

## Original Research

## Muscle recruitment patterns and saddle pressure indexes with alterations in effective seat tube angle

Reece McDonald, Wendy Holliday\*, Jeroen Swart

Department of Human Biology, Faculty of Health Sciences, University of Cape Town, South Africa

## ARTICLE INFO

## Keywords:

EMG  
Muscle recruitment  
Seat tube angle  
Pressure mapping

## ABSTRACT

Alteration of the effective seat tube angle (ESTA) may affect muscle activation patterns of the lower limbs in cycling. There is conflicting evidence due to inadequate kinematic controls in previous studies. The primary aim of this study was to determine the muscle activity of seven lower limb muscles during alterations of the ESTA by altering the position of both the handlebars and saddle forwards or backwards by 3 cm while ensuring controlled kinematics. Secondly, to determine the effect on the saddle pressure indexes. Ten participants performed two 5 min electromyography (EMG) trials at 70% of peak power output (PPO) for three consecutive visits. There was a significant increase in muscle activity in the biceps femoris, gluteus maximus, and medial gastrocnemius with reductions in ESTA while a significant increase in tibialis anterior with increases in ESTA was observed. Saddle pressure indices demonstrated a significant change in frontal versus back pressure as well as mean pubic pressure with changes in ESTA. Alteration in the ESTA affects muscle activity in some, but not all of the lower limb muscles. Further research needs to be conducted to adequately understand the mechanism behind the differences in muscle activation.

## Introduction

The cyclist has three contact points with the bicycle; the handlebars, the pedals, and the saddle. The saddle height, saddle setback, handlebar reach, and handlebar drop are the four standard measurements that relate to these three contact points of the cyclist to the bicycle.<sup>1</sup> (Fig. 1). Understanding these four objective standard measurements and their orientation around the crank axle is important in the optimisation of comfort, economy, and performance.<sup>2</sup> The seat tube angle (STA) is the angle between the actual physical seat tube and a horizontal line extending from the crank axle towards the rear axle and is fixed with the geometry of the bicycle frame. The effective seat tube angle (ESTA) differs from the STA as it is the angle from the crank axle to the point of contact on the saddle for the ischial tuberosities. Shifting the saddle forward or backward relative to the crank axle may alter the ESTA of the cyclist and therefore potentially elicit a change in muscle recruitment and economy.

There are several studies that have investigated the effect of STA alterations on muscle recruitment and economy in cycling.<sup>2,3</sup> These studies altered the STA, but did not conform to the subject's freely chosen saddle height, nor did they control the torso position and associated hip flexion

angle by adjusting the handlebars in conjunction with the saddle setback. Increasing the ESTA while maintaining the same handlebar configuration will lead to an increase in trunk inclination and hip joint angle.<sup>3</sup> This distributes the cyclist's mass further forward and over the crank axle but also allows results in a greater hip extension<sup>4</sup> potentially altering hip torque or oxygen cost.<sup>5</sup> Conversely, a shallower STA has been reported to allow pre-stretching of the gluteus maximus, which may improve propulsion.<sup>6</sup> Altering the body position, saddle height, and body orientation will, in turn, affect joint angles, muscle length, and muscle moment arm length.<sup>7</sup> By changing the length-tension properties of the muscle, there may be changes in force, velocity, and power production of the muscles as well as altering measured the muscle activity.<sup>8</sup>

Gonzalez and Hull<sup>2</sup> concluded that the joint moment cost is affected by STA, saddle height, and crank arm length. They further propose that these three variables interact, and it is important to consider individual cyclist variation. This means that any alteration in one of these three variables could potentially result in a change in muscle activity. As seen in Ericson and Nisell,<sup>9</sup> Heil et al.,<sup>10</sup> and Price and Donne,<sup>11</sup> the alteration of saddle height and consequently pedal-foot position can result in hip, knee, and ankle joint changes during the pedal cycle. In lieu of the above, not adjusting the handlebar position and saddle height in relation to ESTA and therefore hip, knee, and shoulder kinematics may have

\* Corresponding author.

E-mail addresses: [Mcdree002@myuct.ac.za](mailto:Mcdree002@myuct.ac.za) (R. McDonald), [wendzh@gmail.com](mailto:wendzh@gmail.com) (W. Holliday), [Jeroen.swart@uct.ac.za](mailto:Jeroen.swart@uct.ac.za) (J. Swart).<https://doi.org/10.1016/j.smhs.2021.10.007>

Received 6 July 2021; Received in revised form 28 September 2021; Accepted 20 October 2021

