

Before getting into a detailed analysis of the biomechanics of cycling it is vital to understand the fundamentals of how cycling occurs. Therefore, this chapter outlines the two main skeletal muscle types in the body, the key muscle groups of the lower limb employed in cycling and the basic biomechanics involved in cycling.

2.1 Major Muscle Groups of Cycling

Motions involved in cycling predominantly occur in the sagittal plane. Therefore, power is generated by flexion and extension movements produced by the flexor and extensor muscles of the lower limb, respectively (Figure 1).

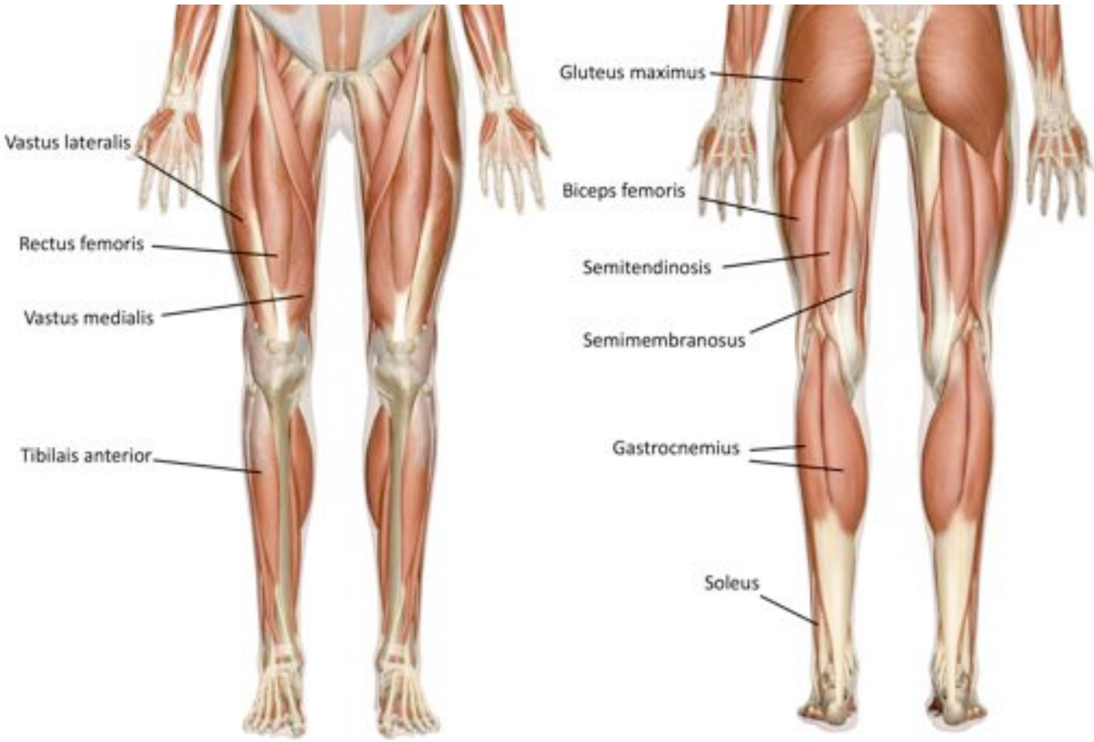

Figure 1 Major superficial muscles of the lower limb (anterior (left) and posterior (right) views). [1]

These muscles can be separated into functional groups based on location. These include the gluteal region, femoral region, and leg (i.e. calf) region. The femoral and the leg regions can be further separated into anterior and posterior groups to differentiate between the major functions of the muscle groups (Table 1).

Table 1 The functions and locations of the major muscles of the lower limb (superficial muscles)

Muscle	**Location**	**Functions**
Gluteus maximus	Gluteal region (superficial)	- Hip extension - Hip lateral rotation - Hip abduction
Biceps femoris	Thigh region (posterior)	- Knee flexion - Hip extension
Semimembranosus	Thigh region (posterior)	- Knee flexion - Hip extension
Semitendinosus	Thigh region (posterior)	- Knee flexion - Hip extension
Rectus femoris	Thigh region (anterior)	- Knee extension
Vastus lateralis	Thigh region (anterior)	- Knee extension
Vastus medialis	Thigh region (anterior)	- Knee extension
Gastrocnemius	Leg region (posterior)	- Plantarflexion - Knee flexion
Soleus	Leg region (posterior)	- Plantarflexion
Tibialis anterior	Leg region (anterior)	- Dorsiflexion - Ankle stability

These muscles play a significant role in cycling as they are the main contributing factor to generate force and propel the bike forward. It is important to understand how these muscles function before being able to properly understand reasons behind the muscle activation patterns in cycling as well as to provide a deeper understanding of why positional changes will affect a muscle's function.

2.2 Muscle Types

Therefore, to understand cycling at a deeper level it is vital to understand the way in which athletes utilize their muscles to produce forces that move the bicycle forward. The musculoskeletal system is composed of many different muscles acting on the body to elicit movement. These muscles involved in movement are known as skeletal muscles. Skeletal muscles are composed of type-I and type-II muscle fibres (MF). The presence of each muscle fibre type in a muscle largely depends on the training method so that the body is able to adapt and perform optimally under certain conditions. Type-I MF are commonly known as 'slow-twitch' fibres due to their low force production and slow contraction time. This muscle type has a high density of mitochondria that makes these fibres suited for aerobic activities and resistance to fatigue [2]. On the other hand, type-II MF are commonly referred to as 'fast twitch' due to the fibre's ability to generate a high force with a very fast contraction time. These muscles contain more adenosine triphosphate (ATP) and creatine, which is consumed during exercise. This means that although the muscle can produce high forces they can only sustain this for a very short period of time (< 1 minute) [2].

2.3 Kinematics

Pedalling is a cyclic movement that involves flexion and extension of the lower limb. As such, the crank kinematics of pedalling can be separated into four main sections: top dead centre (TDC), propulsive phase, bottom dead centre (BDC) and pulling phase (Figure 2). At the TDC the hip, knee and ankle joints are all in maximal flexion. Following TDC, the crank cycle enters the propulsive phase. In the propulsive phase, the leg is extended until the pedal reaches BDC where the leg is in maximal extension. After the pedal reaches BDC, the leg then begins to flex again toward TDC. As the pedal moves in a circular motion, the leg cannot extend and flex in a straight line. Therefore, the activations of the extensors and flexors of the leg happen at different times [3].

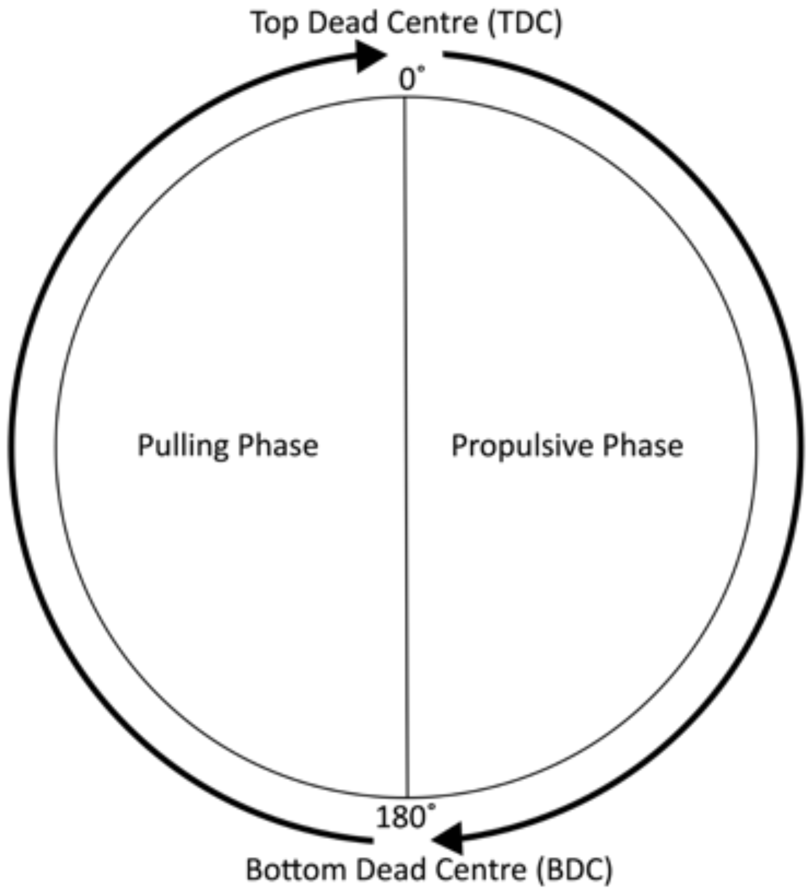

Figure 2 Crank cycle and main phases of crank cycle during motion analysis

The main purpose of using crank kinematics is to map major events to a relative position within the crank cycle, similar to the various phases of human gait used to assess bipedal locomotion. The crank cycle can be used to map events such as muscle activations and joint kinematics.

The focus of kinematics in the lower limb is mainly to assess joint angles and how they move in 3D space. The main joint angles of the lower limb are hip angle, knee angle and ankle angle (Figure 3). The hip angle was calculated by using angle between the axis parallel to the pelvic transverse axis passing through the hip joint centre and the sagittal thigh projection. The knee angle was defined as the angle between the femur and forelimb of the lower leg. Ankle angle was calculated from the tibia and the line running through the ankle to the second metatarsal.

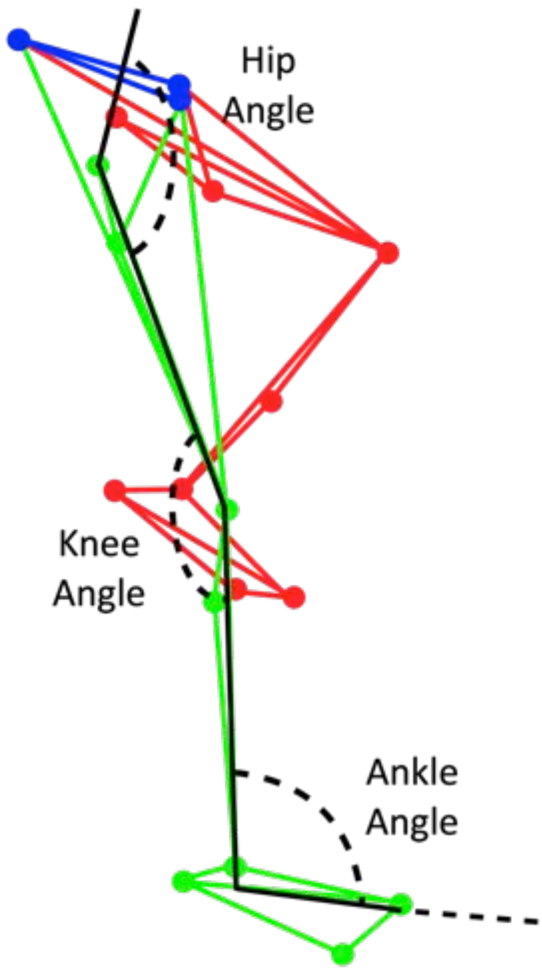

Figure 3 Visual representation of the joint angles present in the sagittal plane of the lower limb. Red lines represent the left leg and green represents the right leg. Joint angles are defined using the right leg in this diagram.

3 Literature Review

This literature review presents and analyses previous research comparing muscle and force generation between cyclist type and level, the kinematic analysis of cycling, muscle activation patterns and the effect of seat height on kinematics and muscle activation.

3.1 Cyclist Type/ Skill level

Cyclist type and skill level plays a significant role in an individual's ability to recruit muscles of the leg for efficient pedal forces during the crank cycle. As previously discussed, training type and load causes and variation in the muscular adaptation of athletes. In spite of this, previous studies have compared the forces acting on the pedal in both trained and untrained cyclists [4] and muscular activation patterns [5,6]. Consequently, this results in a lack of acknowledgement of the discrepancies between athlete type and level.

Two studies by Chapman et al [5,6] showed that there is a significant difference in the muscular recruitment of an untrained cyclist and a trained cyclist. The most notable difference was the ability to recruit the biceps femoris and the tibialis anterior muscles. This is due to neuromuscular conditioning, or the fact that elite cyclists repeat this motion many times every day, while untrained cyclists are not conditioned to these specific exercises [5–7]. Studies that have included untrained or amateur cyclists may have consequently produced inaccurate and unreliable results. Chapman et al also found that although someone is trained or considered competitive, there may be discrepancies in muscle activation and force production due to training type. Both studies conducted by Chapman et al [5,6] found that untrained subjects and triathletes showed different muscle recruitment than that of trained cyclists [5]. Typically, untrained subject muscle activity lacked uniformity throughout the crank cycle. Instead, the activation patterns of these muscles of the leg were sporadic. This differed significantly to trained athletes where there was a distinct muscle activation pattern exhibited for each crank cycle [6]. As expected, there is a clear difference between untrained and trained cyclists. However, significant differences were also identified between cyclists trained in different types of cycling. This difference between specificity of cyclist type therefore contributes to the fact that some studies may not be relevant to all athlete groups. In competitive cycling, there are multiple disciplines that exist and within these disciplines there is a difference in the goal of training.

Endurance cycling has the training goal of maximising efficiency and reducing fatigue. Conversely, the primary goal of training for track sprint cycling is to create strong muscles that can produce the most force and power to allow the bike to go as fast as possible for a short period of time. Although both types of athletes are elite in their specific areas of cycling, they should be considered as separate types of athletes as muscle activation pattern differs significantly. Therefore, when looking at papers regarding cycling there is a need to look at the demographic of subjects tested, rather than just using the general term, ‘elite athletes’. The reason for this is training specificity, which is a very important aspect to explore. Studies which use elite athletes tend to only mention their elite status rather than the type of cycling they participate in. The problem with this is that to apply findings to a specific group of cycling they need to be directly representing that discipline, therefore the results of these studies are difficult to apply to the area of track sprint cycling.

In previous studies, detailed information relating to the type of athlete recruited to a cycling study is lacking, meaning there is potential for error when basing the reliability of a study on past studies of a similar nature with the profile of participants is not known. The outcomes of these studies highlight why this study required the use of elite level athletes.

3.2 Kinematics

Motion analysis involves the detection of the position of joints and segments, which enables users to assess the relevant translations and rotations [3]. Motion analysis alone is a powerful tool in assessing movement. However, pairing motion analysis with pedal forces further improves the power and usability of the data in understanding how the body systems interacts with the bike.

For motion capture, markers are placed on a subject and they are tracked as they perform a given task. Tracking these markers throughout the given task enables the user to assess changes in segments and joint motions [3]. There are two methods of motion capture including 2D and 3D motion analysis. Fundamentally, 2D motion analysis utilises a single camera to capture motions in one plane. This can be a useful tool when there is only a need for a single plane to be analysed. However, 2D motion analysis has the issue of being more inaccurate than 3D motion analysis, this is due to a lack of additional cameras to verify the marker position against. On the other hand, 3D motion analysis uses two or more cameras to track a given coordinate by using mathematical algorithms [3]. As such, 3D motion analysis is better suited to analysing dynamic movements occurring in multiple planes.

The majority of studies that have been looked at use 2D motion capture to analyse the motions of the lower limb in the sagittal plane [8]. In cycling, the most important joint angles are those of the hip, knee and ankle joints. These joints have their largest ranges of motion in the sagittal plane. Therefore, many studies have focussed solely on this single plane of movement rather than conducting a full three-dimensional analysis. Many studies have also used 2D motion capture due to the additional complexity involved in implementing multiple cameras in three-dimensional motion analysis. However, one of the most significant drawbacks of two-dimensional motion capture is the high risk of marker loss due to obstructions blocking the camera's field of view. Therefore, the only markers that have a high reliability are the markers that are positioned laterally, if the focus of the study requires additional analysis of these markers then there is an increase error present in the results. Three-dimensional motion capture benefits from greater reliability in the position of the markers as each marker is only visible if a minimum of two or more cameras are detecting it.

There are multiple ways in which kinematics are used to analyse motions involved in cycling. These include the analysis of the crank kinematics, upper body kinematics and lower body kinematics. Lower body kinematics has been the primary focus of most studies as the muscles of the lower limb contribute significantly to the power transfer from the rider to the pedals. Utilising cycling ergometers and motion capture systems allows for researchers to track the motions of cycling to calculate joint ranges and motions. Similar to crank kinematics, the analysis of lower limb motion is generally kept to the two-dimensional sagittal plane. The overall range of the lower limbs have been found to be approximately 45˚ in the hip, 75˚ in the knee and 20˚ in the ankle [3].

Multiple factors have been explored in the literature regarding joint kinematics. Changes in the seat height have been looked at in terms of lower limb kinematics. These studies have shown that as seat height is increased, there is an increased degree of knee flexion and plantarflexion [9]. Workload increases were also looked at relative to lower limb kinematics, and an increased work load was shown to affect the ankle angle [10] and the knee angle [11]. Increasing the cadence has been found to increase the ankle stiffness [12,13].

Understanding joint kinematics and how different variables affect the range of motion and operating range of the lower limb can be valuable in making observations about how the muscles in the leg will respond to these changes, however without quantifying these muscular changes then this can only be assumptions. Therefore, techniques to assess muscle activity to pair it with motion analysis is essential.

3.3 Muscle Activation

As the lower limb is the main attachment that influences pedal force, it is important to look at how the muscles act and which muscles are the most important in this power transfer. In competitive sprint cycling, the main goal is to go as fast as possible for the duration of the race, meaning it is important to determine the most appropriate muscles and training programs for them to be as strong as possible. Therefore, many studies have explored the muscles of the lower limb and what factors influence their recruitment to further understand the biomechanics of cycling. The main factors that are looked at regarding the muscles of the lower limb are the effect of: cadence [12,14], workload level [15,16], fatigue [15,17], and cyclist riding position [18–20]. Of these factors the most important ones related to this thesis are; cyclist riding position and workload level.

In the lower limb, there are many muscles that contribute to the power output in cycling. Measuring muscle activation in deep muscles of the lower limb has proven challenging. Monitoring deep muscles is difficult to do non-invasively, where the majority of studies have used skin surface electrodes [15,16,18,21–25]. Therefore, the large superficial muscles associated with flexion and extension of the leg have been the primary muscles analysed in clinical research. Table 3 outlines muscles that have been evaluated in several lower limb muscle activation studies, including gluteus maximus (GMax), vastus lateralis (VL), vastus medialis (VM), rectus femoris (RF), semi-tendinosus (ST), biceps femoris (BF), medial gastrocnemius (mGas), tibialis anterior (TA), and soleus (Sol). These muscles are the most commonly evaluated as well as the most accessible to place electrodes on, therefore similar to past literature this study will also be focusing on the activity of these muscles.

Generally, the lower limb muscles active during cycling are specific to the region of the crank cycle. As shown in Table 2, the flexors and extensors of the leg show greater activity during certain phases of the crank cycle. Due to the circular movement of the crank, not all of the muscles in the extensor and flexor groups are active at the same time.

Table 2 Lower limb muscle activations in sprint cyclists during submaximal cycling (Adapted from Dorel et al. 2012)[16]

Muscle	***Range***
RF	270°–90°
VL	340°–120°
VM	340°–120°
GMax	350°–135°
ST	10°–210°
BF	0°–210°
mGas	45°–190°
TA	250°–20°
Sol	25°–135°

Table 3 Studies focusing on lower limb muscle activity during cycling. Table list the major muscles of the lower limb and highlights the participant type used in each study to show that there is a large variation in demographic used in literature. GMax=gluteus maximus, PT=pectineus, IL=iliacus, VL=vastus lateralis, RF=rectus femoris, BF=biceps femoris, SM=semi-membranosus, ST=semi-tendinosis, SA=, Gas=, Sol=, TA=tibialis anterior

Paper (Author, year)	Purpose of Study	Participants	Muscles evaluated												
			GMax	PT	IL	VL	VM	RF	BF	SM	ST	SA	Gas	Sol	TA
Yoshihuku & Herzog 1996 [26]	Modelling to determine optimal bike-rider system	Computer models	•	•	•	•	•	•	•	•	•	•			
Raasch et al. 1997 [27]	Computer modelling to determine the muscle coordination at maximal-speed pedalling	9 Normal adults	•	•	•	•	•	•	•		•		•	•	•
Hautier et al 2000 [21]	Exploring the influence of fatigue on EMG and co-contraction in cycling	10 Recreational cyclists (trained for 16 weeks prior to testing)	•			•		•	•				•		
Neptune & Herzog 2000 [22]	Adaptation of muscle coordination to altered tasks during steady-state cycling	8 Competitive cyclists (discipline unspecified)	•				•	•	•				•	•	•
Prilutsky & Gregor 2000 [23]	Prediction of muscle patterns during cycling using computerized models and optimization criteria	5 Recreational cyclists	•				•	•		•			•	•	•
Baum & Li 2003 [28]	Muscle activation patterns in response to cadence and load	16 Recreational cyclists	•			•		•	•				•	•	•
Savelberg et al. 2003 [18]	Focusing on the effect of body configuration on muscle recruitment and movement patterns	8 Recreational cyclists	•				•	•	•		•		•	•	•
Cannon et al. 2007 [24]	Effect of the pedalling technique on the muscle activity and efficiency	11 Trained road cyclists				•			•				•		•
Blake et al. 2011 [25]	Evaluating the muscle coordination patterns to determine optimal VO2 levels	9 Experienced competitive male cyclists	•			•	•	•	•		•		•	•	•
Dorel et al. 2012 [16]	Determine muscle coordination during all-out sprint cycling	15 Elite sprint cyclists	•			•	•	•	•		•		•	•	•
O'Bryan et al 2014 [15]	Determine the changes in muscle coordination and power during sprint cycling	10 Active males	•			•	•	•	•		•		•		

3.4 Cyclist Position

In cycling, the main points of contact between the bicycle and the cyclist are the handlebars, the saddle and the pedals. At these three points, there is a transfer of force from the rider to the bike. The main point to consider is how changing the orientation of these three points can affect the posture of the cyclist, and how the positional changes affect the rider's ability to produce forces on the pedals. The ultimate aim of this work is to make the elite cyclists go faster. Even making small improvements can make a difference. Before we can do this, we need to get a fundamental understanding of how variation of rider position can influence the muscle activations.

Potential parameters that can be changed on a bicycle include the vertical and horizontal handlebar position, seat angle, seat setback, seat height and crank length (Figure 4) [29]. These parameters influence the geometry of the muscles in the upper and lower limb. Varying the position of the rider may result in different muscle recruitment patterns. Consequently, poor positioning of the seat may detrimentally impact pedal force as optimal muscle force production occurs at a certain range of the muscle length (Figure 4) [30]. In cycling, the range of joint angles dictates this range of muscle length and therefore positioning is a vital factor in the performance of a cyclist. Therefore, optimal joint angles would result in optimal forces. Since these changes occur when the cyclist position is changed, the upper and lower body positions have been regarded as the most important parameters in cycling [18,9,31].

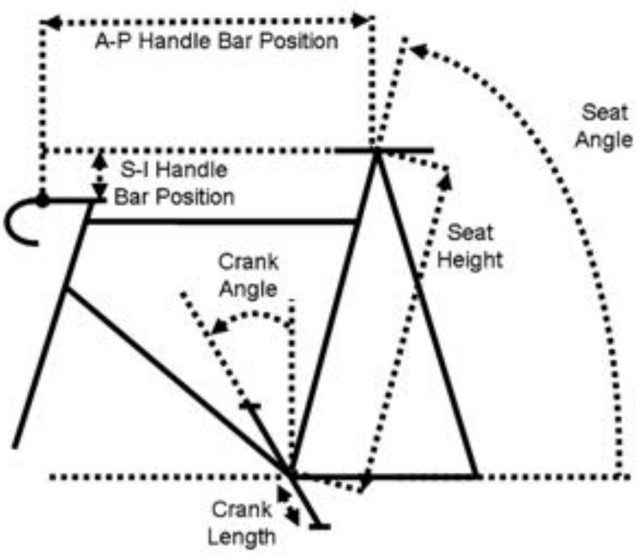

Figure 4 Definitions of bicycle parameters that can be changed [29]

3.4.1 Handlebar Position

Both changes in the horizontal and vertical handlebar positions affect the angle of the trunk. Changing the handlebar position is more commonly done in the vertical direction, however changes in the stem length can also cause changes in the horizontal direction. The influence of changes in the horizontal direction is that the hands will be moved further away from the body, causing a decrease in the hip angle as the torso moves downward. This adjustment to hip angle causes a change in the orientation of the hip flexors and extensors.

The vertical adjustment of the handlebars also causes an increase or decrease in the hip angle, which in turn affects the muscles of the hip. Savelberg et al. [18] found that changes in the trunk angle of 20˚ forward or backward had an influence on the muscle activations and kinematics of the entire lower limb. These changes were shown to be more prominent in the angle of the ankle and hip joints as well as the orientation of the thigh [18].

3.4.2 Seat Height

Changes that can be made to the seat are variation of seat angle, seat setback and seat height. Most studies have explored changing the seat height as it is the easiest and most commonly changed parameter. Changing the seat height has been considered one of the most influential aspects of positioning in cycling due to the major effect it has on the position of the cyclist. Studies have shown that seat height can have effects on power output [26,32–34], joint kinematics [34,35], and muscular activity [36,37].

3.4.2.1 Methods for configuring seat height

There are two aspects that need to be addressed when it comes to cycling seat height – measurement of the seat height with respect to the bicycle geometry and positioning the bike geometry relative to the anthropometric data. There are two methods used to measure the seat height on the bicycle frame itself including the Hamley and Thomas method and the LemMond method. The Hamley and Thomas method is where the crank is aligned with the seat tube and the distance from the pedal to the top of the seat is the measurement of seat height. On the other hand, the LeMond method uses the centre of the crank and the seat to measure the seat height. These two methods have previously been used in various studies. However, neither approach has been classified as the 'standard' method for measuring seat height.

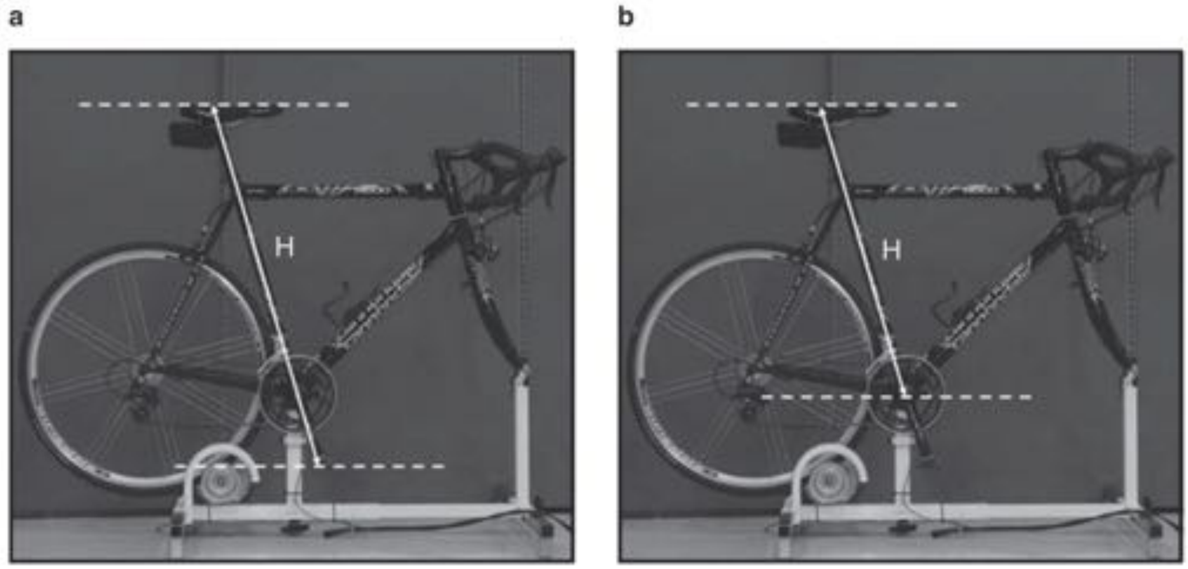

Figure 5 Different ways to measure seat height (a) Hamley and Thomas method of measuring seat height (b) LeMond method of measuring seat height [9]

The second aspect required to determine seat height involves positioning the bike geometry relative to the anthropometric data. Two types of anthropometric data can be used to configure seat height, including the riders leg length or knee flexion. Leg length can be used to determine the relative seat height in relation to one of three leg length measurements. Leg length measurements used for configuring seat height have included the ischial tuberosity height, greater trochanteric height or and inseam length. Using these methods, the measurement of seat height can be made as a percentage of the leg length to keep it constant between different individuals. However, the implementation of the leg length measurement in configuring seat height has varied significantly between studies.

The first of these methods is the Hamley and Thomas method. This method uses the inseam length of the individual as an indicator of how to determine the seat height. In studies it was found that 109% of the inseam leg length was the optimal seat height and therefore this is the value used for this method [9]. The next method uses the trochanteric length. This method measures from the greater trochanter to the floor. Studies have shown that 100% of the greater trochanter length were optimal [38,39]. However, both studies focused on the seat height in relation to optimum oxygen consumption, therefore this value may not be optimal for power output. Length from the ischial tuberosity to the floor is also used. Studies have found that a setting of 113% of ischial tuberosity is the optimal height.

The LeMond method is another method used that was developed by an elite cyclist, Greg LeMond. This method is based purely on empirical data that LeMond gathered during his career as a professional cyclist, therefore, there is little scientific evidence to support it [9]. The LeMond method uses 88.3% of the inseam length as the seat height set from the seat to the bottom bracket of the bicycle. This poses a problem in that this method doesn't consider the crank length and therefore results in inconsistencies in joint kinematics as a result.

The heel method is the most commonly used method in cycling due to its simple nature [9]. In this method, the cyclist is seated and the saddle height is measured when the leg is fully extended with the heel placed on the pedal with the crank in line with the seat tube.

In addition to the use of a percentage of leg length other studies have used methods that are based off the knee angle. In all studies that use this method the knee angle was measured at BDC. Holmes et al. proposed a method of measuring seat height which was based off the angle of knee flexion when the pedal is at BDC and the cyclist is seated on the bike [40]. This method was based off knee injuries and seating methods proposed were designed to lessen the overall strain on the knee that potentially may exacerbate further injury. These ranges were from 25˚ to 30˚ knee flexion depending on the knee injury. Howard et al. (year) used a similar method modality to the Holmes method. The author proposed that the optimal knee angle be set to 30˚ when pedal is at BDC.

The second method uses knee flexion to determine the seat height. However, knee angle methods are not reliable because knee flexion can be altered by a change in ankle angle. For this method to be more reliable, the ankle angle should be fixed in a set position to reduce this inconsistency.

There are many methods of measuring seat height currently in use, however these methods all focused on different optimisation parameters. Similarly, these methods differ in their initial measuring as well. The measurement of knee angle may be useful due to discrepancies between the ratio of shank to thigh not being constant in all subjects. However, there is still the limitation that the ankle angle is not in a fixed position during measurement. In addition, using a percentage of leg length does not always use the same leg length parameter and therefore makes it difficult to compare studies in this area.

3.4.2.2 Effect of Seat Height on Cycling

Since changing the seat height affects the joint kinematics of the lower limb, a flow on effect is that this causes there to be different muscle lengths in the muscle. This results in a change in the power output as well as how the muscle forces are being transferred to the pedals. As there are changes in how the muscles of the lower limb are functioning, this has been found to change the oxygen uptake of the cyclist at varying seat heights.

Vrints et al. [41] conducted a study focusing on the effect of seat height on the maximal power output and the moment generating capacity in the lower limb muscles. The seat heights measured in this study were based on the inseam leg length and six different seat heights were evaluated. Of six seat heights evaluated, the optimal seat height was found to be 109% of the inseam height. This value supports the study by Hamley in which 109% inseam length was optimal [9].

Nordeen-Snyder [39] found that 100% trochanteric height was the optimal seat height. This study focussed on oxygen consumption and lower limb kinematics during cycling. The lower and higher seat heights were shown to have a less efficient oxygen consumption. The kinematics of the lower limb also showed greatest variation in knee angle, while hip and ankle angle were not significantly affected by seat height.

Rankin and Neptune [32] conducted a simulation study on the effect of seat height in cycling. This study focused on determining which seat height produced the greatest power. In this study, they found that 102% of the trochanteric height was the optimal seat height to produce the greatest power. This optimal seat height was similar to the studies by Price and Nordeen-Snyder, which found that the optimal seat height was 100% of the greater trochanteric height. However, these studies looked at the seat height in relation to the oxygen uptake rather than power output.

Peveler [20,42] has conducted multiple studies around the effect of seat height on cycling. Peveler's most recent study focused on seat height in relation to anaerobic power production. This paper compared multiple seat heights against the proposed optimal seat height of 109% inseam length. The knee angle method was used to measure seat height. This study found that knee flexion angle of 25˚ at the bottom dead centre had a lower VO_2 value than 35˚ knee flexion. In addition, 25˚ knee flexion was also found to have the greatest peak power and mean power. Therefore, Peveler determined that 25˚ knee flexion was the optimal choice of seat height for anaerobic power output. This study does not specify what seat height was in relation to any anthropometric value other than knee angle.

Bini et al. [43] looked at the seat height in relation to pedal force effectiveness. This study used four different seat heights, firstly the preferred seat height was chosen and three percent of the preferred seat height was added and subtracted from this height to assess a high and low seat height. The optimal seat height of 25˚ knee flexion as defined in the literature, was also tested. Lower seat heights showed a greater resultant force but a lower effective force. Conversely, 103% preferred seat height showed the greatest effective force but not the greatest resultant force. Although there were changes in the resultant force and effective forces between the seat heights, Bini concluded that changes in seat height, in this range, do not produce a significant difference in effective forces.

3.5 Limitations of Past Literature

There are several limitations in the research regarding seat height and its effect on cycling. Therefore, it is hard to qualify the determination of optimal seat height based on current literature.

Previous studies have all used different methods to measure seat height, making it difficult to compare findings between studies. The methods of configuring seat height based on knee angle provided limited insight as to the angle of the other joints in the lower limb and as such are hard to replicate their results.

In addition, sample size and demographic changed significantly between studies. There have been clear findings demonstrating a clear difference in the muscle recruitment of untrained and trained cyclists [5,6,44]. Therefore, the use of untrained cyclists in the literature is unreliable and should not be compared to studies focused on elite athletes. In addition to untrained versus trained cyclists, there is also the need to address the difference between endurance, triathletes and sprint cyclists.

Studies have shown that in maximal cycling there is an increase in the activity of the extensors [45], which supports the hypothesis that there will be varying performance in sprint cyclists as opposed to endurance cyclists and triathletes. Therefore, a major limitation of past literature is the inability to apply findings to all demographics of cycling.

Adjustment of seat height can lead to multiple outcomes as explored in this literature review, one limitation of past literature is that predominantly one variable was optimised in relation to seat height. Multivariable optimisation is an area of positional analysis that is lacking in current literature and requires more research. This study aims to improve on past research firstly by exploring the influence of seat height on both kinematics and muscle activity.

This study aims to improve on past research by applying analysis of seat height directly to sprint cyclists as well as having the most elite sprint cyclists involved as participants. In addition to this, multiple variables regarding cyclist performance will be analysed to address how each of these factors has an influence on cyclist biomechanics.

There are many limitations present within current literature and more research need to be conducted to assess how variables can influence biomechanics. This study aims to address the lack of past literature regarding sprint cyclist as a cohort. As a result, this study will allow for data to be directly applicable to a specific discipline of cycling. The use of 3D motion analysis and EMG electrodes to assess changes in biomechanics that occur due to positional changes adds to the depth of analysis when determining the affects.

4 Project Aims

4.1 Project Aims

The primary aim of this project is to be able to determine the changes that occur because of adjustment in cyclist position. These changes will be explored over multiple workloads to determine if position has a varying affect relative to changes in power output.

To find these changes, there needs to be a method of testing established that can obtain reliable and consistent data. Therefore, an aim of this project is to firstly establish a protocol that is easily replicated and can be consistently repeated across trials.

In addition, this project aims to explore the effect of position on a cohort that is uncommon in literature. This is a major benefit of the research being conducted as characterising biomechanics in elite cyclists is extremely valuable.

Finally, this project aims to validate the collected data, through statistical analysis of the repeatability and determine if any significant changes occur in the kinematics and muscle activity due to positional changes.

4.2 Hypotheses

Seat height is hypothesised to cause an increase in the joint angles of the athletes. From this there is expected to be a variation in the muscle activity as a result of this change in joint angle, due to muscles operating differently with a change in muscle length as a result of variation in joint angles.

This study aims to explore the differences in kinematics between various cycling positions and workloads, the expected outcome of this study is to be able to determine if it is possible to find measurable differences between these variations in positions.

Looking at the outcomes of past literature it can be hypothesized that there should be certain outcomes exhibited by the results of this study. There has been no past research found that looks at the influence of handlebar types on biomechanics. However, by visual inspection of the cyclist position when using these handlebars, it is hypothesised that there will be a decrease in hip angle when using pursuit handlebars as the position of the cyclist is further forward over the head tube.

In addition, it is hypothesised that an increase in power level will firstly cause increase in the amplitude of the muscle activations. However, research has shown that as power increases there is also an earlier muscle onset exhibited by all muscles of the lower limb [16]. Therefore, when analysing the muscle activation patterns, it is expected that when increasing the power level in this study there should be an increase in muscle onset.

5 Materials and Methods

5.1 Participants

Eight healthy participants (5 male, 3 female) aged 23.5 (± 4) years, with 7.5 (± 2.5) years of experience in cycling at an elite competitive level participated in the study. The inclusion criteria for this study was that the subjects needed to be at a competitive level in track sprint cycling. As such, the demographic evaluated were all elite Olympic level sprint cyclists from Cycling Australia's High Performance Unit (HPU). Past studies [5–7] have found that the effect of athlete specificity has an influence on the muscle activations and force application. Therefore, the inclusion criterion was of the utmost importance as one of the main objectives of the study was to directly apply the results to track sprint cycling. In compliance with the South Australia Human Research Ethics Committee, participants gave their informed consent prior to participation in the experiment (Appendix G: Signed Ethics Approval Form).

5.2 Motion Capture Equipment

The Rehabilitation and Motion Analysis Laboratory at Flinders University was used in this study to facilitate the experiments. The laboratory contains a motion capture system, a wireless EMG acquisition system, and a cycling ergometer modified to use with single speed track bikes.

The motion capture system consists of 10 Vicon Bonita B10 cameras [46]. The Bonita B10 camera series has a sampling frequency of 250fps and a resolution of 1 megapixel. As such, the data acquired from this system will benefit from both a high rate of sampling and high precision to allow for assessing motion at every stage of the crank cycle.

The way the motion capture cameras work is by emitting infrared light onto motion capture markers, which are coated in a retroreflective material that reflects the light back to the camera, allowing multiple cameras to pick up this reflection and determine the position of the marker in 3D space.

5.2.1 Marker Set

To determine the joint angles and position of the body in 3D space, the motion capture marker set that was used needed to be chosen based off these desired outputs. As such a modified plug-in-gait marker set was used (Figure 6). This marker set was modified based on pilot testing that was conducted prior to testing, which will be outlined later in this thesis.

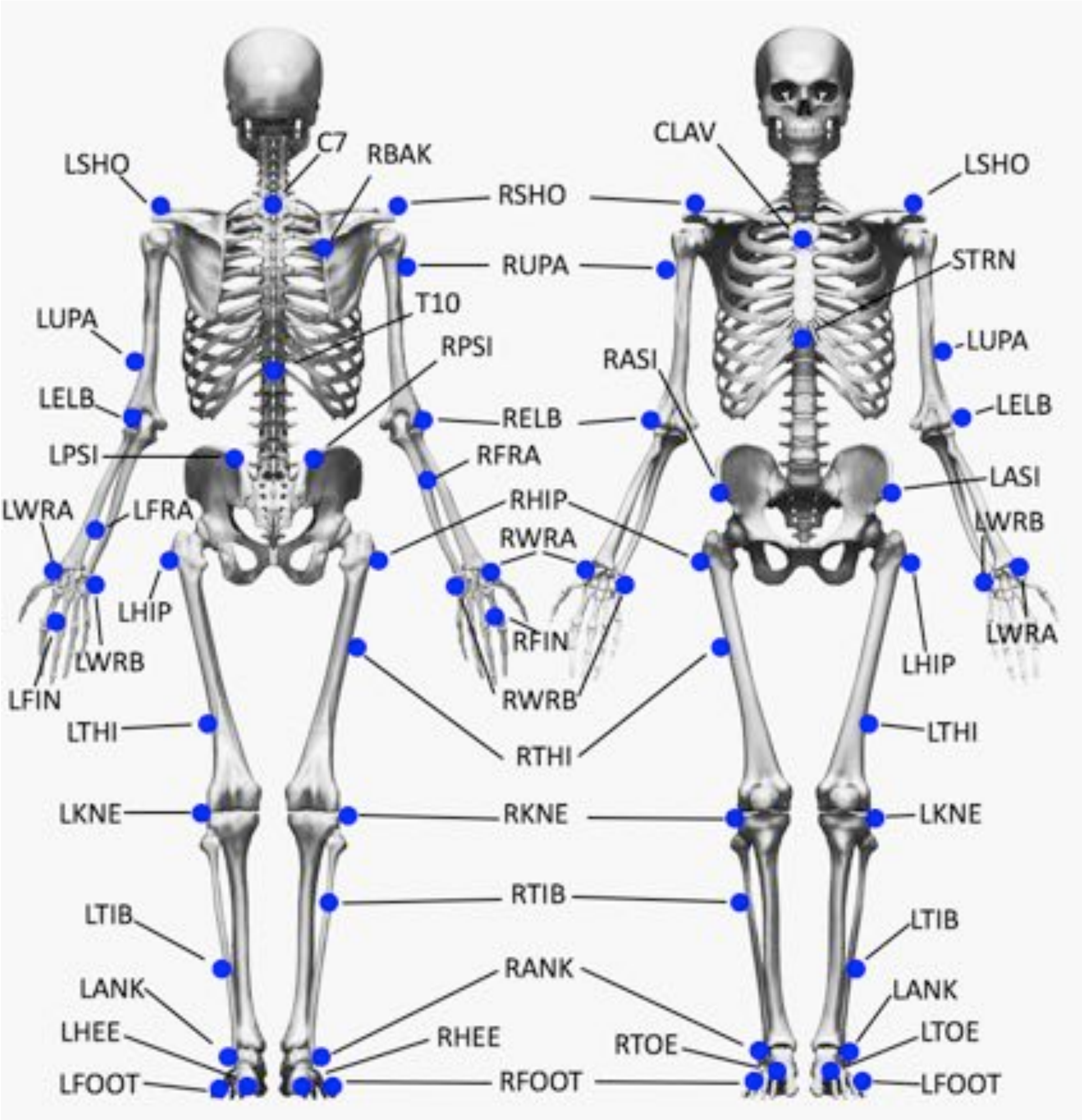

Figure 6 Modified plug-in-gait marker set. Blue dot are locations of the retroreflective motion capture markers in their location relative to their respective bone landmark

All markers shown in this marker set were used for data capture. However, only the lower limb markers were used for data analysis. The markers were placed relative to the bony landmark to ensure repeatability between subjects and days of testing. The placement of these markers as described on the VICON website [47], a detailed description of the marker placement is located in Appendix D: Description of Modified Plug-In-Gait Marker Set. The reason this marker set was used was because it could produce the hip angle, knee angle and the ankle angle, which were the desired kinematic outputs of this study.

5.2.2 Delsys Wireless EMG System

The EMG system consists of 16 wireless Delsys EMG electrodes (*Figure*). The operating range of these electrodes is 40m and have an extremely small delay in their signal acquisition. Only 9 of these electrodes were used as only the major muscles of the lower limb were being explored in this study.

Figure 7 Example of a Delsys wireless EMG electrod. Arrow on the electrode is to orientate the device with the direction of the muscle fibres.

To obtain an accurate representation of how the athletes' muscles function while cycling, the use of an ergometer was used to simulate the athlete riding their own bike, which they were to bring to each trial. An SRM power meter was used as a feedback method for the athlete to monitor their cadence and power output during testing. The SRM crank power meter samples at a rate of 4Hz, which is adequate for visual feedback. However, to get an accurate representation of the entire crank cycle, 4Hz is an inadequate sampling frequency.

5.3 Pilot Testing

Pilot testing was conducted to determine the optimal camera position and the motion capture marker set that should be used for testing. The first round of pilot testing was conducted to determine the motion capture marker set that will be used as well as to determine any errors in the kinematic capture process because of camera position. The importance of this is that if markers are lost during data capture, then the results become less reliable.

The first round of pilot testing was done only using the kinematic aspect of the analysis. The reason for this was to obtain an understanding of potential marker loss and determine the optimal camera configuration. The initial camera layout (Figure 8) consisted of 8 of the motion capture cameras attached to various points on the ceiling and two cameras located in the middle of the room placed on tripods to allow for chest and the anterior pelvic markers to be picked up by the system when the participant was leaning over.

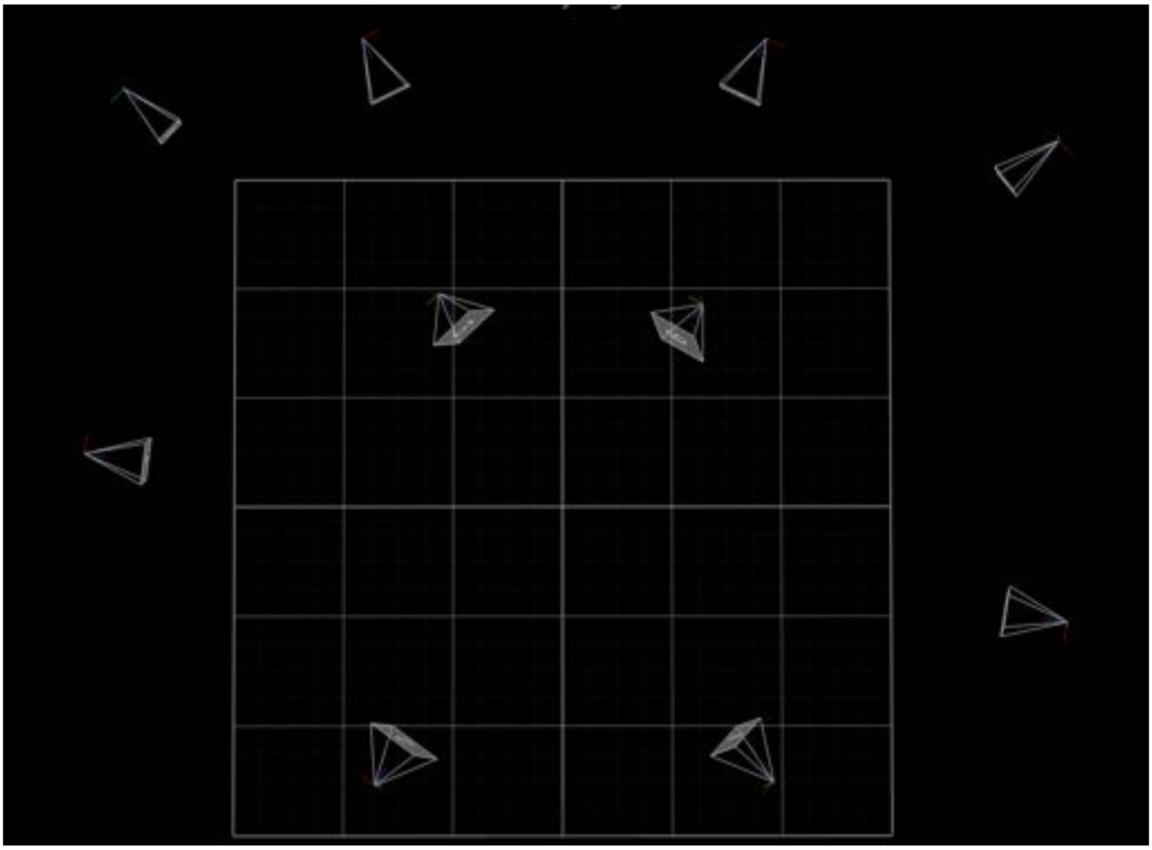

Figure 8 Pilot Testing Motion Capture Camera Layout

In this session, the participant had the full body motion capture marker set placed on them (Figure 9). The limitations of this marker set are that it does not track the pedal position, which is a vital aspect of the analysis of muscle activity. Without this marker, determining events within the crank cycle is not possible.