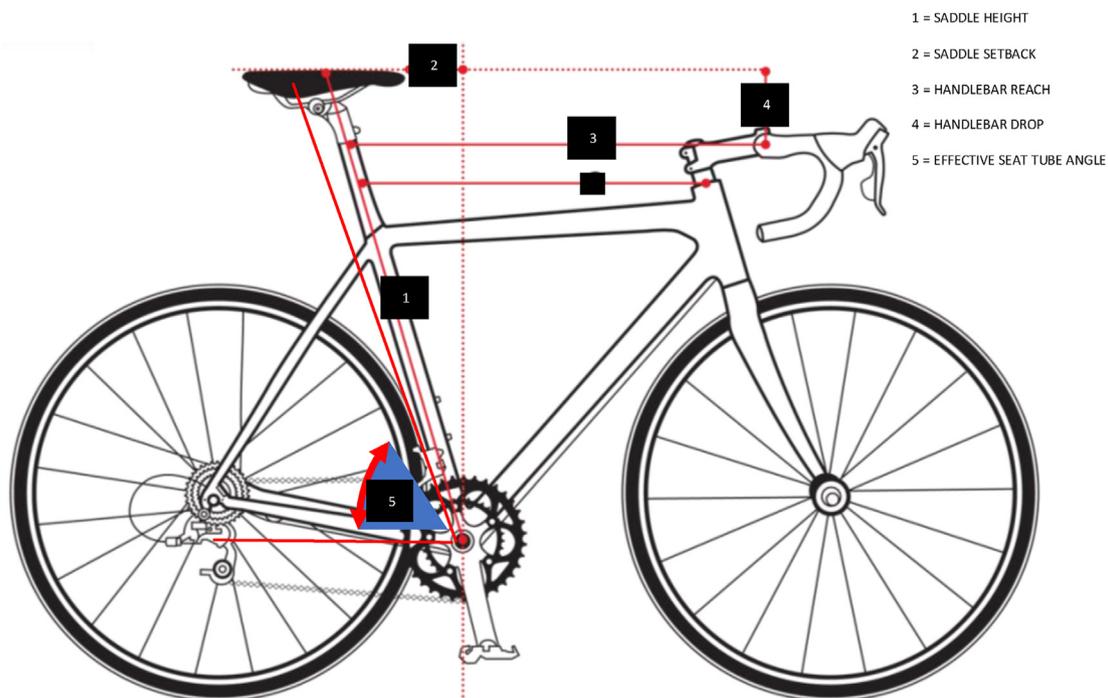
Available online 23 October 2021

2666-3376/© 2021 Chengdu Sport University. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd.

**Abbreviations**

ACSM	American College of Sports Medicine
ANOVA	analysis of variance
BDC	bottom dead centre
BF	biceps femoris
CoP	centre of pressure
EMG	Electromyography
ESTA	Effective seat tube angle
GM	gluteus maximus
iEMGr	integrated electromyography ratio
MG	medial gastrocnemius

PAR-Q	Physical Activity Readiness Questionnaire
PPO	Peak Power Output
RF	rectus femoris
RMS	root mean squared
RPM	revolutions per minute
SD	standard deviation
SENIAM	Surface EMG for Non-invasive Assessment of Muscles
STA	Seat tube angle
TA	tibialis anterior
VL	vastus lateralis
VM	vastus medialis



**Fig. 1.** Demonstration of the four standard measurements. The saddle height, saddle setback, handlebar reach and handlebar drop.

influenced the outcomes of the aforementioned studies. This may explain many of the conflicting findings in the existing literature.

Muscle activity has been extensively studied in the literature in an attempt to improve pedalling economy and efficiency.<sup>12–17</sup> The muscles most typically studied in cycling are the gluteus maximus (GM), rectus femoris (RF), vastus lateralis (VL), vastus medialis (VM), biceps femoris (BF, long head), medial gastrocnemius (MG), and tibialis anterior (TA).<sup>14</sup> The GM and BF act as hip extensors, the BF and MG as knee flexors, the VM, VL, and RF as knee extensors, the MG as an ankle extensor causing plantar flexion, and the TA as an ankle flexor causing dorsiflexion.<sup>18</sup> It is therefore important to investigate muscle activity patterns in cycling with respect to changes in ESTA however ensuring that these are independent of changes in saddle height or changes in joint kinematics.

Recent advances in technology have allowed for the measurement of pressure at the interface between the cyclist and the saddle. Saddle pressure analysis is commonly divided into quadrants, to differentiate between anterior and posterior, and left and right. The reliability and validity of these pressure measurements have been previously determined.<sup>19</sup> This technology may present a convenient and indirect method to assess the position of the cyclist with respect to the contact points.

However, there is currently no evidence to support the use of saddle pressure mapping to optimise ESTA in cycling.

The aim of this study was to determine the muscle activity of the GM, RF, VL, VM, BF, MG and TA, and to assess changes in the saddle pressure mapping indexes with alteration of the ESTA. This was achieved by positioning both the handlebars and saddle forwards or backwards concurrently by 3 cm. In addition, the static joint angles of the elbow, shoulder, hip, knee, and ankle joints were measured after each change to ensure that no kinematic differences occurred. We have previously demonstrated that this technique is valid and reliable.<sup>20</sup>

## Methods

### Participant selection

Ten trained male cyclists ( $26.6 \pm 7.2$  years,  $182.2 \pm 6.3$  cm,  $76.3 \pm 8.0$  kg,  $\dot{V}O_{2\max}$   $63.9 \pm 6.1$  ml  $\text{kg}^{-1}\text{min}^{-1}$ ) conforming to De Pauws<sup>21</sup> Level 2 or greater were recruited for the study. A Physical Activity Readiness Questionnaire (PAR-Q),<sup>22</sup> training history questionnaire, and an informed consent form were completed and signed by each

participant prior to partaking in the study. Each participant was informed of the potential risks and protocol prior to each visit. The study was approved by the Research and Ethics Committee of the Faculty of Health Sciences, University of Cape Town, and conformed to the World Medical Association Declaration of Helsinki<sup>23</sup> and the American College of Sports Medicine (ACSM) Guidelines for the use of Human Subjects.<sup>22</sup> One participant was too tall for the ergometer adjustment limits, and as such his data were excluded.