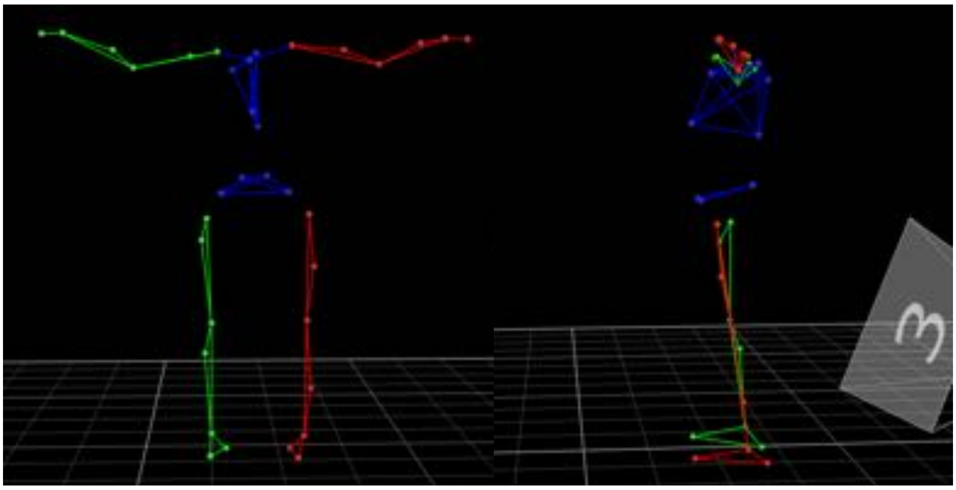

Figure 9 Marker set used in first round of pilot testing. Left side of image shows the anterior view of the T-pose, right side of image shows the left sagittal view of the T-pose.

The protocol for this round of pilot testing was the participant rode the ergometer at a comfortable workload for 10 seconds. The purpose of this was to determine if there was any significant marker loss at different positions in the crank cycle and if the current camera position needed any modifications to ensure minimal marker loss.

The results of this round of pilot testing showed that the floor mounted cameras needed to be moved more laterally around the participant to improve the visibility of both the sternum marker and the anterior sacroiliac marker (Figure 10).

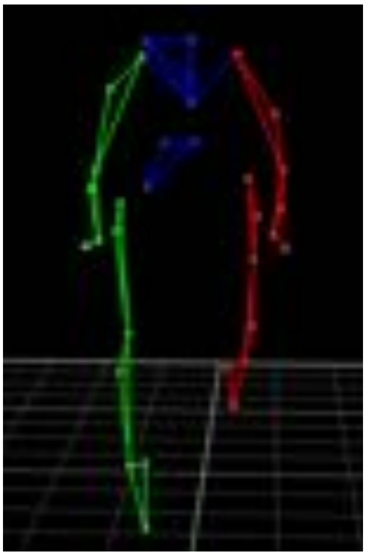

Figure 10 Example of marker loss in pilot testing. Showing that on the left ASIS and sternum marker are missing from the capture. (frontal view)

Secondary pilot testing was conducted to verify if the changes to the camera configuration would minimise marker loss. To assess the ability of the configuration to accurately pick up all markers, the marker set was also changed slightly (Figure 11). This marker set was determined to be the most optimal for use in this study, this modified plug-in-gait model is outlined in greater detail in the previous section of this thesis and Appendix D: Description of Modified Plug-In-Gait Marker Set.

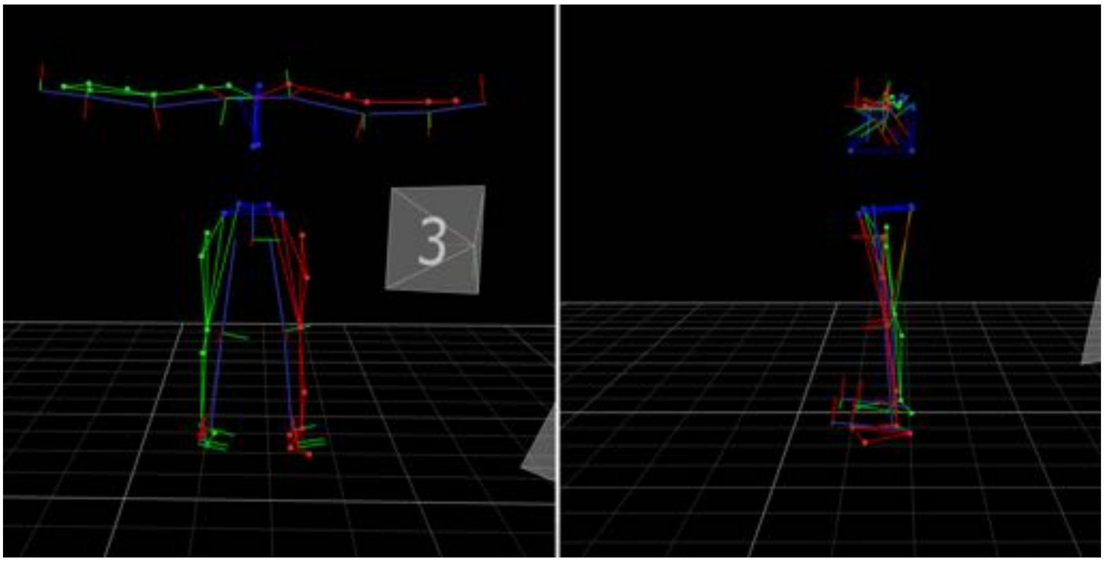

Figure 11 Secondary pilot testing marker set. Left side shows the anterior view of the T-pose, right side of image shows the left sagittal view of the T-pose.

This set of pilot testing consisted of the same procedure to the first pilot test. This was done to assess if there was a certain location in the crank cycle in which marker loss was more prevalent and if so, the cameras were moved to accommodate this.

The results of this testing showed that the adjustment of the camera set up, because of the previous test, allowed no marker loss during the motion capture process (Figure 12).

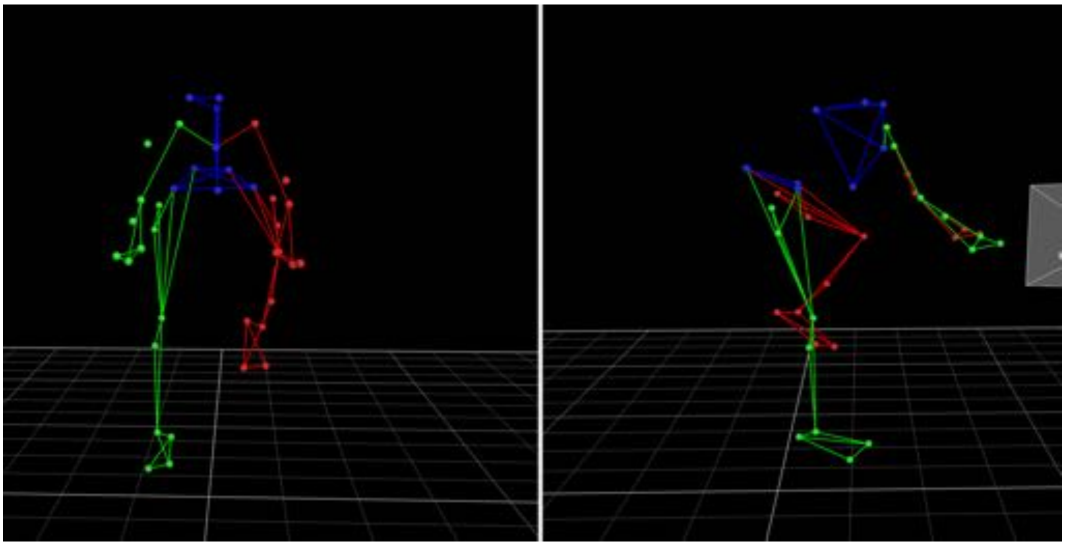

Figure 12 Example of kinematic capture which demonstrates no loss of markers in second pilot test.

Through the process of pilot testing the camera layout as well as the motion capture marker set were refined and decided on. Without this process, the testing process would have experienced many problems regarding loss of markers and a subsequent lack of data. Pilot testing also provided experience in placement of the motion capture markers to allow for more accuracy when later testing occurred.

5.4 Experimental Setup

Before testing can commence, the camera system needed to be calibrated and the origin set to the centre of the room. The origin was set to the centre of the force plates in which the middle of the bike was positioned (Figure 13).

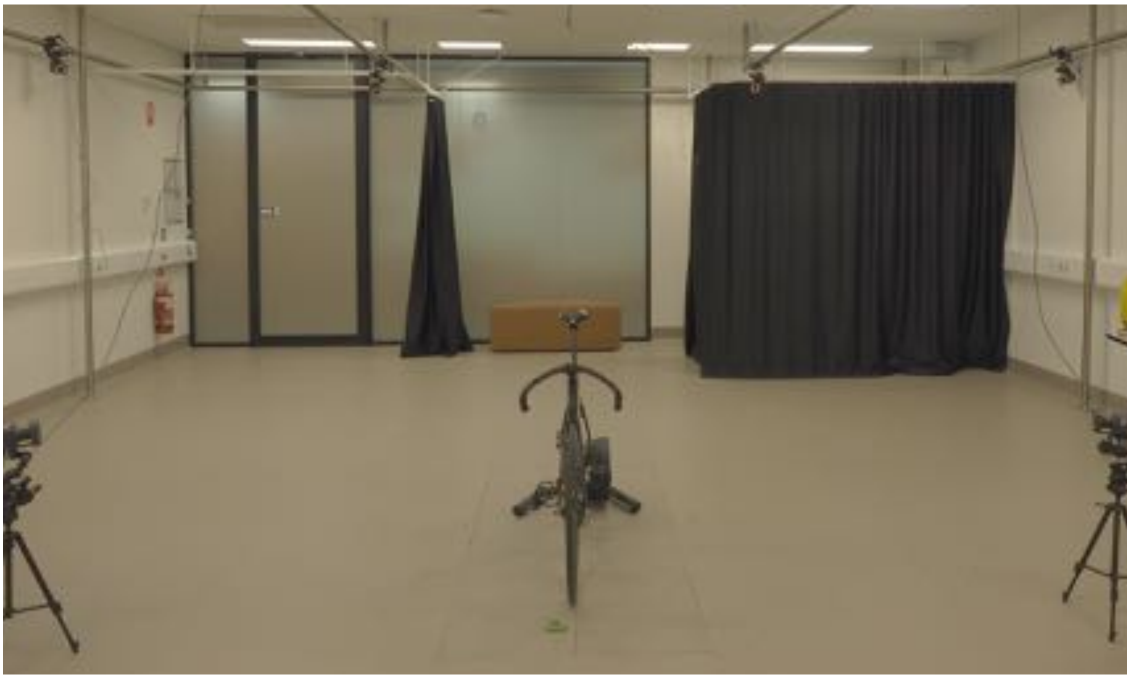

Figure 13 Location of the cycling ergometer and athletes bicycle used for testing

Following this, the experimental procedure was explained to the athlete and written consent was obtained. Before testing, the name, age, gender, and training level were obtained from the subject.

The EMG electrodes were then placed on the subject's gluteus maximus (GMax), biceps femoris (BF), semitendinosus (ST), vastus medialis (VM), rectus femoris (RF), vastus lateralis (VL), tibialis anterior (TA), medial gastrocnemius (mGas) and soleus (Sol) (Figure 14). When placing the EMG electrodes, it was important to place them on the muscle belly and in the direction of the muscles.

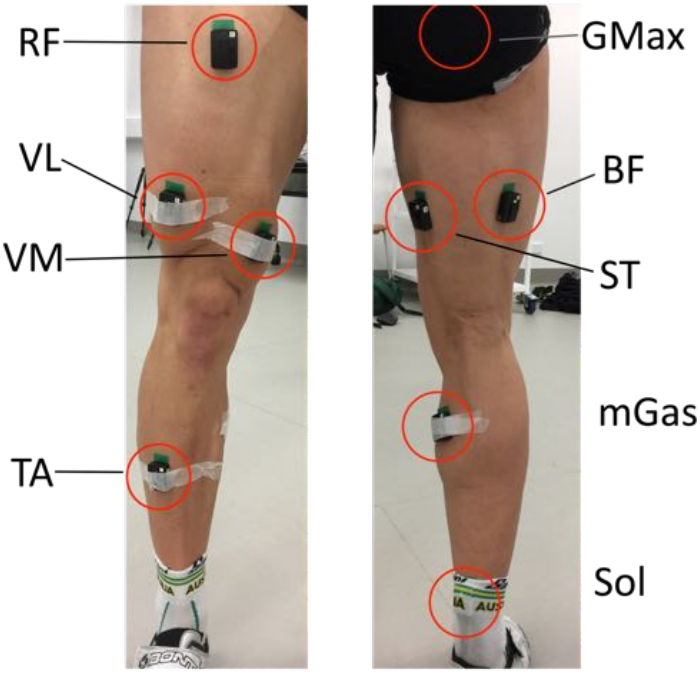

Figure 14 EMG electrode placement during testing. Left side of image is anterior side of the right leg, right side of image is posterior side of the right leg.

Following this, the motion capture markers were placed on the participant using the modified Plug-In-Gait model (Figure 15). The marker system was used to measure torso angle, hip angle, pelvic tilt, knee angle and ankle angles. One marker was placed on the shoe of the subject in line with the pedal spindle to get a positional reading of the pedals position within the crank cycle.

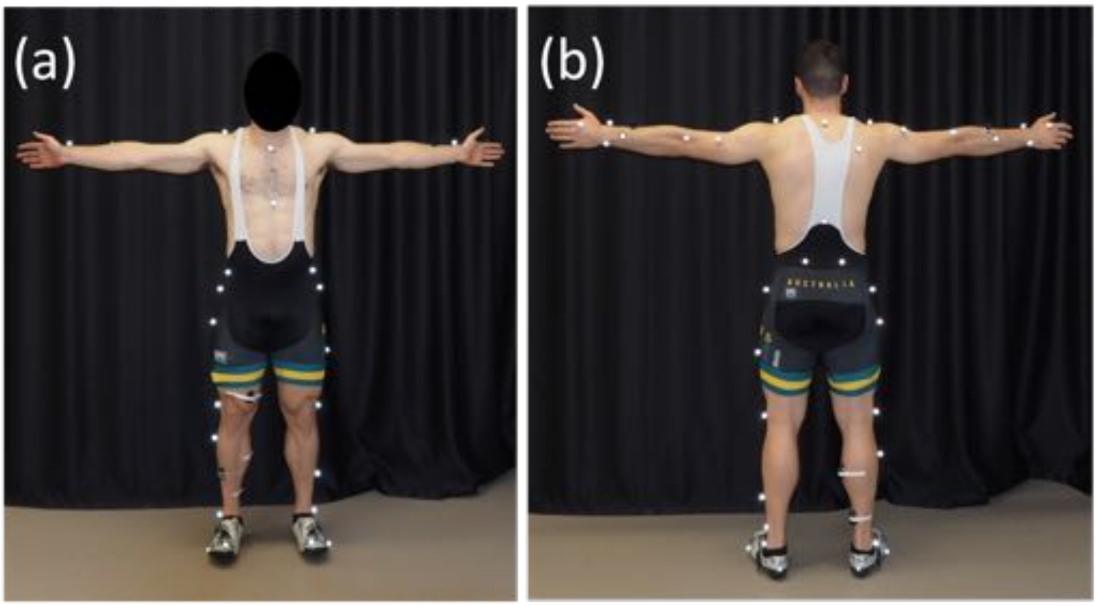

Figure 15 Setup of the modified plug-in-gait marker set during testing. More details on marker locations in Appendix D.

5.5 Experimental Protocol

Each athlete rode their own track fixed gear bicycles attached to a LeMond ergometer. The participants were tested using sprint handlebars and pursuit handlebars (Figure 16), within each of these positions the subjects preferred seat height and an increase in seat height by 5mm. All positions tested were performed at two powers submaximal and maximal, different gear ratios were used to ensure that there was a constant cadence of 115RPM. A gear ratio is the ratio between the number of teeth on the front chain ring to the number on the rear cog. Submaximal for male athletes was 600W and 1000W, with a gear ratio of 54:16 and 58:14 respectively. The female athletes submaximal was 450W with a gear ratio of 50:16 and maximal was 850W with a gear ratio of 53:14. These testing conditions are summarised in

Table 4. Each test condition was repeated twice within each session and then repeated on a second day to provide intra- (within session) and inter-reliability (between sessions) to ensure consistency of kinematics and muscle activations.

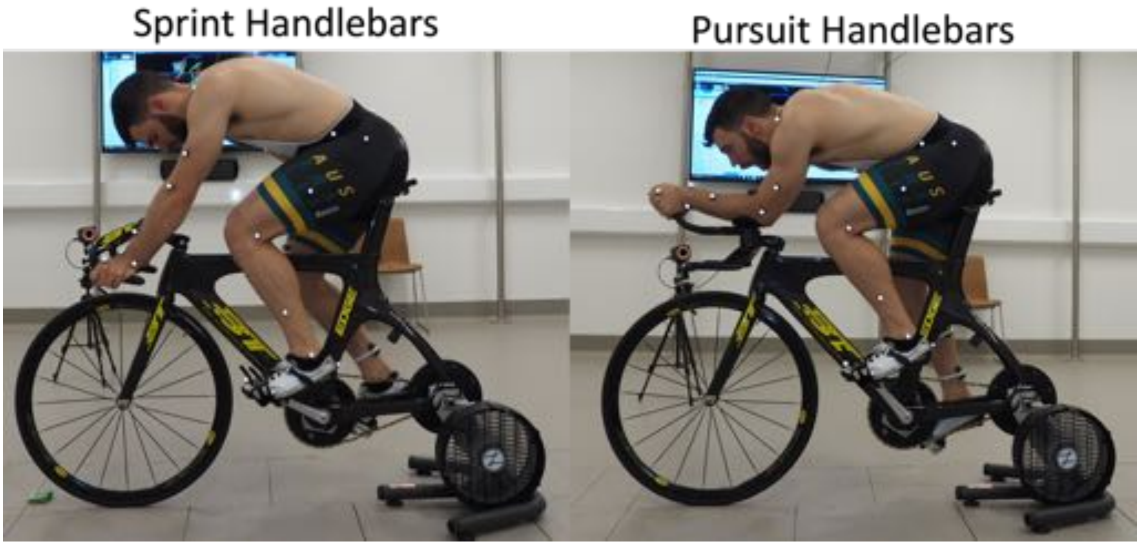

Figure 16 Example of athlete riding sprint handlebars (left) and pursuit handlebars (right).

Table 4 Testing conditions that were used in each session.

Handlebar Type	Seat Height	Power
Sprint	Preferred Seat Height	Submaximal
	Increased 5mm	
Pursuit	Preferred Seat Height	
	Increased 5mm	
Sprint	Preferred Seat Height	Maximal
	Increased 5mm	

Pursuit	Preferred Seat Height	
	Increased 5mm	

In each test condition, athletes were instructed to start cycling and attain a constant cadence of 115rpm. Once they reached this cadence the test began from a running start, each trial went for a total of 6 seconds to obtain 10 crank revolutions per test. After each test a rest period of 5 minutes occurred where the handlebars or seat height was changed in preparation for the next testing condition, between the submaximal and maximal test conditions there was a 15-minute rest period due to the increase time taken to change the gears on the bike and the bike position.

5.6 Data Processing

5.6.1 Identifying Events of Interest

Data was captured using Vicon Nexus software and exported directly into MATLAB (Mathworks, Inc.) for analysis using custom-made scripts. Data variables exported were raw EMG, raw marker trajectories and joint angles that were calculated within the Vicon Nexus processing pipeline. Prior to analysis, the EMG data was rectified and smoothed with a second-order low-pass Butterworth filter with a cut off frequency of 5 Hz (Figure 17c), which was optimized to reduce residuals present in the signal [13].

Reflective markers were placed on the foot relative to the pedal. From the kinematic data in the sagittal plane, the pedal position was used to determine the location of the crank angle throughout each trial. Once the crank angle was determined throughout the trial the TDC was used to separate each trial into individual events consisting of consecutive pedal strokes (Figure 17). The ensemble average of the joint angles (Figure 17e) and filtered EMG (Figure 17d) events were found.

The EMG data for each pedal stroke were normalized to 360 points representing each position in the crank cycle and amplitude was normalized to maximum measure amplitude. The overall muscle activity was identified by using the filtered EMG over one complete cycle (0˚–360˚) and the ensemble average EMG. The reason for using one complete cycle is to classify how the muscles are utilized during cycling at different phases of the crank cycle. From this, the burst of muscle activation was defined using a 20% threshold to detect muscle onset and offset [48] (Figure 17d). This was found for all conditions tested and all athletes (N=8). Further averaging was done to determine if there was a trend between athletes by using the standard deviation to see the degree of variation.

Range of motion was calculated to determine the effect of the conditions on kinematics. Joint angles were produced by the internal pipelining in the Vicon Nexus motion capture software. From the ensemble average of the joint angles, the range was used to define the range of motion in each joint of interest (Figure 17e). This was then averaged and compared between conditions using a two-way T test to determine statistical significance. The significance level, or alpha value, was 0.05 such that a difference in means was deemed significant when $p<0.05$ (2-tailed).

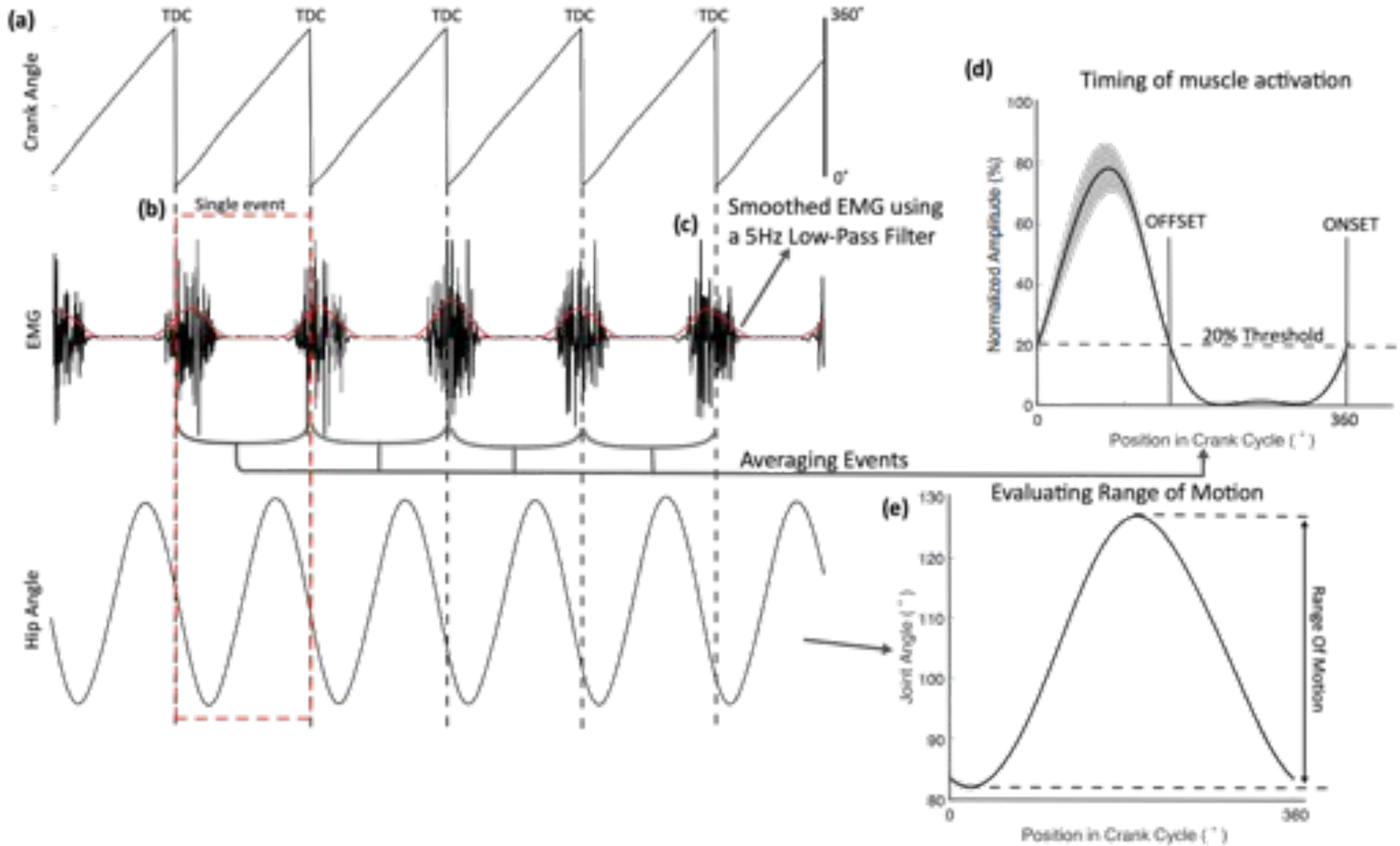

Figure 17 Process of processing the raw EMG data and kinematic data. (a) Outlines the use of the crank angle to define regions of interest. (b) Each test was separated into a series of events relative to the crank cycle. (c) EMG data was smoothed and (d) ensemble average was found for all events to determine the muscle onset and offset. (e) Ensemble average of joint angle used to determine range of motion.

5.6.2 Statistical Parametric Mapping

Statistical Parametric Mapping (SPM) is a MATLAB plug-in, which uses two series of continuous data to conduct a moving statistical analysis of waveforms. Intra-reliability was determined by using a moving t-test to evaluate the validity of the muscle activations within a single session. This t-test determined if each muscle from a trial was valid for use in further comparisons. The muscles were considered valid when the t-test did not show a statistically significant difference between the two repeats, if a difference was found then the muscle was considered invalid and removed from the sample size (Figure 18).

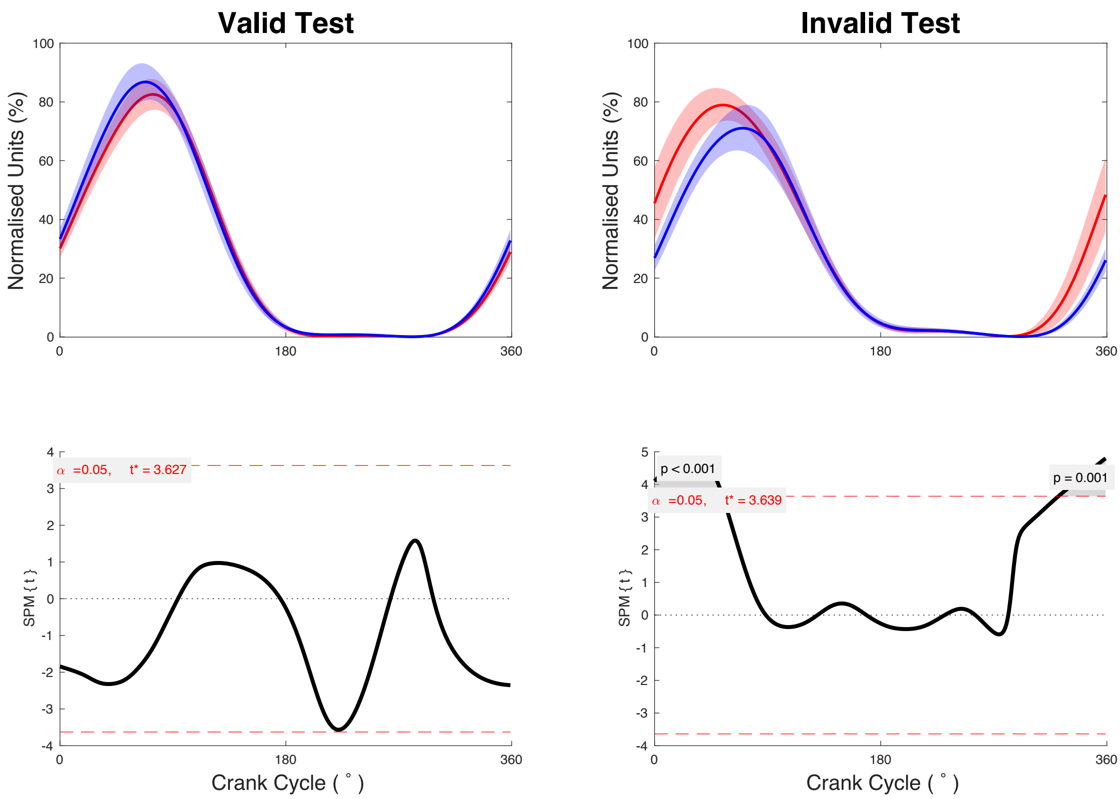

Figure 18 Statistical analysis of variance between trials. Left image shows example of a trial with no statistical variation between repetitions. Right image shows statistically significant difference (p<0.05) between trials showing the data is unreliable. Red curve represents trial 1, blue curve represents trial 2 and shaded region is the standard deviation.

If the muscle was classified as invalid, it was removed from the sample size to prevent outliers from contaminating the quality of the data. Upon removal of all invalid EMG data, the muscle activation patterns were averaged and represented in a circular plot that represents the crank cycle (Figure 19). This was done in order to assess if the muscle activity during one session was constant across both trials, this was necessary to ensure that the muscle activity was properly represented for the activity.

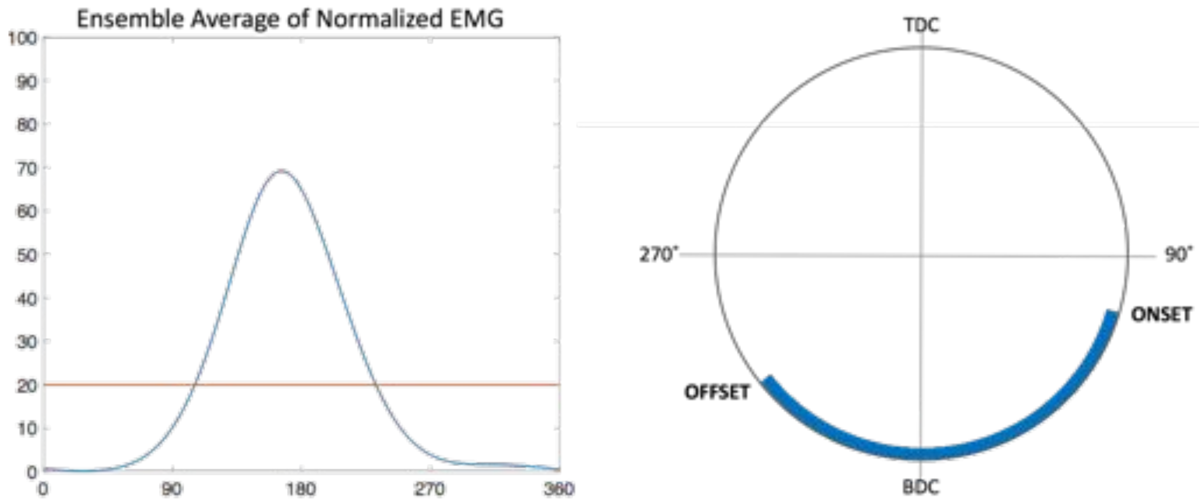

Figure 19 Method of presenting the EMG activation patterns and mapping to the points in the crank cycle. Further graphs will show data in this format to represent the locations of the muscle activation patterns during testing. Threshold of 20% was used to determine the onset and offset.

5.6.3 Trajectory Analysis of Joint Markers

Further kinematic analysis was done to assess the effect of movement variance on the range of motion present. This was done to determine if there were more variables affecting the changes exhibited between conditions. The two markers of interest were the right knee (RKNE) and right posterior sacroiliac (RPSI) markers. The knee marker was analysed in the medial-lateral plane (Figure 20) to quantify knee splay. The pelvic marker was analysed in the superior-inferior plane to assess the degree of pelvic rocking occurring through a trial. These were found for each trial and averaged relative to the condition they represented to assess if there was significant movement in all trials.

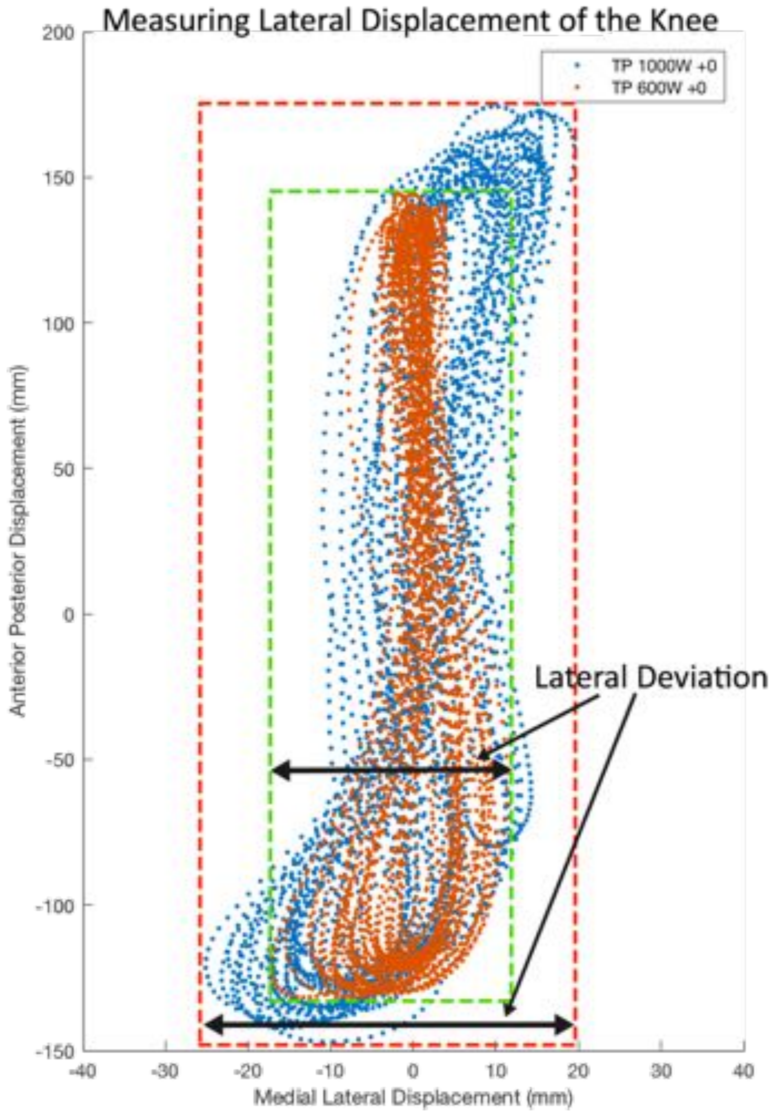

Figure 20 Calculation of the lateral displacement in the transverse plane of the athlete's right knee marker, overlaying two examples of lateral deviation in the same athlete. Plot displays the knee trajectory in the X-Y plane (top view) with positive y-axis showing direction the athlete was facing.

6 Results

6.1 Reliability

The Statistical Parametric Mapping (SPM) plug-ins moving paired T-test was used to assess variance between trial 1 and trial 2 within each session. If a test was found to be unreliable it was removed from the dataset.

6.1.1 Kinematics

Initially, SPM was intended for both kinematic and muscle activity analysis of reliability. However, due to the high repeatability of the kinematics in each trial, slight variation in the curve would show a false positive in kinematic repeatability. Through visual inspection, the joint angles for each trial were repeatable and all trials were used for further analysis.

6.1.2 EMG

To determine if a muscle was valid, SPM analysis was conducted using a running paired t-test on the results. If a test showed repeatability it was considered valid. However, if a significant difference was detected, this value was removed. Figure 21 shows an example of the output of an SPM analysis for one condition in Athlete 2. In this condition, the muscles that were considered invalid and therefore removed were semi-tendinosis, medial gastrocnemius, and soleus muscles. This shows that the rejection of data was extremely sensitive as the curves that were removed showed marginal variation between repetitions. A table of all trials and rejected data is presented in Appendix E: Table of Rejected EMG Channels.

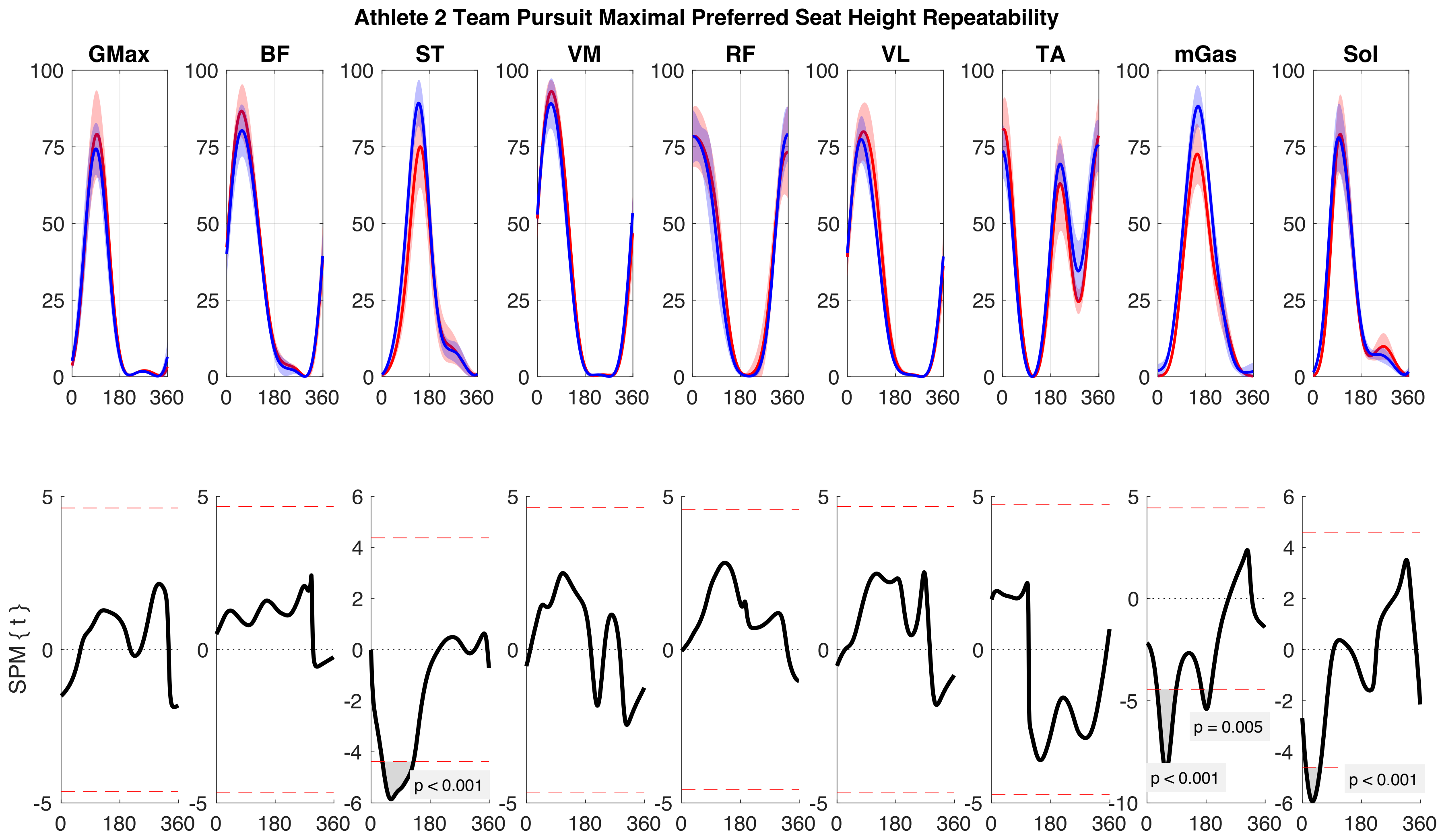

Figure 21 SPM analysis of EMG activation during maximal pursuit bars at preferred seat height. Red curve is repeat one and blue curve represents repeat two. Invalid muscles from this trial are semi-tendinosis, medial gastrocnemius, and soleus muscles.

To visualise how much of the data was removed after the SPM analysis Figure 22 was created. This was calculated by dividing the total number of rejected samples by the total samples collected. To compare this with the athlete representation the N value for each muscle was used to calculate the percentage representation of athletes in each trial. In the graph, lower percentages signify that there was a large representation of the total data in the final results.

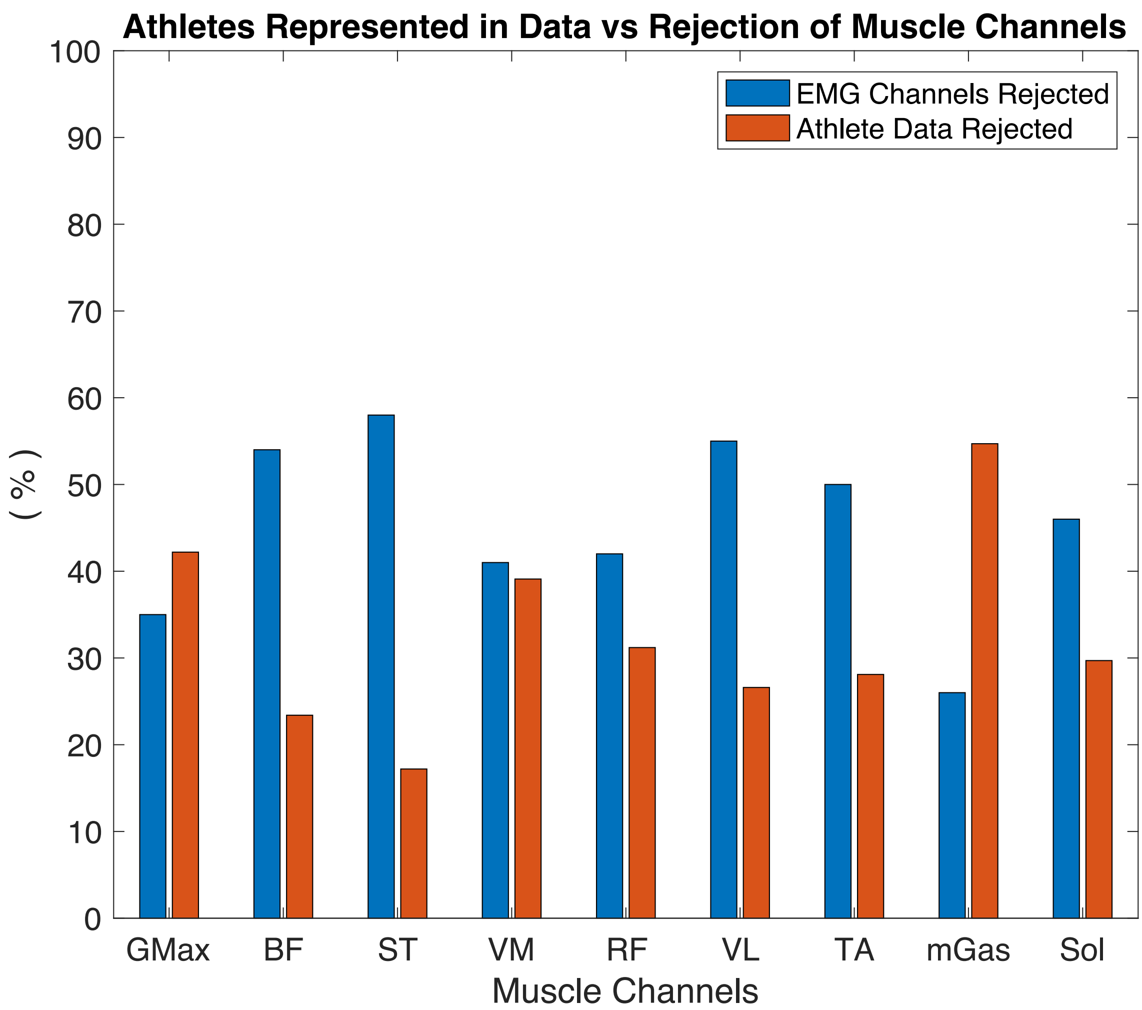

Figure 22 Comparing the rejection of total EMG channels to the number of athletes represented in the data for analysis of muscle activity. Lower percentage in the EMG channels rejected shows more repeatability, lower percentage in athlete's data rejected shows a greater representation of sample size in the analysis of muscle activity.

6.1.3 EMG Reliability Validation

The main muscles that had more rejection were generally the mGas, TA, and GMax. Through observation during testing, it was noted that the muscles that were not covered by the cyclists clothing were the main muscles rejected. In contrast, GMax had a high level of rejection and this was noted to be bumped or sat on by the athletes causing shift in the electrode during testing.

To verify this, a secondary series of validation tests were conducted in which 3 conditions were evaluated including, uncovered (Figure 23), covered (Figure 24) and sweaty (Figure 25) uncovered EMG electrodes. The uncovered and sweat tests reported higher standard deviations and waveform variance, supporting the hypothesis that these were the causes of high rejection rates in EMG channels during testing.