### Testing protocol

The participants were required to visit the laboratory on four separate occasions, at one-week intervals. A preliminary visit was followed by three experimental visits, where the bicycle configuration was altered. During the first visit, an anthropometric assessment of stature, body mass, and seven-site skinfolds were performed. The participants were then set up on an adjustable ergometer (CycleOps 400 Indoor Pro Cycle: Power Tap: Saris Corp., Madison, WI, USA) with their freely chosen position on the road bike matched using the methods as described in Appendix A. Prior to a standardised warm-up,<sup>24</sup> participants' static joint angles were measured using a digital inclinometer as described in Appendix B (Digi-Pas® DWL-80E model). The inclinometer was calibrated using manufacturer-provided instructions. Joint angles were measured to ensure the bicycle and CycleOps positions corresponded, and all angles were checked after any position change during the trial to ensure no change occurred. We have previously demonstrated that this measuring technique is reliable.<sup>20</sup> A standard saddle (Fabric® Scoop Elite Shallow, 142 mm) was used for all participants to standardise the saddle pressure data.<sup>19</sup>

At visit one the participants completed a standardised warm-up protocol,<sup>24</sup> which was followed by a 10 min rest period before performing a PPO ramp test and Peak Oxygen Consumption test to determine the current training status of the participants, as well as the workload for subsequent visits.

Following the first visit the participants bicycle was randomly altered to conform to one of three positions described below:

- a) Preferred freely chosen position
- b) Forward position – saddle and handlebar moved 3 cm forward and saddle height adjusted to maintain joint kinematics
- c) Backwards position - saddle and handlebar moved 3 cm backward and saddle height adjusted to maintain joint kinematics

Furthermore, once adjustments had been made, kinematic measurements were performed to ensure that joints remained in the range measured during the preliminary visit. If measurements fell outside the expected range then adjustments were made to the contact points to adjust the kinematics to the preliminary values.

Participants then completed their usual training load for seven days using the adjusted position to allow for familiarisation with the new configuration and adaptation to any muscle recruitment changes that may occur, before returning to the lab for further testing. The participants' bicycles were adjusted after each visit.

During the remaining three trials, Electromyography (EMG) electrodes (Blue Sensor, Medicotest, Denmark) were placed on the participant's right lower limb. The seven muscles (MG, BF, GM, TA, RF, VL and VM) were prepared according to the recommendations by Surface EMG for Non-invasive Assessment of Muscles (SENIAM). A standardised warm-up was performed, during which pressure mapping data (Gebiomized®, Munster, Germany) was collected for the preferred or the altered positions depending on the trial order. This was then followed by two 5-min EMG normalisations at 70% PPO at a cadence of 90 revolutions per minute (rpm).

The two normalisations were performed in either the preferred position trials or in the preferred and then the altered position.<sup>25</sup> When altering positions between normalisations one and two, static joint angles were assessed to ensure that there was no change in kinematic data as per the methods described in Appendix B. This allowed for the comparison of EMG activity for the adjusted positions as normalised to the freely chosen position.

Following the EMG normalisation, each trial consisted of 20 min of steady-state cycling at 60% of PPO and was started 3 min after completion of the normalisation protocol. The EMG data were recorded for 15 s in the 10–15 min segment of the steady-state effort, at 10:00 to 10:15, 12:00 to 12:15, and 14:00 to 14:15 min. The participants were asked to place their hands on the hoods during each EMG recording as a standard reference position.

### Pressure mapping data

A saddle pressure mapping system (GebioMized®) was used for the data collection in conjunction with the EMG measurements. The mat is comprised of thin, flexible material, housing 64 pressure sensors. The data collected was transmitted wirelessly to the manufacturing software which was installed on a standard Windows computer. The GebioMized system generates a report of the mean pressure (defined as the average instantaneous peak of the maximum pressure recorded at each sensor in each area) and loaded area for the anterior pubic bone, rear left sit-bone, and rear right sit-bone zones. The absolute maximum of force (defined as the maximum instantaneous peak force) and mean of total force are then determined. The system classifies the cyclist sitting position as either Front or Rear and determines a regression line angle, indicating pelvis orientation. Longitudinal and transverse mean movement of the centre of pressure (CoP), known as the point of load incidence, are also determined.

### Electromyography (EMG)

The two electrodes (Blue Sensor, Medicotest, Denmark) were taped to the belly of each muscle, parallel to the muscle fibres with an inter-electrode distance of 20 mm with activity captured at 2000 Hz.

EMG readings were recorded using an 8-channel EMG system (Telemyo 2400 G2, Noraxon, USA, Inc., Arizona, USA) with a 50 Hz notch filter applied to the raw EMG data (Myoresearch 2.02). The signal was filtered using a 15–500 Hz band pass filter to movement artefact below 15 Hz and non-physiological signals above 500 Hz. The data were smoothed using root mean squared analysis (RMS), which was calculated for a 50 ms window.