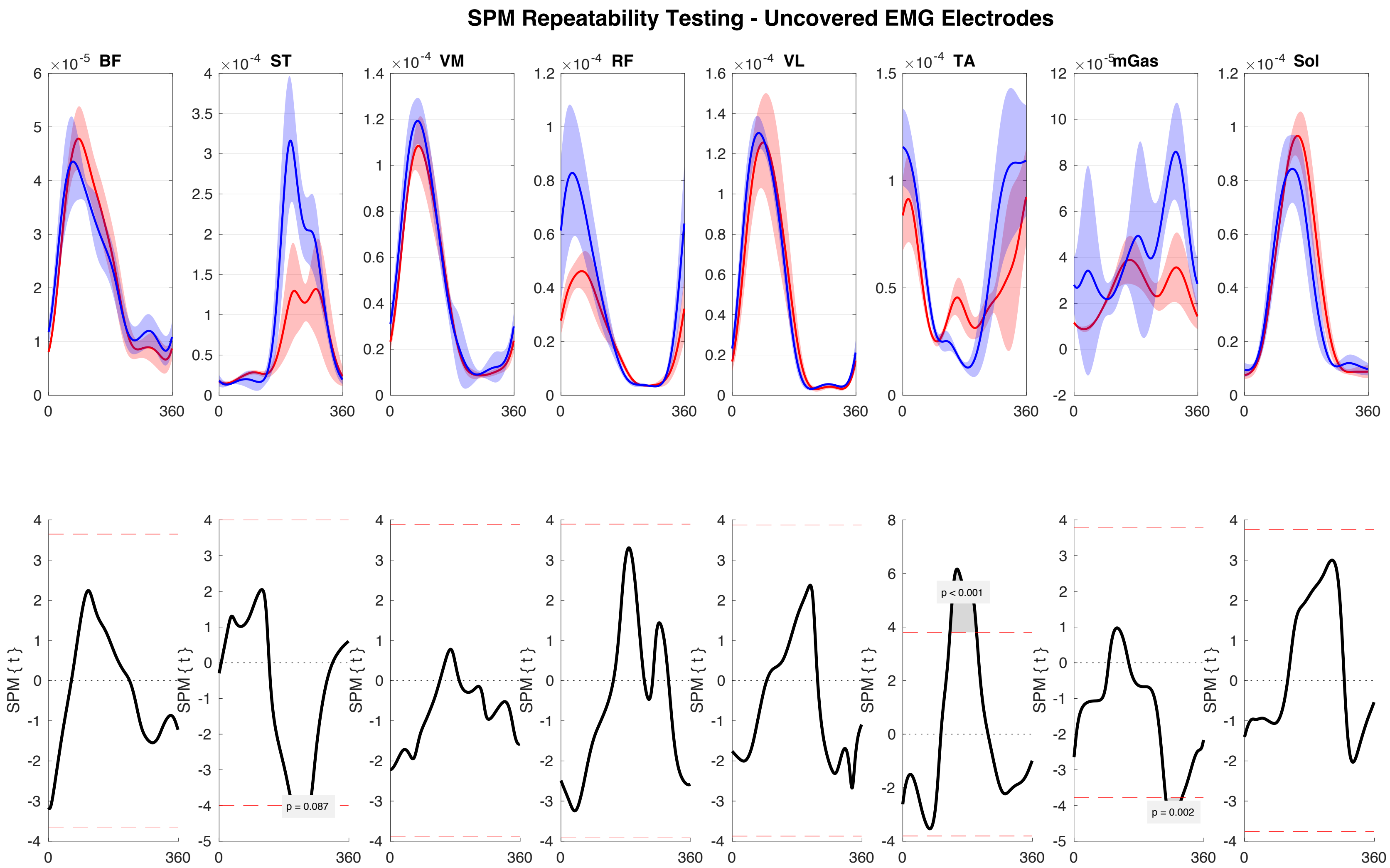

Figure 23 SPM output from EMG validation testing for uncovered electrode condition. Rejected EMG channels were ST, TA and mGas.

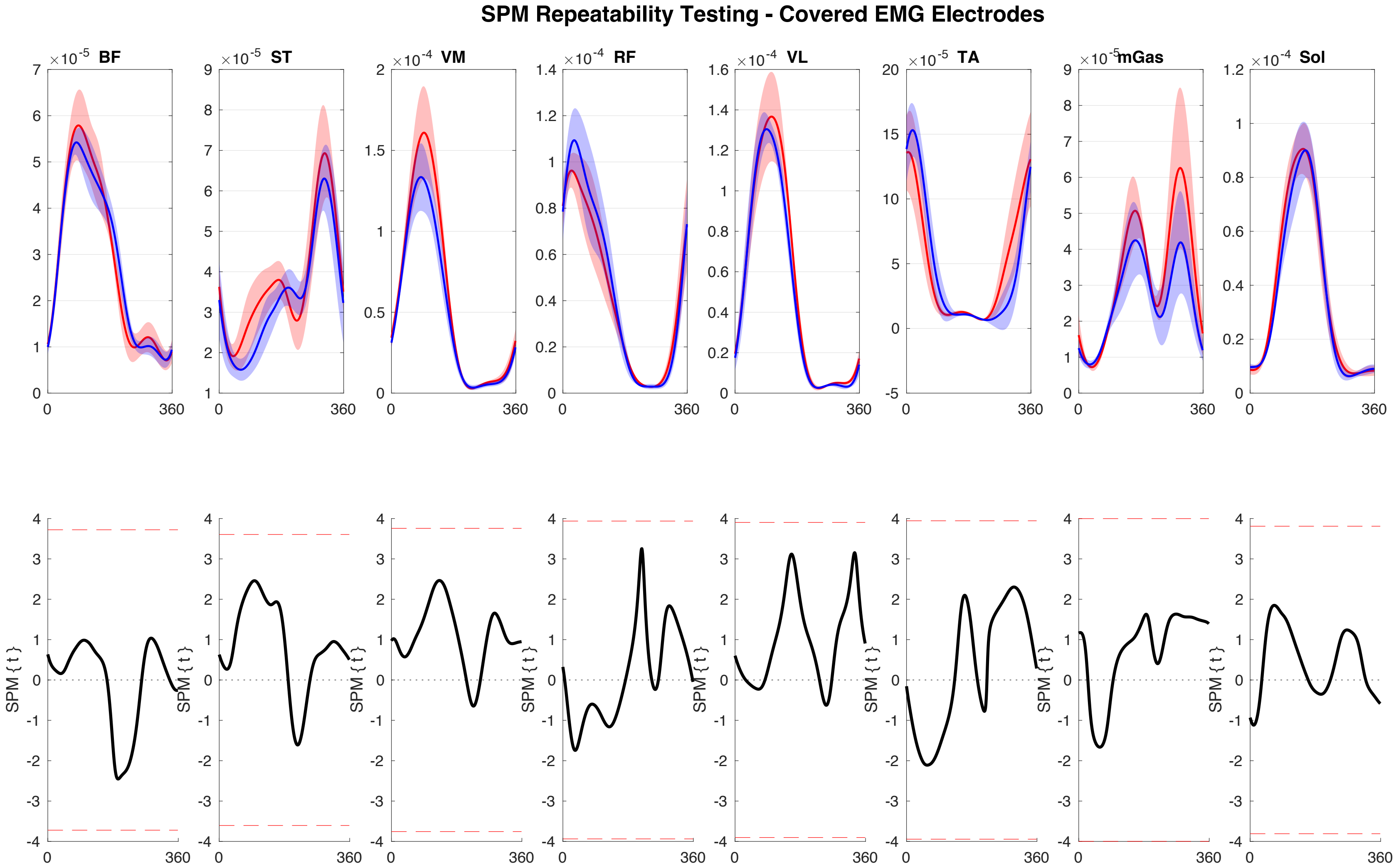

Figure 24 SPM output from EMG validation testing for covered electrode condition. Complete reliability found with all data channels.

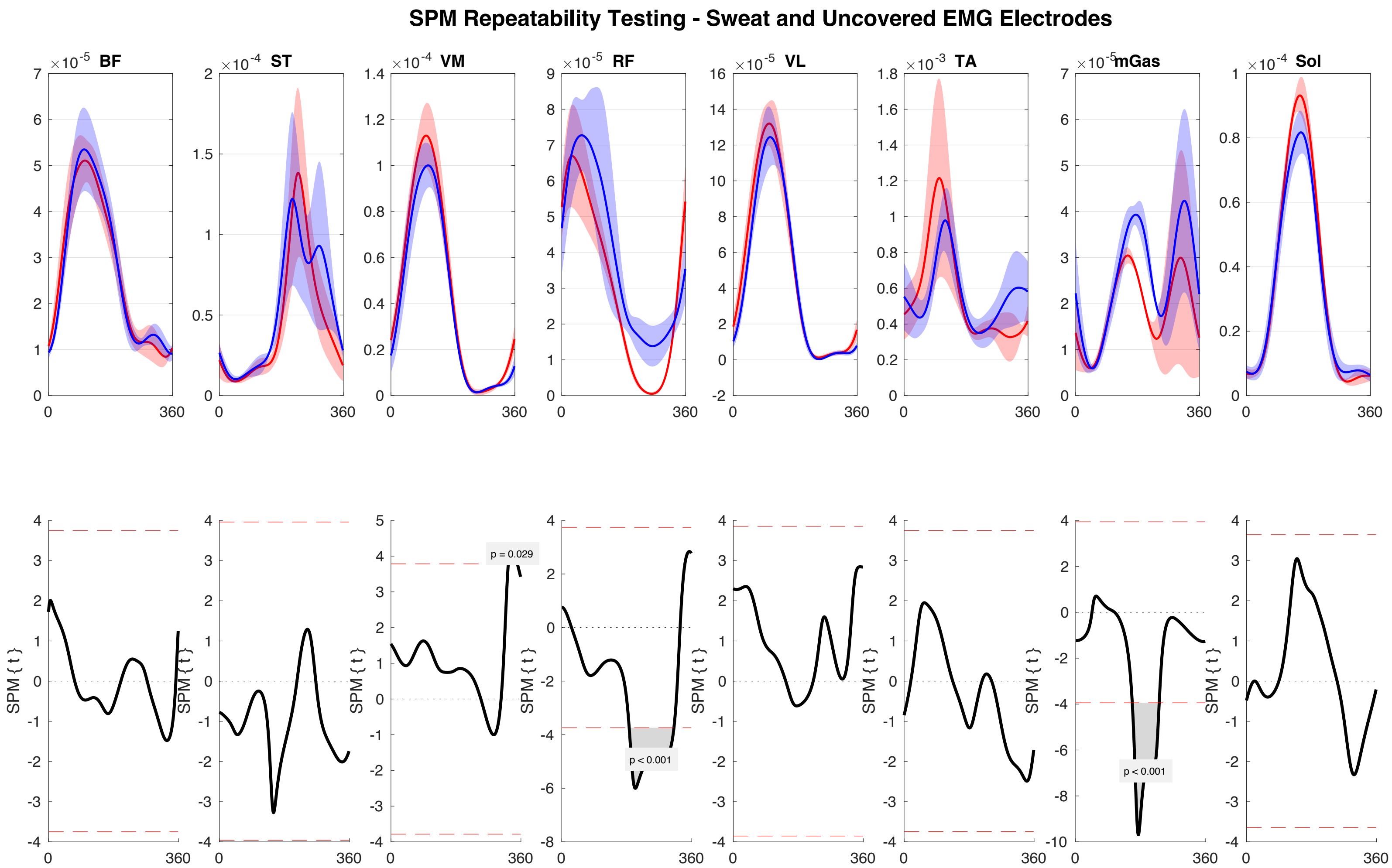

Figure 25 SPM output from EMG validation testing for sweaty and uncovered electrode condition. EMG channels rejected RF, VM and mGas and a larger degree of standard deviation in the accepted waveforms then previous conditions.

6.2 Kinematics

The range of motion (ROM) was used to assess the effect of each condition on the joint angles, this was used due to the variance that existed between athlete's preferred seat height. To analyse if there was an overall trend in the cohort, the average range of motion was calculated for each joint and compared between each condition (Figure 26).

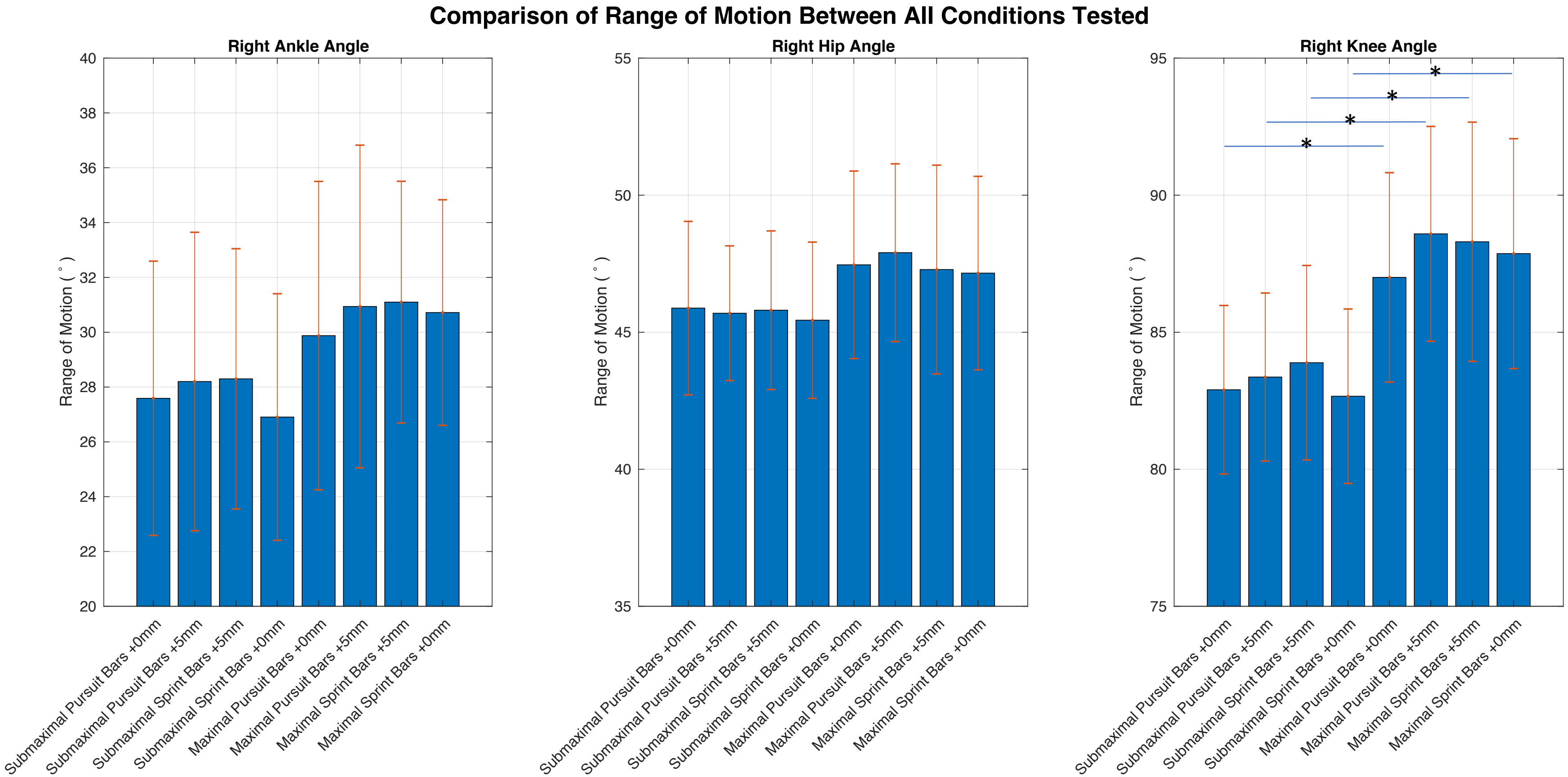

Figure 26 Range of motion in joints of the lower limb in response to positional and power changes. (p < 0.05)*

In order to compare the effects of the variables on the range of motion for difference was taken and a t-test was conducted to evaluate significance. The differences in range of motion were calculated as a result of increase the power from submaximal to maximal (Table 5). The difference between seat height was also calculated using preferred seat as a baseline and finding the difference in range of motion (Table 6). Finally, the effect of handlebars was investigated and showed very little difference between sprint handlebars and pursuit handlebars (Table 7).

Table 5 Comparison of the effects of power level on range of motion in all positions evaluated during testing.

Position	**Joint Angles**	**Submaximal Power ROM (˚)**	**Maximal Power ROM (˚)**	**Difference (˚)**
Pursuit Bars Preferred Seat Height	Ankle	27.6	29.9	2.3
	Hip	45.9	47.5	1.6
	Knee	82.9	87.0	4.1*
Pursuit Bars Raised Seat Height	Ankle	28.2	30.9	2.7
	Hip	45.7	47.9	2.2
	Knee	83.4	88.6	5.2*
Sprint Bars Preferred Seat Height	Ankle	28.3	31.1	2.8
	Hip	45.8	47.3	1.5
	Knee	83.9	88.3	4.4*
Sprint Bars Raised Seat Height	Ankle	26.9	30.7	3.8
	Hip	45.4	47.2	1.7
	Knee	82.7	87.9	5.2*

* $p < 0.05$

Table 6 Comparing the effects of increasing seat height on range of motion in lower limb joints.

Constants	**Joint Angles**	**Preferred Seat Height**	**Increased Seat Height**	**Difference**
Submaximal Pursuit Handlebars	Ankle	27.6	28.2	0.6
	Hip	45.9	45.7	-0.2
	Knee	82.9	83.4	0.5
Submaximal Sprint Handlebars	Ankle	26.9	28.3	1.4
	Hip	45.4	45.8	0.4
	Knee	82.7	83.9	1.2
Maximal Pursuit Handlebars	Ankle	29.9	30.9	1.1
	Hip	47.5	47.9	0.4
	Knee	87.0	88.6	1.6
Maximal Sprint Handlebars	Ankle	30.7	31.1	0.4
	Hip	47.2	47.3	0.1
	Knee	87.9	88.3	0.4

Table 7 Comparing differences in the effect of handlebar type on range of motion in lower limb joints.

Constants	Joint Angles	Team Pursuit	Sprint	Difference
Submaximal Preferred Set Height	Ankle	27.6	26.9	-0.7
	Hip	45.9	45.4	-0.4
	Knee	82.9	82.7	-0.2
Submaximal Increased Set Height	Ankle	28.2	28.3	0.1
	Hip	45.7	45.8	0.1
	Knee	83.4	83.9	0.5
Maximal Preferred Seat Height	Ankle	29.9	30.7	0.8
	Hip	47.5	47.2	-0.3
	Knee	87.0	87.9	0.9
Maximal Increased Seat Height	Ankle	30.9	31.1	0.2
	Hip	47.9	47.3	-0.6
	Knee	88.6	88.3	-0.3

As there was a significant increase in the range of motion because of power level, it was hypothesised that movement changes were responsible for this. Since the athlete is fixed at the pedal and seat, the knee and hip movements are the two main areas of interest when assessing movement of the lower limb that could cause variation in joint angles when positional aspects were kept constant. To validate this theory the knee lateral movements (Figure 27) and pelvic vertical displacements (Figure 28) were assessed. This showed there was an increase in movement of the hip and knee joint centres as a result of increasing the power, however no statistical significance was reported.

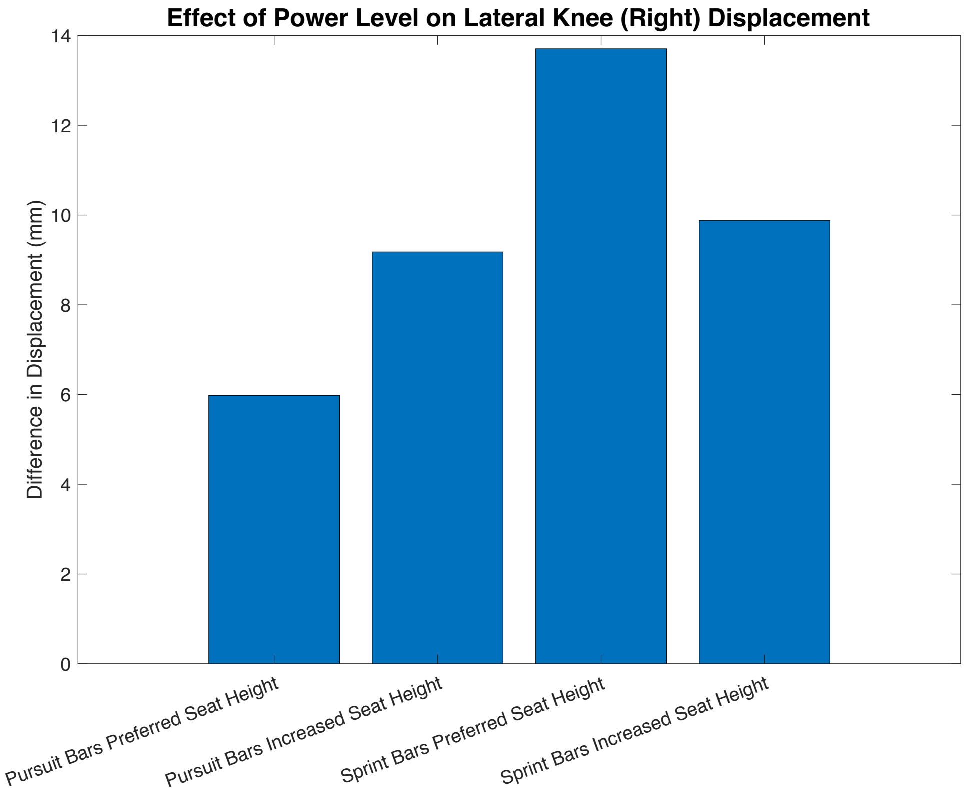

Figure 27 Effect of increasing power level, from submaximal to maximal, on right lateral knee displacement.

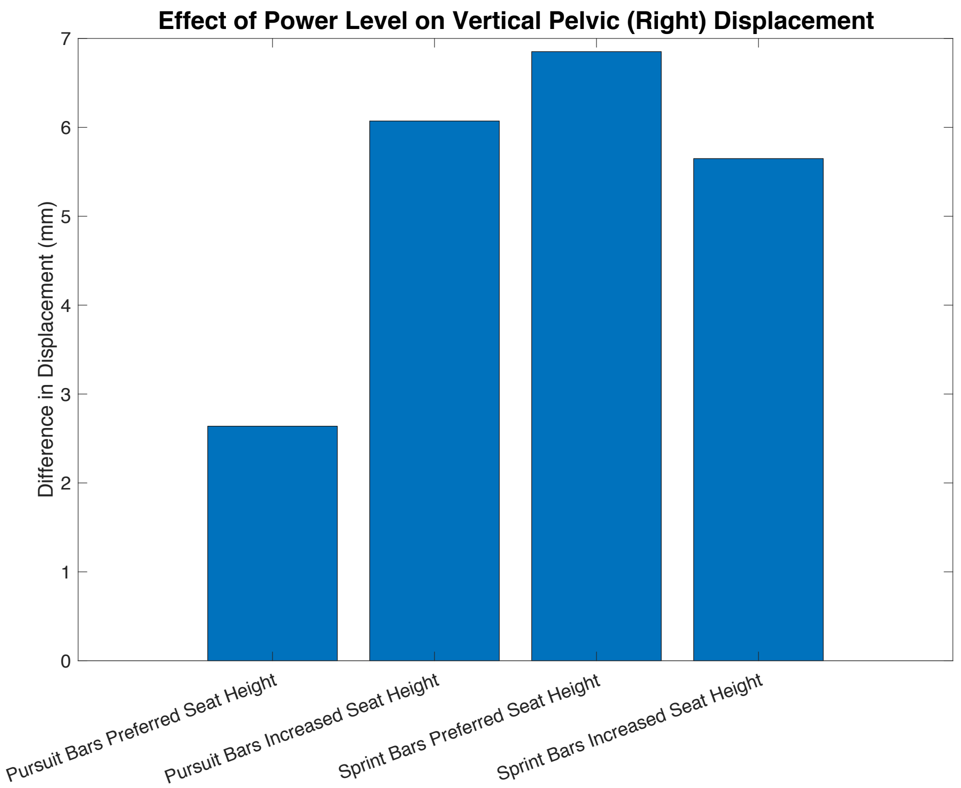

Figure 28 Effect of increasing power level, from submaximal to maximal, on vertical pelvic displacement. Vertical pelvic displacement represents pelvic rocking during pedalling.