Processed EMG signals for each 15 s period were visually inspected to ensure that the quality and capture were of sufficient standard. Corresponding 15 s EMG signal data were compared for each of the positions relative to the normalisation data captured in the freely chosen position.

The magnitude of the EMG data for the cycling trial was expressed as the ratio of the freely chosen position data to the adjusted position data.

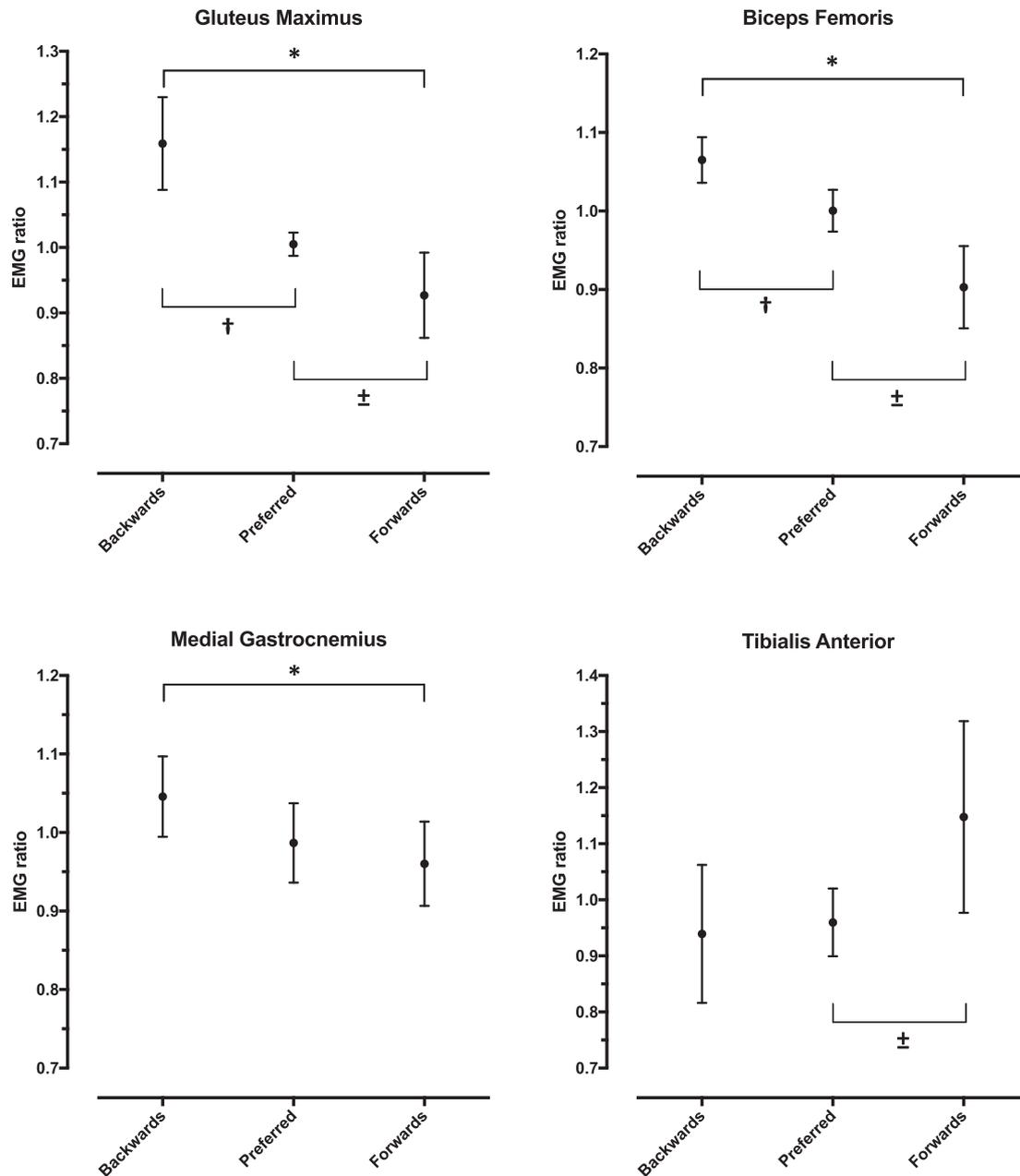
### Statistical analyses

All results were analysed using a statistical software programme GraphPad Prism v7.03 (GraphPad Software, San Diego, CA, USA). Results were expressed as mean  $\pm$  standard deviation (SD). A one-way analysis of variance (ANOVA) with repeated measures was used to detect significant differences between the preferred, forward and backwards positions. A Tukey post hoc multiple comparison was performed to compare the muscle activity differences between the three positions. A two-way ANOVA with repeated measures was used to detect any significant differences between the preferred, forwards and backwards positions static joint angles.