6.3 Muscle Activation Patterns

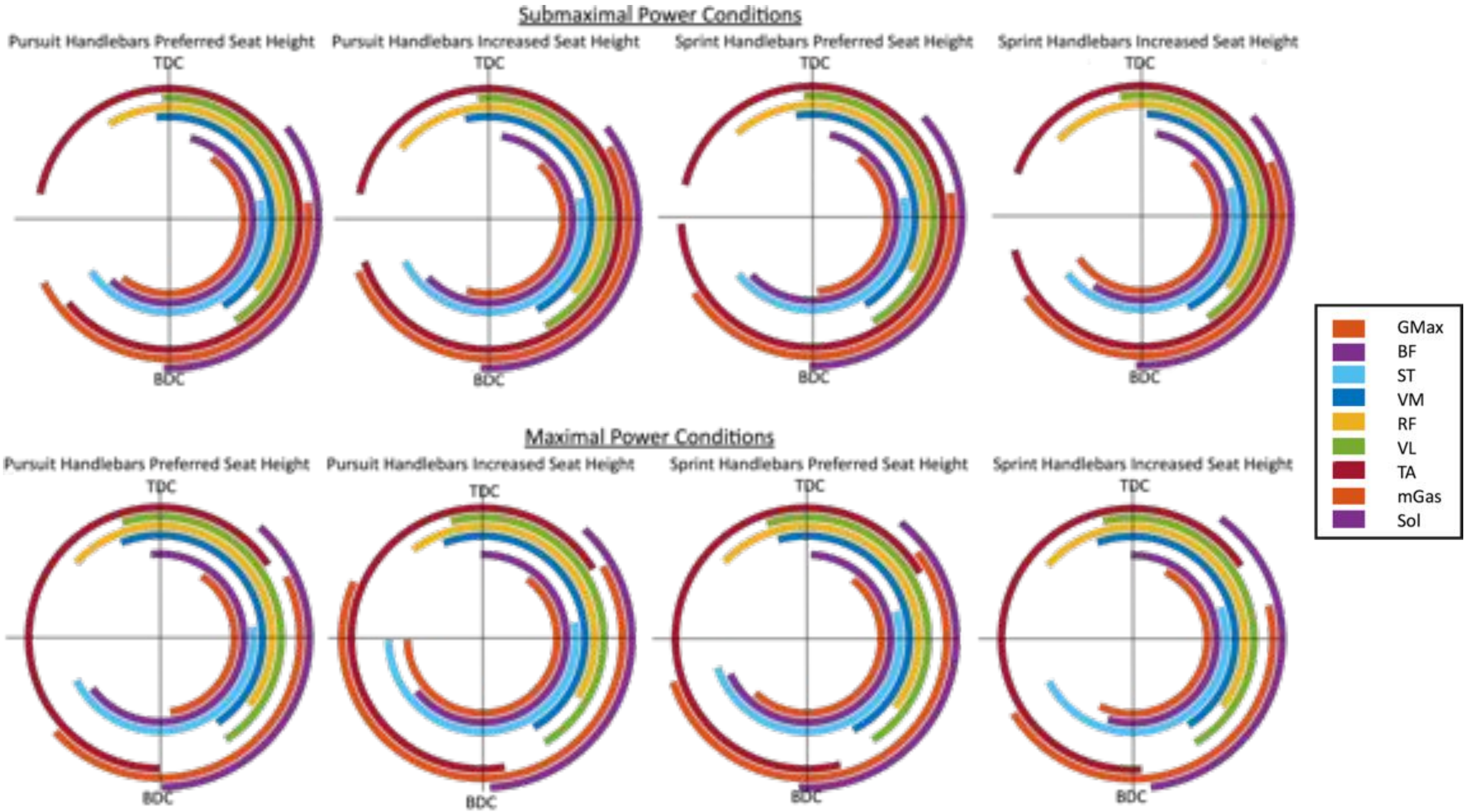

Figure 29 Muscle activation patterns mapped to the crank cycle. Visual representation of the mean muscle activation patterns from statistically valid EMG signals.

When assessing the muscle activation patterns, the arbitrary threshold of 20% was used to determine muscle bursts during the crank cycle. Figure 29 shows the various muscle activation patterns that were exhibited for each testing condition. The data displayed shows the average activation for all statistically valid trials.

Table 8 Example of large standard deviation in the muscle activation patterns between athletes using maximal effort sprint handlebars at preferred seat height.

Muscles	**Onset (˚)**	**Offset (˚)**	**Duration (˚)**
GMax (6)	38 (64)	223 (37)	192 (49)
BF (6)	3 (40)	245 (58)	228 (54)
ST (7)	73 (37)	252 (38)	165 (28)
VM (5)	344 (28)	153 (8)	168 (18)
RF (6)	313 (50)	128 (51)	168 (26)
VL (5)	341 (9)	147 (8)	165 (11)
TA (5)	165 (87)	60 (70)	272 (38)
mGas (4)	52 (50)	252 (46)	207 (40)
Sol (7)	39 (39)	183 (48)	150 (35)

From the muscle activation plots, there was a large standard deviation shown in the muscle onsets and offsets (Table 8). However, in the muscle duration on average this was found to show a smaller standard deviation in some muscles. To determine the effect of this the ratio of standard deviation to mean duration was calculated to find the coefficient of variation (Figure 30). A low ratio of standard deviation to total muscle duration indicates small variance in duration of muscle activation and thus, a large variance in onset and offset is present. This is most likely due to a phase shift rather than increased duration.

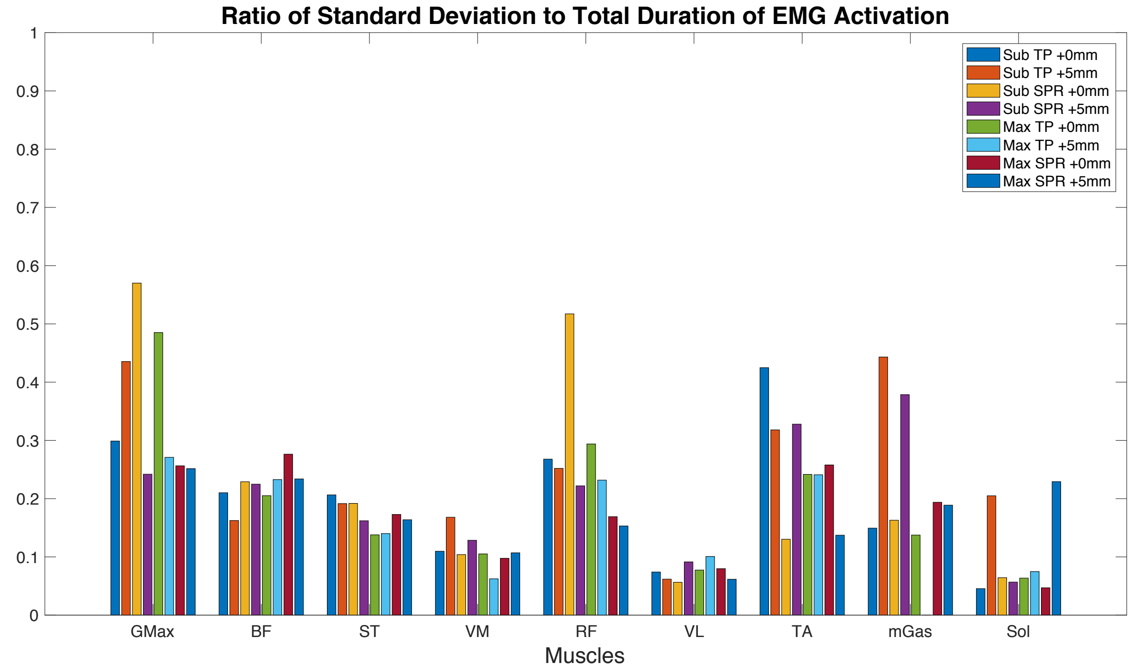

Figure 30 Ratio of the standard deviation of EMG duration to total EMG duration. TP = Pursuit Handlebars, SPR = Sprint Handlebars.

Looking at the ratios of standard duration to total duration, it shows there is significantly more variation in the gluteus maximus, rectus femoris, tibialis anterior and medial gastrocnemius. The lowest of these is the vastus lateralis, which has a maximum variance of approximately 0.1, from this it can be determined that any changes in vastus lateralis are a result of varying activation onset and offset.

The cohort being analysed in this study was composed of sprint cyclists. The athlete's preferred seat height and sprint handles to assess this variation in activation timing between athletes (Figure 31). As expected, the vastus lateralis had similar durations and activation patterns between all athletes. However, soleus showed athlete 6 was responsible for the large deviation in this trial.

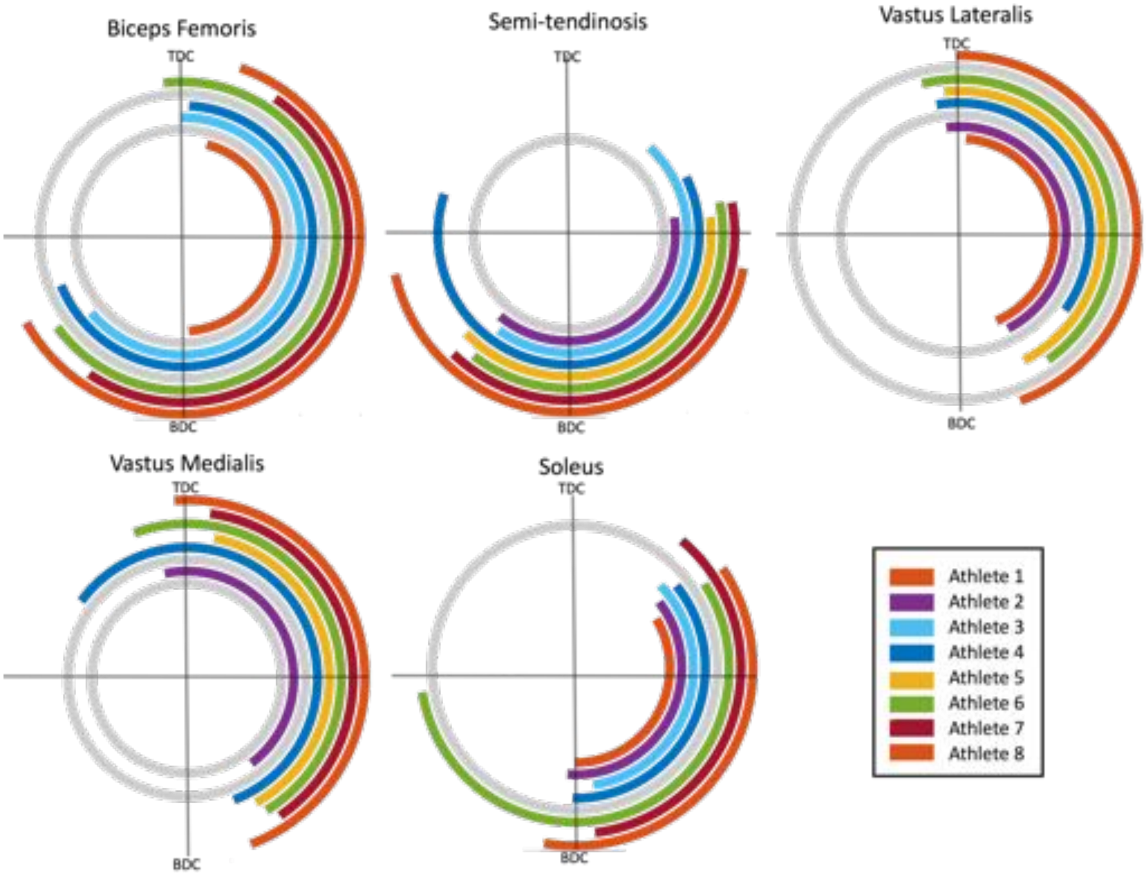

Figure 31 Comparison of individual muscle activations during submaximal cycling on sprint handlebars and preferred seat height. Grey circles represent no reliable data for current condition for athlete.

7 Discussion

The primary purpose of this project was to develop and refine a protocol for obtaining 3D motion analysis and EMG data from elite cycling athletes that was accurately repeatable both within session and between sessions. From this data, the aim was to assess the biomechanical response due to positional changes at submaximal and maximal workloads.

7.1 Data Reliability

The purpose of this study was to determine if handlebar, seat height or power level influence a cyclist's performance during a given task. Identifying a trend in performance could potentially be applied to maximise cycling output among all sprint cyclists. Therefore, it was essential that the data obtained was representative of not only the athlete's performance, but also, the cohort of sprint cyclists. To ensure there was minimal variance between athlete sessions and between athletes, the intra-session and inter-athlete variation was assessed, respectively.

7.1.1 Intra-Session Reliability

Intra-session reliability was assessed by comparing the variance between repeat one and two within a given session. Data was classified as 'unreliable' if the SPM paired t-test reported significant variance between repetitions in a trial (Figure 19). However, the SPM analysis tool was extremely sensitive, where small changes in kinematic trials were reported as significant variance. Therefore, kinematic intra-session reliability was instead deemed repeatable based on visual inspection. This visual analysis showed repeatable joint angles between an athlete's sessions. Although intra-session kinematic data was highly repeatable, the EMG SPM results showed 54.84% acceptance rate for all muscles. This means that almost half of the data collected regarding muscle activity during testing was rejected. This rejection was found to be higher in BF, ST, and VL all of which had a rejection rate of approximately 50%. Although these muscles showed a high rate of rejection, the number of athletes represented in these muscles is still high, this shows that in one session for all athlete's one of these muscles was considered valid (Figure 22).

Muscles are responsible for movement in the human body. If a specific movement is conducted, muscle activation should be consistent between trials. As the kinematics were observed to be reliable in all athletes, the rejection that occurred cannot be attributed to variation within testing performance. Therefore, high EMG rejection rates may be attributed to perspiration, movement of an EMG electrode during testing, fatigue or degradation of the adhesive used for electrode placement.

Further testing was performed to test the hypothesis that the skin-electrode interface was impacting the repeatability of EMG data. These findings showed that both uncovered electrodes (Figure 23) and increased perspiration (Figure 25) resulted in rejection of EMG channels. EMG channels that were classified as 'reliable' typically had much higher standard deviations. This increase in variance ultimately allowed these muscles to pass the t-test. Further tests showed that covering the EMG electrodes with a compressive material improved the reliability of the data and decreased variance (Figure 24).

Although this follow up testing showed both sweat and uncovered electrodes were less reliable, the muscles that exhibited the largest percent rejection were BF, ST and VL (Figure 22). These muscles were located under the cyclists shorts and as such under compression during testing. Therefore, the reason for why the EMG channels were unreliable requires further testing to refine a protocol to produce more repeatable data.

7.1.2 Individual Variation

Inter-athlete variation was conducted once all data was collected. This reliability test was required to assess and ensure minimal variance between subjects. The first step in evaluating muscle activation patterns was to determine muscle onsets and offsets. Figure 29 shows that muscle activity about the crank cycle follows a general pattern. Although there was a large standard deviation in muscle onsets and offsets, there was little variance in mean duration of muscle activation (Table 8). To visualize the theorised phase shift in muscle activation, an example condition was plot to compare each muscle activation pattern for each athlete (Figure 31). This example validated the theory of there being a phase shift causing an increase in the standard deviation within the onset and offsets of muscle activations. This shows that there was a degree of individual variation within muscle onsets and offsets. Consequently, muscle activation plots are not valid tools for identifying trends occurring due to positional or power level changes.

7.1.3 Effects of Seat Height

Seat height is one of the most important aspects of position that ultimately effects cyclist performance. The question this study aimed to answer is; do small changes in seat height result in significant changes in kinematics and muscle activity? The purpose of only increasing the seat height by 5mm was to determine what resolution of seat height adjustments make a significant different.

Seat height is necessarily statistically significant because it directly determines the joint angles, however 5mm may not have been large enough to be detected by statistical tests if number of repetitions was insufficient. When analysing the data obtained from the two seat heights, the results showed there was a slight increase in the range of motion when increasing the seat height. The angles effected by this were the ankle angle and knee angle, while no notable change was detected in the hip angle (Figure 26). The greatest increase that was detected was 1.6˚ in the knee angle for maximal pursuit handlebars. However, most other variables showed negligible differences between preferred and increased seat height (Table 6). The average ankle angle and knee angle for each athlete was calculated for each session. These results revealed a large standard deviation in ankle and knee angles for each athlete (Figure 26). Therefore, this suggests that there is potential for individualized responses to changing seat height. Evaluating the effect of seat height on joint angles could provide an avenue for maximising athlete performance. However, athletes preferred seat heights were determined using a ratio of anthropometric measurements. Consequently, the joint angles output had a high degree of variability between athletes.

Muscle activity was evaluated as a cohort rather than by individual analysis. Due to the high degree of variation in muscle activation patterns, the effect of seat height on muscle activity could not be determined. Seat height could be a reason for the variation in muscle activation patterns between athletes. One condition of this study was for the participants to cycle at their preferred seat height. At their preferred seat height, athlete's muscles would be working in different joint angle ranges. As such, slight variations in muscle activation patterns would occur. If the preferred seat heights and anthropometric data of each athlete was known this could be validated.

7.1.4 Effect of Handlebar Type

Sprint cycling involves the use of two handlebar types for different events. This study looked at determining if there was a difference in the biomechanics involved in different handlebar types. In the kinematic analysis of the results, the range of motion was shown to not be effected by handlebar type, with most differences under 1˚ (Table 7). However, in maximal cycling, there was greater movement of the knee (Figure 27) and hip joint (Figure 28) markers in the sprint handlebars in comparison to pursuit handlebars for preferred seat height. However, there was little difference between the handlebar types at the increased seat height.

In past literature handlebar position was analysed relative to the ability of the upper limb to support the cyclist in positons, therefore comparisons of these effects when analysing the lower limb kinematics and muscle activations cannot be done as there is a lack of research in this field.

7.1.5 Effect of Power Level

The results of the kinematic analysis showed that there was the most significant effect on the range of motion when increasing the power level from submaximal to maximal (Figure 26). Increasing power effectively increased all ranges of motion. This increase in range of motion was notably reported in the ankle and knee joints. Statistical significant was shown for the knee angle with an increase in power level. The most significant increases were when combining increased seat height and handlebar type with both sprint handlebars ($p=0.0434$) and pursuit handlebars ($p=0.0101$) showing an increase in ROM by 5.2˚ (Table 5).

To further evaluate why there was an increase in range of motion in the joints, the knee lateral movement (Figure 27) and vertical pelvic displacement (Figure 28) were found. This showed that as power increased, the movements in the knee marker's lateral plane also increased. Pelvic vertical movement was also increased due to the power level increase. In both cases, the most significant increase in movement occurred in sprint handle bars at the athletes preferred seat height. These increases in joint movement at the joint centres during increased power levels provide an explanation for the significant increase in range of motion. However, since there were no pedal forces calculated, there is no way of determining if this was detrimental to the efficiency of cycling. This could also be a source of aerodynamic drag. In cases that included sprint handlebars, there was an increase of up to 13mm lateral deviation. This is important as cyclists aim to be as aerodynamic as possible. Track sprint cycling races frequently come down to fractions of a second. Therefore, even a slight decrease in aerodynamic may influence the result.

7.2 Limitations

Although this study had many strengths there were several limitations that reduce the validity of the results. Some of these limitations include the skill level involved in EMG electrode and marker placement, interference with the skin-electrode interface, sampling frequency of visual feedback, variation between preferred seat height and the potential for fatigue.

An untrained professional placed the EMG electrodes and reflective markers on subjects. As a result, placement of these electrodes and markers may have been inaccurate. Consequently, the EMG data may not have been directly from the muscle belly and there may have been cross contamination from adjacent muscles. Similarly, placing reflective markers on bony landmarks can result in issues in repeatability between sessions. Variation in electrode and marker placement will consequently limit and confound comparisons between athletes.

The Delsys wireless EMG electrodes function using a direct metal to skin electrode interface without the use of any contact gels. As testing progressed, there was an increase in perspiration and the conditions of this interface changed over time. This was found to be an issue with repeatability of testing. Therefore, there is a potential for the results to differ with change in skin conditions.

Another limitation of this study was that the sampling frequency of the visual feedback was only relaying the power output at 4Hz. This resulted in the power and cadence changing slowly during testing, causing a variation in power output each test was conducted at. Some athletes found that they were overshooting the defined power level, while others slowly approached it causing potential differences in the muscle activity.

In addition, a limitation that existed in this study was not all variables that effect seat height were kept constant between athletes. Preferred seat heights were not determined the same way between athletes and some are based on personal preference rather than a calculated percentage of an anthropometric variable. As outlined in literature review, the seat height is a vital aspect in keeping the kinematics constant. If a different ratio of seat height to inseam is used, then the athlete's joints will be operating at different angles. Subsequently, this can lead to muscles operating in optimal and suboptimal conditions, causing variation in activations between subjects. This could be the reason for large stand deviations between subject's muscle activation patterns. This also resulted in the inability to directly compare raw joint angles and only the effect on range of motion could be explored.

Finally, there was no restriction on the activity on days prior to testing. This limitation related to the degree of fatigue that was potentially present in the athlete before testing. This could also result in a faster rate of fatigue throughout testing and less confidence in the results.

8 Conclusion

In this project, the biomechanics of elite track sprint cyclists was evaluated in response to various positional changes at maximal and submaximal power levels. Various studies have evaluated the effects of these conditions on road cyclists and triathletes, while very few papers have focussed on track sprint cyclists. As such, this study aimed to analyse the kinematics and EMG muscle activation patterns of the lower limbs in response to changes in handlebar type, seat height and power level in sprint cyclists.

Kinematic data showed that increasing power level from submaximal to maximal resulted in a significant increase in knee range of motion, while there was only a slight increase in ankle range of motion. Changing seat heights and handlebar types had very little effect on the kinematics of each cyclist. To understand the effects of these positions, further analysis is required to assess individual variations within the results. Due to poor skin to EMG electrode contact, there was a high rejection rate of EMG channels and consequently, muscle activity could not be compared between conditions. Finally, one of the most significant outcomes of this study was the development and refinement of a cycling 3D motion analysis protocol for future studies at Flinders University.

9 Future Work

Further work is required to develop a complete understanding of the kinematics and muscle activation patterns involved in cycling. The ultimate goal of Cycling Australia is to generate musculoskeletal models of their athletes to determine the ideal position of elite track sprint cyclists. The findings from this study will ultimately be used to refine a protocol for the testing procedure to create these models.

In this study, only the average results of the cohort were assessed in the analysis. From the graphs of kinematics and muscle activity, there was found to be a large standard deviation between athletes and this can be attributed to individualised responses to the different variables. Therefore, further individual analysis to determine which changes to position would provide more personal benefit to the athlete in relation to their understanding of their own biomechanics.