**Table 1**  
Muscle groups.

muscle	preferred	backwards	forwards			
	Mean iEMGr $\pm$ SD			preferred vs backwards	preferred vs forwards	backwards vs forwards
				p value		
BF	1.000 $\pm$ 0.027	1.065 $\pm$ 0.029	0.903 $\pm$ 0.052	0.004	0.003	< 0.001
GM	1.005 $\pm$ 0.018	1.159 $\pm$ 0.071	0.927 $\pm$ 0.065	0.001	0.020	0.001
MG	0.990 $\pm$ 0.052	1.040 $\pm$ 0.051	0.951 $\pm$ 0.049	0.095	0.672	0.011
TA	0.957 $\pm$ 0.064	0.931 $\pm$ 0.128	1.175 $\pm$ 0.157	0.874	0.010	0.056
VL	0.989 $\pm$ 0.021	0.940 $\pm$ 0.056	0.955 $\pm$ 0.047	0.146	0.440	0.731
VM	1.009 $\pm$ 0.047	0.968 $\pm$ 0.056	0.969 $\pm$ 0.076	0.358	0.481	0.966
RF	1.013 $\pm$ 0.038	0.969 $\pm$ 0.099	0.922 $\pm$ 0.110	0.317	0.144	0.687

iEMGr = integrated electromyography ratio. SD = standard deviation. BF = biceps femoris. GM = gluteus maximus. MG = medial gastrocnemius. TA = tibialis anterior. VL = vastus lateralis. VM = vastus medialis. RF = rectus femoris.

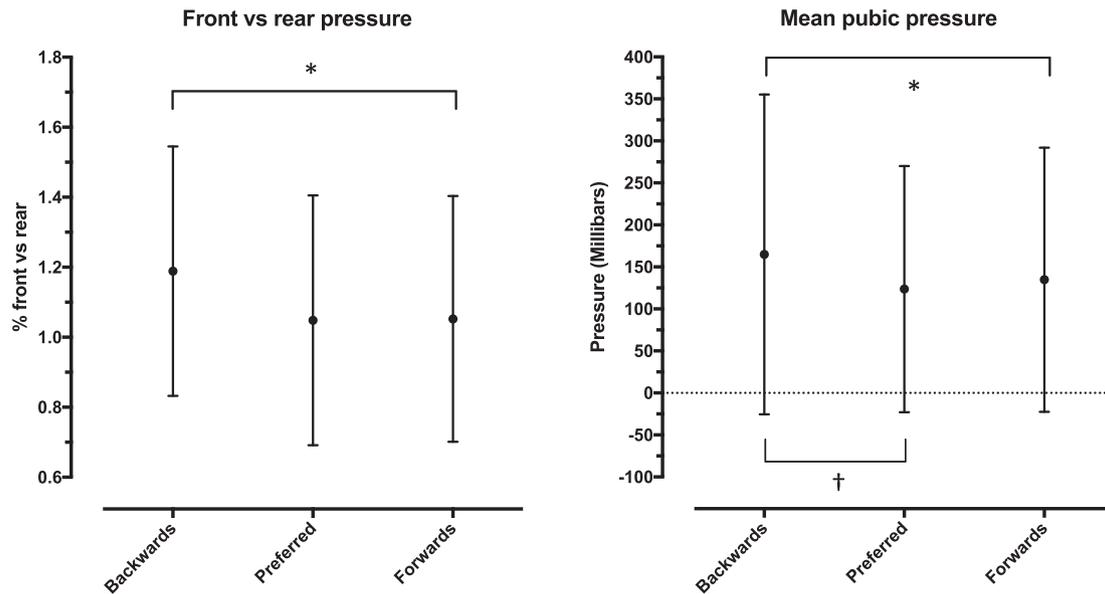


**Fig. 2.** Electromyographic data for the backwards, preferred and forwards positions. **A.** Gluteus Maximus \*  $p = 0.0013$  (backwards vs. forwards); #  $p = 0.02$  (preferred vs. forwards); †  $p = 0.001$  (preferred vs. backwards); **B.** Biceps Femoris \*  $p = 0.0002$  (backwards vs. forwards); #  $p = 0.0028$  (preferred vs. forwards); †  $p = 0.0039$  (preferred vs. backwards); **C.** Medial Gastrocnemius \*  $p = 0.011$  (backwards vs. forwards); **D.** Tibialis Anterior #  $p = 0.0096$  (preferred vs. forwards).

**Table 2**  
Pressure mapping regions.

pressure region	preferred	backwards	forwards	preferred vs backwards	preferred vs forwards	backwards vs forwards
	Mean ± SD			p value		
Front versus rear	1.12 ± 0.52	1.35 ± 0.48	1.15 ± 0.50	0.097	0.998	0.017
Mean pubic pressure	259.89 ± 93.06	346.89 ± 103.62	283.56 ± 91.27	0.008	0.479	0.046

SD = standard deviation.



**Fig. 3.** Saddle pressure mapping data. **A.** Front versus rear pressure ratio in the backwards, preferred and forwards positions. \* $p = 0.017$  (backwards vs. forwards); **B.** Mean pubic pressure in the backwards, preferred and forwards positions. \* $p = 0.04$  (backwards vs. forwards); † $p < 0.01$  (preferred vs. backwards).

**Results**

*Electromyography*

A significant change in BF was demonstrated between the preferred to backwards ( $p = 0.004$ ), preferred to forwards ( $p = 0.003$ ) and backwards and forwards ( $p < 0.001$ ).

A significant change in GM was demonstrated between the preferred to backwards ( $p = 0.001$ ), preferred to forwards ( $p = 0.020$ ) and backwards and forwards ( $p = 0.001$ ).

A significant change in MG was demonstrated between the backwards and forwards ( $p = 0.011$ ), although no differences were observed between preferred to backwards ( $p = 0.095$ ) and preferred to forwards ( $p = 0.672$ ).

A significant change in TA was demonstrated between the backwards and forwards position ( $p = 0.056$ ) and the preferred to forwards position ( $p = 0.010$ ). There were no significant changes between the preferred and backwards positions ( $p = 0.874$ ).

The remaining three quadriceps muscles did not demonstrate any clear trend nor significant differences. The full integrated electromyography ratio (iEMGr) and  $p$  values may be viewed in (Table 1 and Figs. 2 and 4).

*Saddle pressure mapping*

The ratio of pressure distribution (front to rear) was significantly higher in the backwards saddle position compared to the forwards position (1.35 vs 1.15;  $p = 0.17$ ). However, there were no significant differences between forward and preferred positions nor between preferred and backwards positions (Table 2) (see Fig. 3).

Similarly, the mean pubic pressure was significantly different between the forward and backward positions (346.89 vs 283.56 Mb;  $p = 0.04$ ) as well as the preferred and backward positions (346.89 vs 259.89 Mb;  $p < 0.01$ ). However, there were no significant differences between forward and preferred positions.

All other pressure regions demonstrated no significant differences.

*Static joint angles*

A repeated-measures ANOVA indicated that there was no significant effect of any of the positions on the static joint angle kinematics (Table 3).

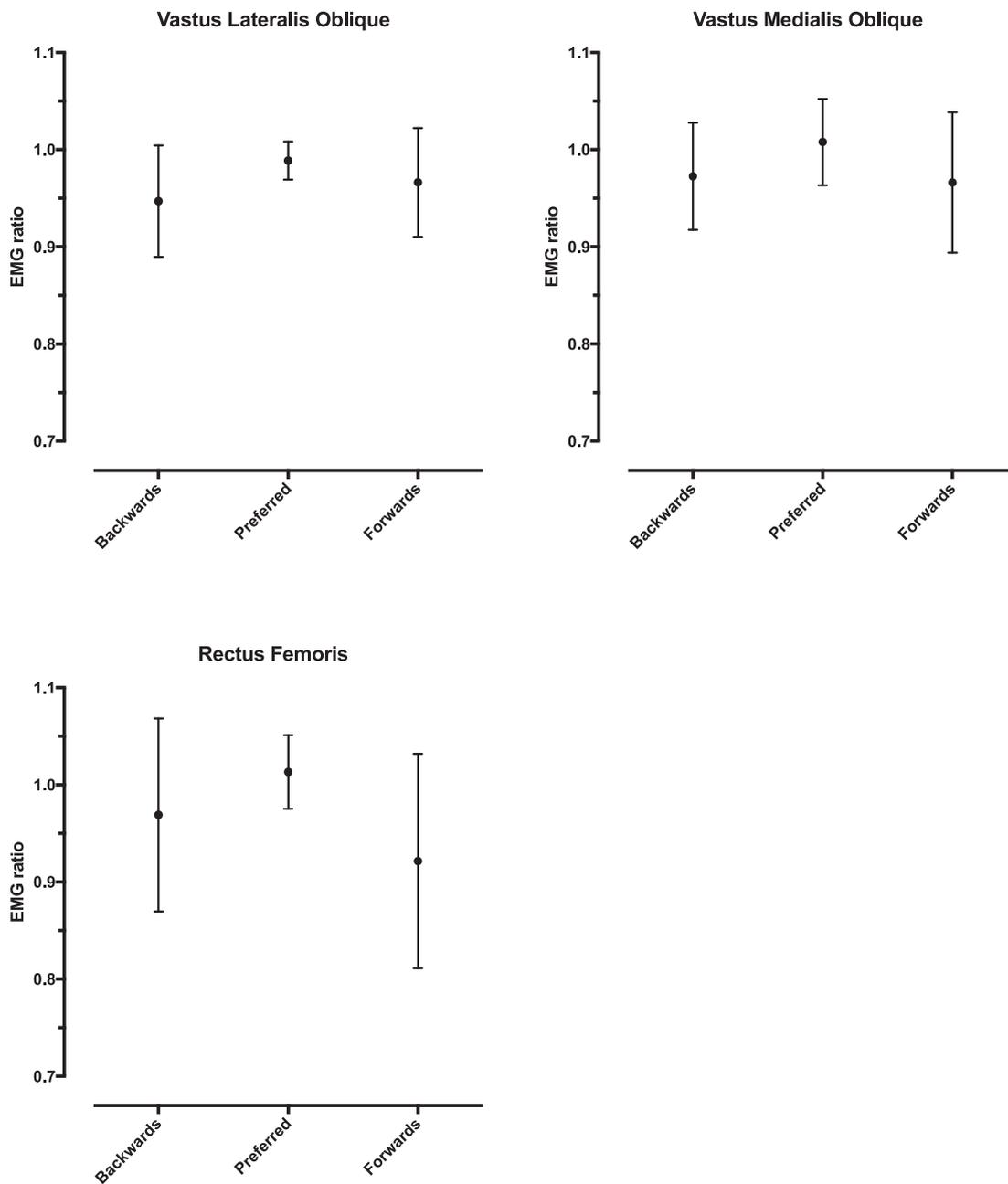


Fig. 4. Electromyographic data for the backwards, preferred and forwards positions in the A. Vastus Lateralis, B. Vastus Medialis and C. Rectus Femoris.