As one of the most important aspects of this study was to evaluate the effects of position on the biomechanics of cycling, future studies need to be conducted using more reliable data acquisition methods to produce more significant results. The error in this study could be attributed to the high percentage of rejection in the EMG data as well as the individual variation in preferred seat heights. Future studies would benefit from focusing on seat height as a function of anthropometric variables to minimise variance between subjects.

As previously mentioned, the high rejection rate of EMG channels was a major limitation to the validity of the muscle activity in this study. Based upon additional testing, poor skin to electrode contact was found to cause unreliable results. Therefore, it would be recommended that future studies at Flinders University eliminate this limitation by firmly holding the electrodes were placed with an elastic wrapping material or athletes be asked to wear long leg cycling pants.

Finally, the findings of this study show that changes in power level had a significant effect on the range of motion and displacement of joint centres. Future studies could benefit from pairing these findings with instrumented pedals to measure the force transfer from the athlete. As a result, the influence of these kinematic changes on the efficiency could be determined. The increase in lateral deviation of the knee was also theorised to have a potential impact on the aerodynamics of the athlete. Through the use of a wind tunnel or modelling to predict the impact of increasing power levels on aerodynamic, drag can be determined.

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Appendices

9.1 Appendix A: Participant Information Sheet/ Consent Form

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Participant Information Sheet/Consent Form

Non-Interventional Study - *Adult providing own consent*

Title	*Biomechanical Analysis of Cycling*
Coordinating Principal Investigator/ Principal Investigator	*Professor Mark Taylor* *Mr David Hobbs*
Associate Investigator(s)	*Mr Timothy Prins*
Location	*Flinders University, South Australia*

Part 1 What does my participation involve?

1 Introduction

You are invited to take part in this research project, *Biomechanical Analysis of Cycling*. This is because you have been nominated as a potential participant by Cycling Australia. The research project is aiming to obtain 3D motion capture and electromyography (EMG) data from you in our motion analysis laboratory for the purpose of movement analysis and understanding muscle activation patterns.

This Participant Information Sheet/Consent Form tells you about the research project. It explains the tests and research involved. Knowing what is involved will help you decide if you want to take part in the research.

Please read this information carefully. Ask questions about anything that you don't understand or want to know more about. Before deciding whether or not to take part, you might want to talk about it with a relative, friend or local doctor.

Participation in this research is voluntary. If you don't wish to take part, you don't have to.
If you decide you want to take part in the research project, you will be asked to sign the consent section. By signing it you are telling us that you:

• Understand what you have read

• Consent to take part in the research project
• Consent to the research that is described
• Consent to the use of your personal and health information as described.

You will be given a copy of this Participant Information and Consent Form to keep.

2 What is the purpose of this research?

This research is being conducted by Flinders University in conjunction with Cycling Australia for the purpose assessing motion capture and muscle activity during cycling at different positions and seat heights, with the aim to understand the muscle activation patterns during the crank cycle and how these activation patterns change with changes in position.

We already know that changing the seating position and general pose of the rider can change the direction of muscle forces and this improve the forces on the pedals. Therefore this study aims to explore how these changes can be used to improve training methods and the understanding of muscle recruitment.

The data obtained in each session will be processed in order to find the joint angles and muscle activity. This data will be used to determine if all training positions will train the same muscles in the same way or if one position shows a significant difference in muscle activity.

The results of this research will be used by the student, Timothy Prins, to obtain a Bachelor of Engineering (Biomedical), Master of Engineering (Biomedical) degree.

3 What does participation in this research involve?

To participate in this research the consent form must be signed prior to any parts of this study to be performed.

You are invited to be the participant in a motion capture study in the Rehabilitation and Motion Analysis Lab at Flinders University (*Figure 3*). Participation is entirely voluntary. You will be asked to attend 2 session in non-consecutive days, over a period of up to 2 weeks. Each individual testing session will take up to two hours. Once recorded, the data will be stored and processed as a computer file on a password protected hard drive.

The study involves the following tasks:

1. Be fitted with Vicon reflective motion capture markers (*Figure 1*) and electromyography (EMG) skin electrodes (*Figure 2)*.
2. You will then be asked to perform the following cycling tasks on a cycling ergometer (*Figure 4)*
3. Submaximal* on pursuit bars at preferred seat height
4. Submaximal on pursuit bars with seat height increased 5mm
5. Submaximal on sprint bars with seat height increased 5mm
6. Submaximal on sprint bars at preferred seat height
7. Repeat four previous tests for intra-testing reliability
8. 15 minute break where the gear ratio will be changed to reflect the change in power output.
9. Maximal** on pursuit bars at preferred seat height
10. Maximal on pursuit bars with seat height increased 5mm
11. Maximal on sprint bars with seat height increased 5mm
12. Maximal on sprint bars at preferred seat height
13. Repeat four previous tests for intra-testing reliability
14. Sensors will be removed and data collection process complete

**Sub-maximal efforts = 600 Watts for men's sprint team, 450W for Women/U19 men*

***Maximal efforts = 1000 Watts for men's sprint team, 850W for Women/U19 men*

All tests will be conducted over 5 second efforts at 115rpm.

Each test session will be repeated a total of 2 times, the purpose of this is to ensure that the data is reliable between testing dates.

This results in a total of 32 data captures over non-consecutive 2 days.

This research project has been designed to make sure the researchers interpret the results in a fair and appropriate way to avoid investigators or participants jumping to conclusions.

Figure 1 Reflective Motion Capture Marker

Figure 2 Delsys Wireless EMG Skin Electrodes

Figure 3 Rehabilitation and Motion Analysis Laboratory, Flinders University

Figure 4 Ergometer Attached to Road Bicycle (Examples only, testing will be done on track bikes with a LeMond Ergometer)

4 What do I have to do?

This study does not involve any restictions on your daily life. All you will be asked to do is participate in the data acquisition sessions.

5 Other relevant information about the research project

There may be up to 23 other participants in this study. These individuals will be chosen from track cyclists at Cyling Australia. This number is subject to variation depending on how many of these participants volunteer to participate in the study.

All of the participants of this study will be analysed separately as the output of this research is expected to be personalised musculoskeletal models of the athletes from the High Performance Unit of Cycling Australia.

6 Do I have to take part in this research project?

Participation in any research project is voluntary. If you do not wish to take part, you do not have to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage.

If you do decide to take part, you will be given this Participant Information and Consent Form to sign and you will be given a copy to keep.

Your decision whether to take part or not to take part, or to take part and then withdraw, will not affect you in any way or your relationship with Flinders University.

7 What are the possible benefits of taking part?

We cannot guarantee or promise that you will receive any benefits from this research, however possible benefits may include a better understanding of muscle activity during the crank cycle and how you are using your muscles when you ride. The potential benefit of this is to improve your overall performance during competitive track cycling and potential benefits to your training regime.

8 What are the possible risks and disadvantages of taking part?

While this research is of extremely low risk there may still be potential risks associated with this study that, while highly unlikely, may occur. These risks exist only due to the physical nature of this research, these include:

- slight physical discomfort due to the demanding nature of the cycling tasks
- potential injury if falling off of the ergometer

As all participants will be trained elite cyclist these risk is highly unlikely but still need to be addressed. In terms of physical discomfort you will not be pushed harder than you are capable of and adequate rest periods will be given to ensure that you are not exhausted at the end of the session. The bicycle will be attached to the ergometer, which has supports to prevent it from falling over, therefore this risk is extremely minimal.

9 What if I withdraw from this research project?

If you decide to withdraw from this research project, please notify a member of the research team before you withdraw. A member of the research team will inform you if there are any special requirements linked to withdrawing.

If you do withdraw your consent during the research project, the relevant study staff will not collect additional personal information from you, although personal information already collected will be retained to ensure that the results of the research project can be measured properly and to comply with law. You should be aware that data collected up to the time you withdraw will form part of the research project results.

10 What happens when the research project ends?

At the end of this project there will be no follow-ups, all information regarding the outputs of this project will be provided to Cycling Australia who will then provide you with the outcomes of the study and if it has been completed successfully.

Part 2 How is the research project being conducted?

11 What will happen to information about me?

By signing the consent form you consent to the relevant research staff collecting and using personal information about you for the research project. Any information that is obtained in connection with this research that can identify you will remain confidential to the public. The only people who have access to the data will be the research team at Flinders University and the trainers and managers at Cycling Australia.

All of the data obtained will be stored on password protected hard drives and participants will be given a number rather than directly identifying you. The participant numbers and names will then be stored in a password protected file on the password protected hard drive that only members of the project team will be aware of. Your information will only be used for the purpose of this research project and it will only be disclosed with your permission, except as required by law. The data and hard drives will be stored in the Professor Mark Taylor's office to prevent unauthorized access.

It is anticipated that the results of this research project will be published and/or presented in a variety of forums such as university assessment items (Masters thesis and associated presenations). In any publication and/or presentation, information will be provided in such a way that you cannot be identified.

In addition to this, reports will be released to both you and Cycling Australia containing your personal results of this study. In these reports your data will be identifiable in order for both Cycling Australia and you to understand the findings specific to you and how these can be used to improve your riding position, this will include EMG data, VO_2, motion capture data and pedal force data at varying seat heights. Please note that the reports will not influence you're position in your current cycling program and will only be used to improve your performance, however all personal processed data regarding your performance in the study will be returned to trainers and managers at Cycling Australia.

In accordance with relevant Australian and/or South Australian privacy and other relevant laws, you have the right to request access to the information collected and stored by the research team about you. You also have the right to request that any information with which you disagree be corrected. Please contact the research team member named at the end of this document if you would like to access your information.

12 Complaints

If you have any complaints about how the study is handled or if there are any problems with your treatment by members of staff please contact Flinders University at 8201 2118.

If you suffer any injuries or complications as a result of this research project, you should contact the study team and our Cycling Australia contact as soon as possible and you will be assisted with arranging appropriate medical treatment. The study team contact numbers are located at the end of this information sheet if there is need for contact.

13 Who is organising and funding the research?

This research project is being conducted by Timothy Prins as part of his Masters project at Flinders University in conjunction with Cycling Australia. All initial funding for this project will be coming from Flinders Univeristy's Masters thesis allocation that is assigned to each student prior to commencing their thesis.

Flinders University and Cycling Australia are the two main parties involved with the organisation of this project. Although these parties are involved they will not benefit financially from this research project.

No member of the research team will receive a personal financial benefit from your involvement in this research project (other than their ordinary wages).

14 Who has reviewed the research project?

All research in Australia involving humans is reviewed by an independent group of people called a Human Research Ethics Committee (HREC). The ethical aspects of this research project have been approved by the HREC of Flinders University of South Australia

This project will be carried out according to the *National Statement on Ethical Conduct in Human Research (2007)*. This statement has been developed to protect the interests of people who agree to participate in human research studies.

15 Further information and who to contact

The person you may need to contact will depend on the nature of your query.

If you want any further information concerning this project, you can contact any of the following people:

Project contact person

Name	Timothy Prins
Position	Masters Student Researcher, Flinders University

Telephone	8201 5732 (Professor Mark Taylor's Office Phone)
Email	Prin0057@flinders.edu.au

For matters relating to research at the site at which you are participating, the details of the local site complaints person are:

Complaints contact person

Name	Villis Marshall
Position	Director, Office for Research
Telephone	8204 6453
Email	Heath:SALHNofficeforresearch@sa.gov.au

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about being a research participant in general, then you may contact:

Reviewing HREC approving this research and HREC Executive Officer details

Reviewing HREC name	Southern Adelaide Clinical
HREC Executive Officer	Damian Creaser
Telephone	8204 6453
Email	Heath:SALHNofficeforresearch@sa.gov.au

Local HREC Office contact (Single Site -Research Governance Officer)

Name	Southern Adelaide Clinical
Position	Research Governance Officer
Telephone	8204 6139
Email	Heath:SALHNofficeforresearch@sa.gov.au

Consent Form - *Adult providing own consent*

Title	*Biomechanical Analysis of Cycling*
Coordinating Principal Investigator/	*Prof. Mark Taylor*
Principal Investigator	*Mr David Hobbs*
Associate Investigator	*Mr Timothy Prins*
Location	Flinders University, South Australia

Declaration by Participant

I have read the Participant Information Sheet or someone has read it to me in a language that I understand.

I understand the purposes, procedures and risks of the research described in the project.

I have had an opportunity to ask questions and I am satisfied with the answers I have received.

I freely agree to participate in this research project as described and understand that I am free to withdraw at any time during the project without affecting my future health care.

I understand that I will be given a signed copy of this document to keep.

Name of Participant (please print) ______________________________

Signature ______________________ Date ______________________

Declaration by Senior Researcher†

I have given a verbal explanation of the research project, its procedures and risks and I believe that the participant has understood that explanation.

Name of Senior Researcher† (please print) ______________________________

Signature ______________________ Date ______________________

† A senior member of the research team must provide the explanation of, and information concerning, the research project.

Note: All parties signing the consent section must date their own signature.

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Form for Withdrawal of Participation - *Adult providing own consent*

Title	Biomechanical Analysis of Cycling
Coordinating Principal Investigator/	*Prof. Mark Taylor*
Principal Investigator	
Associate Investigator(s) *(if required by institution)*	*Mr Timothy Prins*
Location	*Flinders University, South Australia*

Declaration by Participant

I wish to withdraw from participation in the above research project and understand that such withdrawal will not affect me in any way, or my relationship with Flinders University.

Name of Participant (please print) ______________________________

Signature ______________________________ Date ______________________________

Reason for Withdrawing:

Declaration by Senior Researcher†

I have given a verbal explanation of the implications of withdrawal from the research project and I believe that the participant has understood that explanation.

Name of Senior Researcher†
(please print) ______________________________

Signature ______________________________ Date ______________________________

† A senior member of the research team must provide the explanation of and information concerning withdrawal from the research project.

Note: All parties signing the consent section must date their own signature.

9.2 Appendix B: Demographic Questionnaire

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DEMOGRAPHIC QUESTIONNAIRE FOR PARTICIPATION IN RESEARCH

Biomechanical Analysis of Cycling

Participant Name ....

Age..

Gender..

Organisation..

Training Level..

Number of Hours Training per Week..

How long have you been cycling at a competitive level?

....

What type of cycling do you currently compete in?

....

I, the participant whose signature appears below, certify that the information provided in this document is accurate and agree for this information to be used in the study, Biomechanical Analysis of Cycling.

Participant's signature..**Date**......................

v1 dated 16 May 2017

9.3 Appendix C: Experimental Protocol (As Submitted to Ethics Committee)

Experimental Protocol

Biomechanical Analysis of Cycling

Equipment

- Vicon Camera System
- Reflective Motion Capture Markers
- Delsys Wireless Electromyography (EMG) Electrodes (surface electrodes)
- Notch Motion Sensors
- VO_2 MAX Portable Testing Machine
- Track Bicycle
- Cycling Ergometer

Equipment Setup

The laboratory is set up using 10 Vicon cameras with a cycling ergometer set up in the middle of the room (Figure 1).

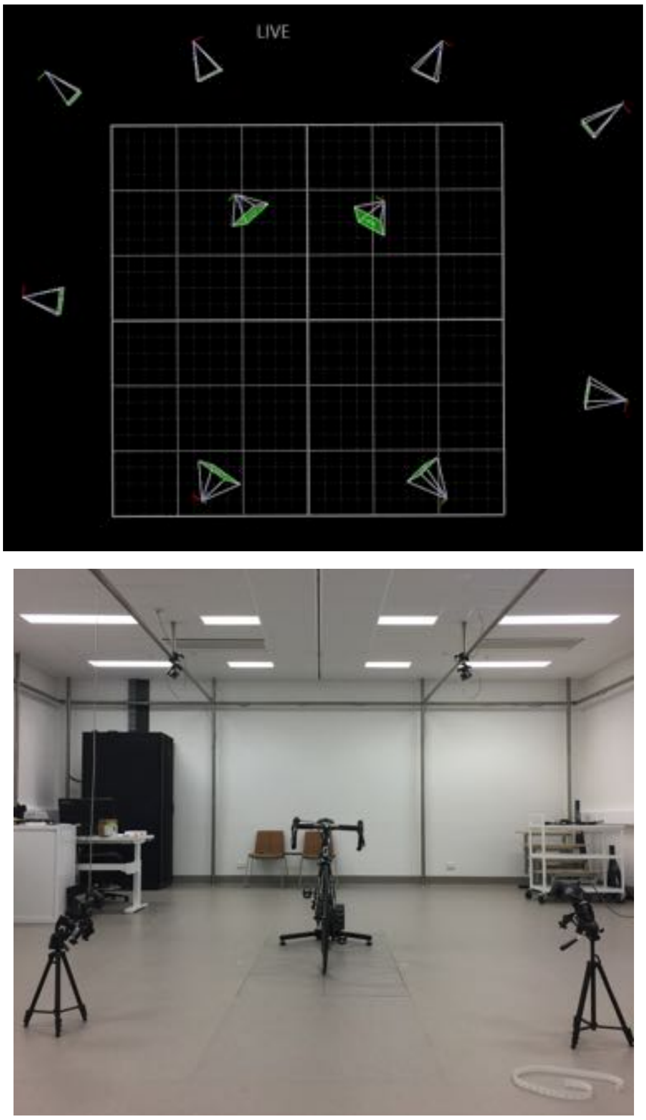

Figure 1 Laboratory layout for 3D motion capture

The motion capture markers are attached to the subject in the following configuration:

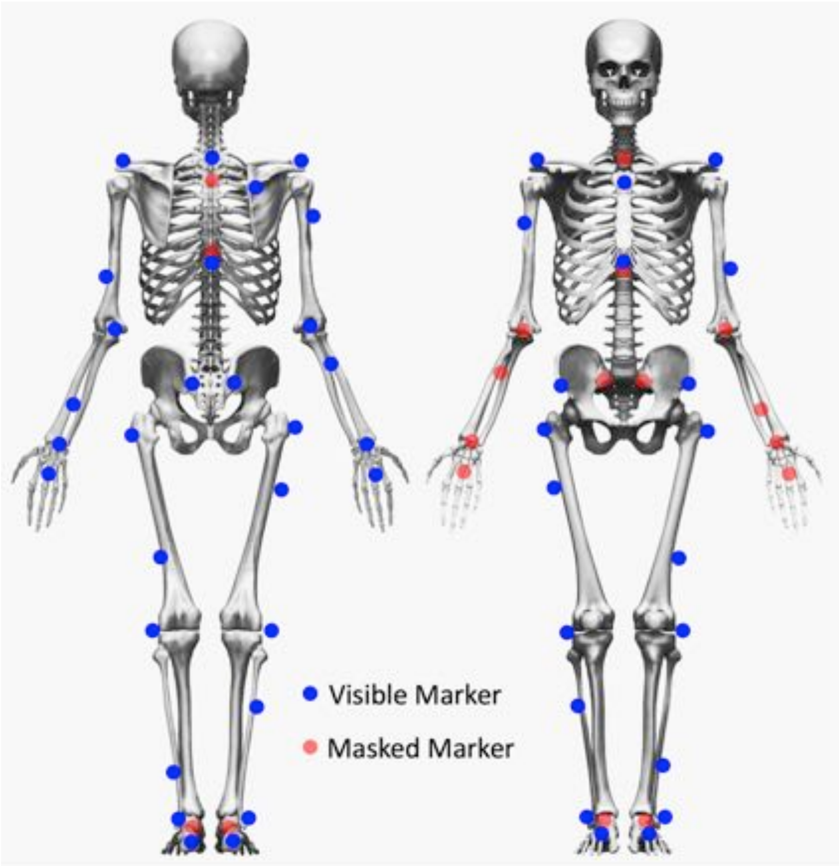

Figure 2 Placement of the reflective motion capture markers during testing

The Delsys wireless EMG surface electrodes were placed on 9 muscles of the leg: Gluteus maximus, bicep femoris, semitendinosus, rectus femoris, vastus lateralis, vastus medialis, tibialis, anterior, medial gastrocnemius, and soleus (Figure 3).

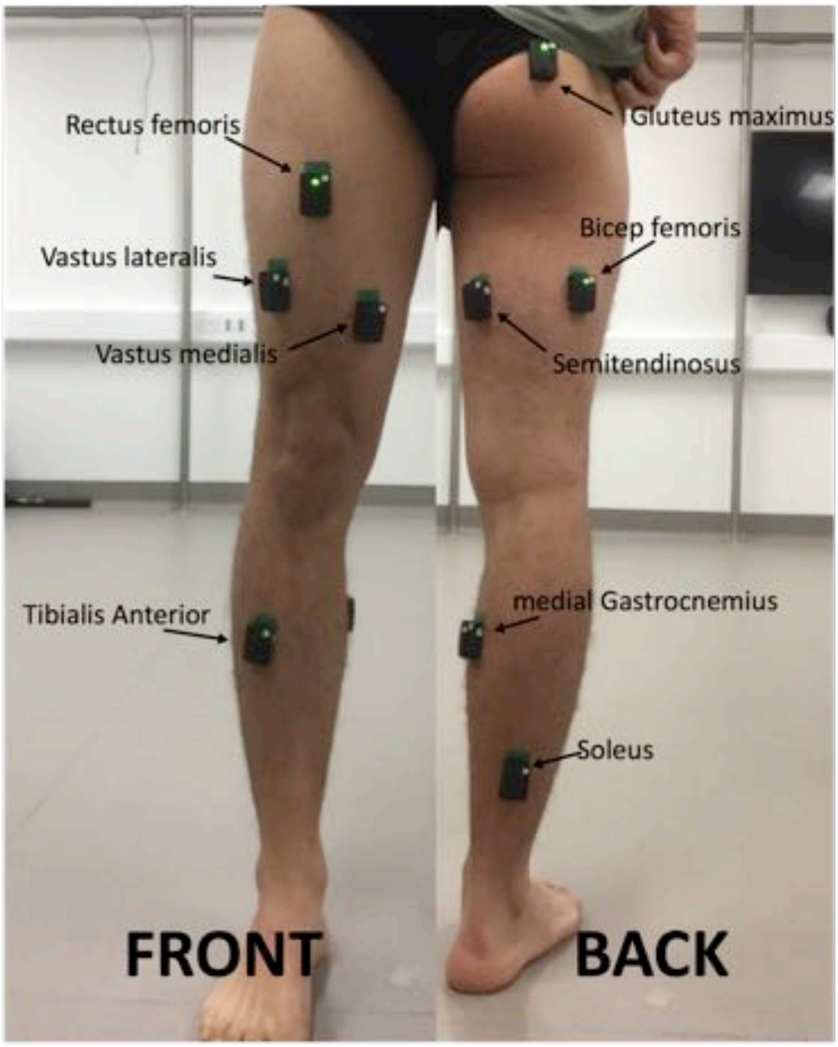

Figure 3 EMG electrode placement (note placement is not perfectly on muscle bellies as just taken as visual aid)

Experimental Procedure (for one test session)– Total Time: 2hours 10 minutes

Initial Test Preparation (Duration: 30minutes)

- Calibrate Vicon Camera System (Set up in Figure 1)
- Set up the bicycle and ergometer in the centre of the camera system (Figure 1)
- Explain protocol and study information to subject and obtain written consent
- EMG electrodes then applied to the muscles of the lower limb by double-sided tape (Figure 3)
- Apply the reflective motion capture markers to the subject's skin with double-sided tape in the configuration shown in Figure 2
- Static T-pose to obtain the positions of the markers to apply a marker labels to subject
- Label the markers on Vicon Nexus 2.5 using the static T-pose capture

*<u>Submaximal Tests (Gear Ratio: Men's=**54:16**, Women's/U19Mens=**50:16**)</u>*

Trial	Power (Watt)	Handlebars	Seat Height	Rep	Completed
1	600	TP	0	1	
2	600	TP	+5	1	
3	600	SPR	+5	1	
4	600	SPR	0	1	
5	600	TP	0	2	
6	600	TP	+5	2	
7	600	SPR	+5	2	
8	600	SPR	0	2	

*<u>Maximal Tests (Gear Ratio: Men's=**58:14**, Women's/U19Mens=**53:14**)</u>*

Trial	Power	Handlebars	Seat Height	Rep	Completed
9	1000	TP	0	1	
10	1000	TP	+5	1	
11	1000	SPR	+5	1	
12	1000	SPR	0	1	
13	1000	TP	0	2	
14	1000	TP	+5	2	
15	1000	SPR	+5	2	
16	1000	SPR	0	2	

<u>Clean Up/ Saving Data (Duration: 10 minutes)</u>

15. Remove EMG and motion capture markers –5 minutes
16. Save test data in .c3d and .csv formats from Vicon Nexus 2.5 (motion capture program)

Repeat each test session 3 times to test inter-test reliability (i.e. rough measure of technical testing error)

Total of 9 data captures over 3 days.