Table 3  
Static joint angles.

joint	preferred	backwards	forwards
	<i>mean</i>		
Knee	31.5°	32.0°	32.6°
Hip	76.6°	75.9°	76.9°
Ankle	121.7°	120.6°	120.6°
Shoulder	114.1°	111.5°	113.7°
Elbow	15.6°	19.0°	16.8°

**Discussion**

The purpose of this study was to assess the effect of alterations in the ESTA (forward or backward position of handlebar and seat of 3 cm) on the activity of seven lower limb muscles as well as the effect on saddle pressure mapping indexes. A novel approach of this study was to control

the position of the handlebar relative to the saddle and by this means to maintain the kinematics of the elbow, shoulder, hip, knee, and ankle joint to ensure that any changes were solely due to the alterations in the ESTA and not related to kinematic changes. This has been a confounding factor in the research conducted to date.<sup>2,3,26</sup>

Our first major finding was that BF, GM, and MG muscle activity increased progressively from the forwards to backwards position (Fig. 2A, B, C). In contrast, muscle activity of TA decreased progressively from forwards to backwards position (Fig. 2D). Despite the significant change in activity in BF, GM, TA and MG, there was no concomitant change in the VM, VL, and RF across the three position-changes. It is not immediately clear how the activity of the other major muscles decreased from backward to forward positions without a concomitant increase in the quadriceps activity. However, this may be due to surface EMG measurements not being able to detect changes in deeper or different fibres of the muscles that are being activated. Anecdotal feedback from athletes and the participants indicates increased use of the quadriceps in

a forward saddle position.

Our findings are similar to those found by Ricard et al.<sup>26</sup> who examined the effects of STA on power output and EMG amplitude for VL, VM, semimembranosus, and BF during a Wingate test. Their results demonstrated that EMG amplitude for BF was significantly reduced when the STA was moved from 72° to 82°, but there was no significant difference in EMG amplitude for VL, VM, and semimembranosus despite the same power output during the Wingate sprints performed.<sup>27</sup>

Silder et al.<sup>27</sup> conducted a trial to examine triathletes hand positions (hoods, drops and time trial bars) at three different STAs (73°, 76° and 79°) and demonstrated no effect on muscle recruitment patterns for lower limbs other than an increased RF activity when STA increased from 73° to 79°. However, in their study the seat height was self-selected for comfort by the participants, while the previously mentioned study by Ricard et al.<sup>26</sup> did not indicate any control of the seat height. This relates to our findings as seat height and static kinematics were controlled for, which is vital in revealing any potential muscle recruitment differences. Changes of more than 4% in seat height can significantly change pedal force<sup>28</sup> which could lead to increases in the gluteus medius, medial hamstring, and MG muscle activation.<sup>29</sup> This was confirmed by another study which demonstrated a decrease in integrated EMG value of gastrocnemius muscle with decreased saddle height.<sup>30</sup>

Another study examined the ESTA by comparing the preferred saddle position to a saddle position 5 cm forward or backward. Ten experienced male cyclists were required to pedal for a fixed 3 min set at a standard relative power output.<sup>31</sup> The participants were allowed to set their reach and saddle setback, with their saddle height set by the testers. The backward position led to a greater peak EMG activity for peroneus longus, lateral and medial gastrocnemius, soleus as well as semitendinosus and BF. The forward position was associated with a greater peak for RF, VL, and VM activity. These findings mirror ours for the gastrocnemius and BF. However, we did not find similar changes for the quadriceps muscles. A key difference in this study is that the researchers adjusted the saddle height so that the knee flexion angle at the bottom dead centre (BDC) was positioned between 25° and 35°, which may have been different to the participants' preferred bicycle set-up. More importantly, this study only manipulated the saddle displacement while the handlebar stayed in the same original position. It is therefore not possible to exclude the effect of altered hip joint kinematics on the muscle recruitment patterns as the hip joint position may have changed significantly with the change in STA. Changes in kinematics were also not reported.

In contrast, we were able to ensure that there was no change in any of the kinematic variables between the three trials, and all the joints measured demonstrated no significant difference between the three positions. All joint angle measurements fell within the typical measurement error<sup>20</sup> for the technique used. As such we can infer that any changes in muscle activity occurred independently of any changes in joint angle. Our findings likely represent the first data that has assessed the independent effect of ESTA on muscle activity.

A reduction in ESTA (moving the cyclist backwards) will result in the cyclist being further behind the crank axle. With no alteration in kinematics, the cyclist will be required to produce a greater force on the crank in a forward direction before the crank reaches a top dead centre position and may require greater hamstring activity to propel the crank “backward” (from 180° to 210° in the revolution) through the lowest crank position. In contrast, increasing the ESTA (moving the cyclist forwards) may result in forces being applied to the crank in a more vertical orientation, reducing the requirement to “push” and “pull” the crank over the top and BDC. The crank length and axle being fixed means that the activation of the lower limb muscles may need to change in order to effectively turn the cranks, which may explain some of our findings.