9.4 Appendix D: Description of Modified Plug-In-Gait Marker Set

Torso Markers

C7	7th Cervical Vertebrae	Spinous process of the 7th cervical vertebrae
T10	10th Thoracic Vertebrae	Spinous process of the 10th thoracic vertebrae
CLAV	Clavicle	Centre of the sternoclavicular joints
STRN	Sternum	Xiphoid process of the sternum
RBAK	Right Back	Placed on the middle of the right scapula as an asymmetrical marker to help define the marker set during auto-labelling.

Arm Markers

LSHO	Left shoulder	Centre of the acromio-clavicular joint.
LUPA	Left upper arm	Upper arm. Left upper arm is located lower on the upper arm than the right to provide asymmetry for auto-labelling.
LELB	Left elbow	Lateral epicondyle
LFRA	Left forearm	Placed on the forearm. Asymmetrically to the right side, left lower on the forearm close to wrist and right closer to elbow.
LWRA	Left wrist marker A	Radial styloid process
LWRB	Left wrist marker B	Ulnar styloid process
LFIN	Left finger	Just below the head of the second metacarpal

Pelvis Markers

LASI	Left ASIS	Over the left anterior superior iliac spine
RASI	Right ASIS	Over the right anterior superior iliac spine
LPSI	Left PSIS	Over the left posterior superior iliac spine
RPSI	Right PSIS	Over the right posterior superior iliac spine

Leg Markers

LHIP	Left Hip	Placed on the centre of the greater trochanter
LTHI	Left Thigh	On the left thigh between the greater trochanter and the knee. Left marker is placed lower than right to provide asymmetry.
LKNE	Left Knee	Lateral epicondyle of the knee
LTIB	Left Tibia	On the lateral side of the tibia. Left is low and right is higher to provide asymmetry.

Foot Markers

LANK	Left Ankle	On the lateral malleolus
LHEE	Left Heel	Placed on the shoe relative to the calcaneous
LTOE	Left Toe	Marker was placed on the toe in line with the second metatarsal head
LFOOT	Left Foot	This marker represents the location of the pedal in the crank cycle. Placed on the shoe relative to the head of the fifth metatarsal joint which is directly located in line with the cleat attachment to the pedal

9.5 Appendix E: Table of Rejected EMG Channels

Athlete Number	Session	Condition	Muscle Usability (1 = p > 0.05, 0 = p < 0.05)								
			Gmax	BF	ST	VM	RF	VL	TA	mGas	Sol
1	1	TP +0 Sub	1	1	0	1	1	1	0	0	0
1	1	TP +5 Sub	0	0	0	0	0	0	0	0	0
1	1	SPR +5 Sub	0	1	0	1	1	1	0	1	1
1	1	SPR +0 Sub	1	0	0	1	1	1	1	1	1
1	1	TP +0 Max	0	1	0	1	0	1	0	1	0
1	1	TP +5 Max	1	1	1	1	1	0	0	1	1
1	1	SPR +5 Max	0	0	0	0	0	0	0	0	0
1	1	SPR +0 Max	0	0	0	0	0	0	0	0	0
1	2	TP +0 Sub	0	0	0	0	0	0	0	1	1
1	2	TP +5 Sub	0	0	1	1	1	0	0	1	0
1	2	SPR +5 Sub	0	0	0	1	1	0	1	0	0
1	2	SPR +0 Sub	1	0	1	1	0	1	1	1	0
1	2	TP +0 Max	1	1	0	1	1	0	1	1	1
1	2	TP +5 Max	1	0	1	0	0	1	1	1	0
1	2	SPR +5 Max	1	0	0	1	1	0	1	1	0
1	2	SPR +0 Max	1	1	0	0	1	1	1	1	0
2	1	TP +0 Sub	1	1	1	1	1	1	1	0	1
2	1	TP +5 Sub	0	1	0	0	1	0	0	0	0
2	1	SPR +5 Sub	1	0	1	1	0	1	0	1	1
2	1	SPR +0 Sub	0	0	0	1	1	0	0	0	0
2	1	TP +0 Max	0	0	0	0	0	0	0	0	0
2	1	TP +5 Max	0	0	1	0	0	0	0	1	1
2	1	SPR +5 Max	0	0	1	0	0	0	0	0	0
2	1	SPR +0 Max	0	0	0	1	0	0	1	0	0
2	2	TP +0 Sub	1	0	1	0	0	1	1	0	0
2	2	TP +5 Sub	1	1	0	1	0	0	0	1	1
2	2	SPR +5 Sub	1	1	0	1	1	0	0	0	1
2	2	SPR +0 Sub	1	0	1	1	0	1	0	0	0
2	2	TP +0 Max	1	0	1	1	0	1	1	1	0
2	2	TP +5 Max	1	1	0	1	1	0	0	1	0

Athlete Number	Session	Condition	Muscle Usability (1 = p > 0.05, 0 = p < 0.05)								
			Gmax	BF	ST	VM	RF	VL	TA	mGas	Sol
2	2	SPR +5 Max	0	0	0	0	0	0	1	1	1
2	2	SPR +0 Max	1	1	0	1	1	0	0	1	1
3	1	TP +0 Sub	1	1	0	1	1	1	0	1	1
3	1	TP +5 Sub	1	0	0	1	1	1	0	1	0
3	1	SPR +5 Sub	1	1	1	1	1	1	0	1	1
3	1	SPR +0 Sub	1	1	0	1	1	1	0	0	0
3	1	TP +0 Max	1	1	1	0	1	1	1	1	0
3	1	TP +5 Max	1	0	0	1	1	0	0	1	0
3	1	SPR +5 Max	1	0	0	1	0	0	1	1	1
3	1	SPR +0 Max	1	1	0	1	0	0	0	0	1
3	2	TP +0 Sub	0	0	0	0	0	0	0	0	0
3	2	TP +5 Sub	0	0	0	0	0	0	0	0	0
3	2	SPR +5 Sub	0	0	0	0	0	0	0	0	0
3	2	SPR +0 Sub	0	0	0	0	0	0	0	0	0
3	2	TP +0 Max	0	0	0	0	0	0	0	0	0
3	2	TP +5 Max	0	0	0	0	0	0	0	0	0
3	2	SPR +5 Max	0	0	0	0	0	0	0	0	0
3	2	SPR +0 Max	0	0	0	0	0	0	0	0	0
4	1	TP +0 Sub	1	1	0	1	1	0	1	1	1
4	1	TP +5 Sub	0	1	0	0	1	0	1	1	1
4	1	SPR +5 Sub	0	0	1	1	0	0	1	1	0
4	1	SPR +0 Sub	1	0	0	1	1	0	1	1	0
4	1	TP +0 Max	0	0	1	0	1	0	0	1	0
4	1	TP +5 Max	1	0	0	1	0	0	0	1	1
4	1	SPR +5 Max	1	0	1	1	1	0	0	1	1
4	1	SPR +0 Max	1	0	0	0	1	0	1	0	0
4	2	TP +0 Sub	0	0	0	0	0	0	0	1	0
4	2	TP +5 Sub	0	0	0	0	1	1	0	1	0
4	2	SPR +5 Sub	0	1	0	1	1	0	1	1	0
4	2	SPR +0 Sub	0	1	1	1	0	1	0	1	0
4	2	TP +0 Max	0	1	1	1	0	0	0	1	0

Athlete Number	Session	Condition	Muscle Usability (1 = p > 0.05, 0 = p < 0.05)								
			Gmax	BF	ST	VM	RF	VL	TA	mGas	Sol
4	2	TP +5 Max	1	1	0	1	0	0	1	1	0
4	2	SPR +5 Max	0	1	0	1	1	0	0	1	0
4	2	SPR +0 Max	0	1	0	0	1	0	1	1	0
5	1	TP +0 Sub	1	0	0	0	1	1	1	1	1
5	1	TP +5 Sub	1	1	0	1	1	0	1	1	1
5	1	SPR +5 Sub	1	1	1	1	1	1	1	1	1
5	1	SPR +0 Sub	1	1	0	0	1	1	0	1	1
5	1	TP +0 Max	1	1	1	1	1	1	1	1	1
5	1	TP +5 Max	1	1	0	1	0	0	1	1	1
5	1	SPR +5 Max	1	1	1	0	1	1	0	1	1
5	1	SPR +0 Max	1	0	0	0	0	1	1	1	0
5	2	TP +0 Sub	1	1	1	1	0	1	1	0	1
5	2	TP +5 Sub	0	1	1	0	1	0	0	1	1
5	2	SPR +5 Sub	0	1	0	1	0	1	0	0	1
5	2	SPR +0 Sub	1	1	0	0	0	1	0	0	1
5	2	TP +0 Max	0	1	1	0	1	1	1	1	1
5	2	TP +5 Max	1	0	0	1	1	0	1	1	0
5	2	SPR +5 Max	1	1	1	1	1	0	1	0	1
5	2	SPR +0 Max	0	0	1	0	1	1	0	1	0
6	1	TP +0 Sub	0	1	1	1	0	0	0	1	1
6	1	TP +5 Sub	0	1	1	0	0	1	0	0	1
6	1	SPR +5 Sub	1	0	0	1	1	0	1	1	1
6	1	SPR +0 Sub	1	1	0	1	1	0	1	0	1
6	1	TP +0 Max	0	0	1	0	1	0	1	1	1
6	1	TP +5 Max	1	0	1	1	1	0	0	1	1
6	1	SPR +5 Max	1	1	1	0	0	1	1	1	1
6	1	SPR +0 Max	1	1	1	1	1	1	1	1	0
6	2	TP +0 Sub	1	1	0	1	1	0	1	1	1
6	2	TP +5 Sub	0	0	0	1	1	0	0	1	0
6	2	SPR +5 Sub	1	1	0	0	1	0	1	1	1
6	2	SPR +0 Sub	1	0	1	1	1	0	1	1	1

Athlete Number	Session	Condition	Muscle Usability (1 = p > 0.05, 0 = p < 0.05)								
			Gmax	BF	ST	VM	RF	VL	TA	mGas	Sol
6	2	TP +0 Max	1	0	1	1	1	1	1	1	1
6	2	TP +5 Max	0	0	0	0	0	0	1	0	1
6	2	SPR +5 Max	1	1	1	0	0	0	1	1	1
6	2	SPR +0 Max	0	0	1	1	0	0	1	1	0
7	1	TP +0 Sub	1	0	1	0	1	0	1	1	0
7	1	TP +5 Sub	1	1	0	0	1	1	1	1	1
7	1	SPR +5 Sub	1	0	0	1	1	1	1	1	0
7	1	SPR +0 Sub	1	0	0	1	1	1	1	0	0
7	1	TP +0 Max	0	1	1	1	1	1	0	0	1
7	1	TP +5 Max	0	0	1	0	0	0	0	1	1
7	1	SPR +5 Max	1	0	0	1	0	0	0	1	1
7	1	SPR +0 Max	0	1	1	1	0	1	0	1	1
7	2	TP +0 Sub	1	0	0	1	0	0	1	1	0
7	2	TP +5 Sub	0	0	0	0	0	1	0	0	0
7	2	SPR +5 Sub	0	0	0	0	0	0	0	1	0
7	2	SPR +0 Sub	0	0	1	1	0	1	1	1	0
7	2	TP +0 Max	1	0	0	0	0	1	0	0	0
7	2	TP +5 Max	1	0	0	0	0	1	0	1	0
7	2	SPR +5 Max	1	0	0	0	0	1	0	1	0
7	2	SPR +0 Max	0	0	0	0	0	1	1	1	0
8	1	TP +0 Sub	0	0	1	1	1	0	1	0	1
8	1	TP +5 Sub	1	0	0	0	0	0	0	0	0
8	1	SPR +5 Sub	0	0	0	0	0	0	1	0	0
8	1	SPR +0 Sub	1	1	0	0	0	1	0	1	1
8	1	TP +0 Max	1	0	1	0	0	0	0	0	0
8	1	TP +5 Max	1	0	0	0	1	0	0	1	1
8	1	SPR +5 Max	1	0	0	0	0	0	0	1	1
8	1	SPR +0 Max	0	0	0	0	0	0	0	0	0
8	2	TP +0 Sub	0	0	0	0	0	1	0	0	1
8	2	TP +5 Sub	0	0	0	0	0	0	0	0	0
8	2	SPR +5 Sub	1	0	1	0	1	0	0	0	1

Athlete Number	Session	Condition	Muscle Usability (1 = p > 0.05, 0 = p < 0.05)								
			Gmax	BF	ST	VM	RF	VL	TA	mGas	Sol
8	2	SPR +0 Sub	1	0	1	0	0	0	1	0	1
8	2	TP +0 Max	1	0	0	0	1	0	1	0	1
8	2	TP +5 Max	0	0	1	0	1	1	0	1	0
8	2	SPR +5 Max	1	1	0	1	1	1	0	0	0
8	2	SPR +0 Max	0	0	0	0	0	0	0	1	0
All	Total	TP +0 Sub	10	7	6	9	8	7	9	9	10
All	Total	TP +5 Sub	5	7	3	5	9	5	3	9	6
All	Total	SPR +5 Sub	8	7	5	11	10	6	8	10	9
All	Total	SPR +0 Sub	12	6	6	11	8	10	8	8	7
All	Total	TP +0 Max	8	7	10	7	9	8	8	10	7
All	Total	TP +5 Max	11	4	6	8	7	3	5	14	8
All	Total	SPR +5 Max	11	6	6	7	6	4	6	11	9
All	Total	SPR +0 Max	6	6	4	6	6	6	8	10	3

9.6 Appendix F: Tables of Muscle Activation Patterns

Table 1: Muscle activation patterns in response to pursuit handlebars and preferred seat height at submaximal power level.

Muscles	**Onset (˚)**	**Offset (˚)**	**Duration (˚)**
GMax (4)	35 (59)	218 (49)	144 (43)
BF (6)	15 (55)	223 (43)	212 (45)
ST (7)	78 (16)	236 (18)	153 (32)
VM (6)	353 (28)	148 (32)	154 (17)
RF (7)	328 (40)	129 (37)	154 (42)
VL (5)	357 (10)	147 (9)	151 (12)
TA (5)	281 (64)	230 (105)	248 (106)
mGas (4)	83 (89)	243 (54)	158 (24)
Sol (4)	52 (30)	182 (30)	128 (6)

Table 2: Muscle activation patterns in response to pursuit handlebars and increased seat height at submaximal power level.

Muscles	**Onset (˚)**	**Offset (˚)**	**Duration (˚)**
GMax (7)	43 (75)	197 (53)	132 (58)
BF (6)	9 (24)	226 (55)	214 (35)
ST (7)	77 (14)	243 (19)	160 (31)
VM (6)	347 (78)	152 (52)	163 (28)
RF (4)	309 (42)	131 (37)	170 (43)
VL (6)	355 (12)	152 (16)	155 (10)
TA (8)	281 (60)	251 (103)	254 (81)
mGas (4)	59 (59)	248 (45)	159 (71)
Sol (7)	52 (40)	183 (25)	140 (29)

Table 3: Muscle activation patterns in response to sprint handlebars and increased seat height at submaximal power level.

Muscles	Onset (˚)	Offset (˚)	Duration (˚)
GMax (5)	38 (58)	176 (58)	148 (84)
BF (6)	12 (44)	226 (44)	209 (48)
ST (7)	78 (22)	232 (26)	157 (30)
VM (3)	351 (37)	149 (25)	154 (16)
RF (5)	318 (51)	119 (46)	121 (63)
VL (6)	356 (14)	150 (14)	152 (9)
TA (6)	284 (41)	267 (93)	300 (40)
mGas (4)	80 (75)	237 (40)	160 (26)
Sol (4)	48 (42)	181 (30)	131 (9)

Table 4: Muscle activation patterns in response to sprint handlebars and preferred seat height at submaximal power level.

Muscles	Onset (˚)	Offset (˚)	Duration (˚)
GMax (3)	43 (71)	236 (53)	137 (34)
BF (6)	10 (57)	214 (39)	206 (47)
ST (8)	72 (15)	232 (23)	163 (27)
VM (2)	3 (30)	153 (36)	149 (20)
RF (6)	313 (45)	130 (42)	153 (34)
VL (4)	350 (11)	147 (16)	154 (15)
TA (5)	289 (37)	255 (97)	248 (82)
mGas (6)	67 (62)	235 (57)	153 (58)
Sol (5)	48 (14)	182 (13)	134 (8)

Table 5: Muscle activation patterns in response to pursuit handlebars and preferred seat height at maximal power level.

Muscles	Onset (˚)	Offset (˚)	Duration (˚)
GMax (6)	34 (81)	172 (64)	123 (60)
BF (5)	354 (74)	233 (80)	232 (48)
ST (4)	83 (21)	243 (39)	158 (22)
VM (7)	338 (14)	146 (12)	166 (18)
RF (5)	312 (26)	127 (28)	154 (46)
VL (5)	342 (16)	147 (10)	164 (13)
TA(5)	180 (104)	56 (103)	225 (55)
mGas (3)	64 (75)	228 (60)	164 (23)
Sol (6)	42 (89)	179 (65)	138 (9)

Table 6: Muscle activation patterns in response to pursuit handlebars and increased seat height at maximal power level.

Muscles	Onset (˚)	Offset (˚)	Duration (˚)
GMax (4)	37 (87)	269 (62)	209 (57)
BF (8)	359 (70)	231 (52)	223 (52)
ST (7)	80 (22)	269 (51)	172 (24)
VM (5)	338 (16)	150 (10)	171 (11)
RF (6)	322 (21)	122 (14)	153 (36)
VL (8)	345 (9)	149 (7)	162 (17)
TA (7)	170 (71)	58 (73)	249 (60)
mGas (1)	59 (80)	294 (57)	235 (0)
Sol (7)	43 (59)	177 (37)	134 (11)

Table 7: Muscle activation patterns in response to sprint handlebars and increased seat height at maximal power level.

Muscles	**Onset (˚)**	**Offset (˚)**	**Duration (˚)**
GMax (2)	26 (89)	206 (54)	182 (47)
BF (6)	359 (64)	197 (80)	208 (58)
ST (6)	70 (12)	243 (18)	164 (29)
VM (5)	340 (23)	147 (12)	162 (16)
RF (5)	311 (21)	127 (24)	171 (29)
VL (8)	346 (19)	149 (12)	162 (13)
TA (5)	176 (65)	56 (58)	223 (58)
mGas (3)	76 (72)	238 (63)	156 (31)
Sol (5)	36 (59)	173 (77)	137 (7)

Table 8: Muscle activation patterns in response to sprint handlebars and preferred seat height at maximal power level.

Muscles	**Onset (˚)**	**Offset (˚)**	**Duration (˚)**
GMax (6)	38 (64)	223 (37)	192 (49)
BF (6)	3 (40)	245 (58)	228 (54)
ST (7)	73 (37)	252 (38)	165 (28)
VM (5)	344 (28)	153 (8)	168 (18)
RF (6)	313 (50)	128 (51)	168 (26)
VL (5)	341 (9)	147 (8)	165 (11)
TA (5)	165 (87)	60 (70)	272 (38)
mGas (4)	52 (50)	252 (46)	207 (40)
Sol (7)	39 (39)	183 (48)	150 (35)

9.7 Appendix G: Signed Ethics Approval Form

Office for Research

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Government of South Australia
SA Health
Southern Adelaide Local Health Network

Final Approval for Ethics Application

14 July 2017

Prof. Mark Taylor
School of Computer Science, Engineering and Mathematics
Flinders University
GPO Box 2100
ADELAIDE SA 5001

Dear Prof. Taylor

OFR Number: 70.17
HREC reference number: HREC/17/SAC/103
Project title: Biomechanical Analysis of Cycling in High Level Athletes
Chief Investigator: Professor Mark Taylor

Ethics Approval Period: 26 June 2017 – 26 June 2020

The Southern Adelaide Clinical Human Research Ethics Committee (SAC HREC EC00188) have reviewed and provided approval for this application which appears to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007)*.

You are reminded that this letter constitutes **Ethics** approval only. **Ethics approval is one aspect of the research governance process**.

You must not commence this research project at any SA Health sites listed in the application until a Site Specific Assessment (SSA), or Access Request for data or tissue form, has been approved by the Chief Executive or delegate of each site.

The below documents have been reviewed and approved:

- Cover email 27 March 2017
- Low and Negligible Risk (LNR) Research form dated 16 May 2017
- Participant Information Sheet/Consent Form v3 dated 02 April 2017
- Experimental Protocol v2 dated 08 June 2017
- Demographic questionnaire v1 dated 16 May 2017

Terms and Conditions Of Ethics Approval:

As part of the Institution's responsibilities in monitoring research and complying with audit requirements, it is essential that researchers adhere to the conditions below and with the *National Statement chapter 5.5.*

Final ethics approval is granted subject to the researcher agreeing to meet the following terms and conditions:

1. The approval only covers the science and ethics component of the application. A SSA will need to be submitted and authorised before this research project can commence at any of the approved sites identified in the application.
2. If University personnel are involved in this project, the Principal Investigator should *notify* the University before commencing their research to ensure compliance with University requirements including any insurance and indemnification requirements.
3. Compliance with the *National Statement on Ethical Conduct in Human Research* (2007) & the *Australian Code for the Responsible Conduct of Research* (2007).
4. To immediately report to SAC HREC anything that may change the ethics or scientific integrity of the project.
5. Report Significant Adverse events (SAE's) as per SAE requirements available at our website.
6. Submit an annual report on each anniversary of the date of final approval and in the correct template from the SAC HREC website.
7. Confidentiality of research participants MUST be maintained at all times.
8. A copy of the signed consent form must be given to the participant unless the project is an audit.
9. Any reports or publications derived from the research should be submitted to the Committee at the completion of the project.
10. All requests for access to medical records at any SALHN site must be accompanied by this approval email.
11. To regularly review the SAC HREC website and comply with all submission requirements, as they change from time to time.
12. Once your research project has concluded, any new product/procedure/intervention cannot be conducted in the SALHN as standard practice without the approval of the SALHN New Medical Products and Standardisation Committee or the SALHN New Health Technology and Clinical Practice Innovation Committee (as applicable). Please refer to the relevant committee link on the SALHN intranet for further information.

For any queries about this matter, please contact The Office for Research on (08) 8204 6453 or via email to Health.SALHNOfficeforResearch@sa.gov.au

Yours sincerely

A/Professor Bernadette Richards
Chair, SAC HREC