In the saddle pressure mapping indexes, the participants decreased their percentage frontal versus rear pressure when moving from the backwards to the forwards saddle position. For mean pubic pressure, there was also a decrease in pressure from backwards to forwards positions. Cyclists may be able to sense their position relative to the crank axle and may

subconsciously shift their position on the saddle to optimise this position for large ESTA changes, although this is not evident for small ESTA changes. The changes we observed suggest the participants in their backward position allowed greater pelvic rotation, therefore increasing the perineal pressure and the fore/aft pressure distribution to compensate. Similarly, the opposite findings were present when the saddle was shifted forwards.

However, despite our findings, it is clear that the saddle pressure mapping was only sensitive enough to detect a difference in saddle position of 6 cm for the front:rear ratio.

The muscles of the lower limb work in a coordinated way to maximise energy transfer from the cyclist to the crank and propel the bicycle forwards. However, there are a large number of factors that may affect cycling performance and a more detailed analysis with respect to the timing of activation of the muscle groups may establish the effects of these interactions more clearly. Furthermore, additional activity in the agonist's muscles should also not be ignored. It may require a greater emphasis on hip extension versus knee extension to produce force, if the rider is positioned more posterior to the crank axle. Both our GM and BF findings may explain this, however, this does not explain our quadriceps finding. A follow-up study using high-density EMG to more thoroughly assess muscle activity is recommended.

Our data are limited by the lack of synchronised dynamic kinematics. We are therefore unable to quantify the timing of activation of each muscle studied. Future studies should aim to quantify the timing effects of changes in ESTA.

## Conclusion

This is the first study to effectively control and report on muscle EMG, by controlling concurrently for the handlebar and saddle position when altering the ESTA of the bicycle and assessing muscle activity. It is also the first study to date to measure the saddle pressure interface with altered ESTA.

Our data confirm that activation of the BF, GM, TA, and MG are altered when adjusting the ESTA.

Lastly, we found that saddle pressure mapping can detect large changes in ESTA, although these are not practically relevant due to the limited sensitivity and ability to detect small ESTA changes.

Although we did not quantify which ESTA is appropriate for specific cycling discipline or which is the best for performance, our data indicate that an ESTA of  $69.1 \pm 1.1^\circ$  (which equates to a saddle setback distance of less than 5% of the saddle height) results in a muscle recruitment pattern that favours power production in the quadriceps, whereas an ESTA of  $65.3 \pm 1.1^\circ$  (which equates to a saddle setback distance which exceeds 10% of saddle height) results in a muscle recruitment pattern that favours production from the gluteal and posterior lower limb muscles.

This research will add to the existing literature in optimising bike fitment techniques used to improve comfort, economy, and performance. Understanding the muscle activity in response to setup alterations will assist in optimising the positioning of the cyclist for differing cycling disciplines.

## Submission statement

This work has not been published elsewhere, nor is currently under consideration for publication elsewhere.

## Authors' contributions

This original study proposal was drafted by Wendy Holliday and Jeroen Swart. The data was collected and analysed by Reece McDonald with the assistance of Wendy Holliday and Jeroen Swart. This manuscript was written by Reece McDonald with the valued guidance and input of Wendy Holliday and Jeroen Swart.

## Ethical approval statement

A Physical Activity Readiness Questionnaire (PAR-Q) training history questionnaire and an informed consent form were completed and signed by each participant prior to partaking in the study. Each participant was informed of the potential risks and protocol prior to each visit. The study was approved by the Research and Ethics Committee of the Faculty of Health Sciences, University of Cape Town and conformed to the World Medical Association Declaration of Helsinki and the American College of Sports Medicine (ACSM) Guidelines for the use of Human Subjects.

## Conflict of interest

The authors have no conflict of interest to declare.

## Acknowledgements

Thanks are given to all the cyclists who participated in this study.

## Appendix A. Bicycle configuration measurements

### Saddle height

The laser was used and referenced to a 74° line, and then aligned through the centre of the crank axle. The saddle height was then measured from the centre of the crank axle to the top of the saddle, with the laser line in the middle of the tape measure to ensure the angle of 74° is followed. The horizontal line intersecting this point on the top of the saddle was used to read the overall length.

### Reach

The reach was measured horizontally, from the centre of the handlebar next to the stem clamping point to the centre of a 74° laser line, which was set up in the same configuration as described in the saddle height.

### Saddle setback

Using the self-levelling laser, a vertical line was placed through the centre of the crank axle. The distance from the tip of the saddle to the laser line which corresponds to the centre of the crank axle taken as the saddle setback. If the saddle length was not 22.5 cm, the setback would be adjusted for. The saddle length was measured by the distance from the tip of the saddle to where the ischial tuberosity's would sit on the saddle.

### Drop

The drop was measured as the vertical distance from the top of the saddle to the centre of the handlebar clamping joint. The self-levelling laser was run horizontally through the centre of the handlebar, and the distance could then be measured directly from the saddle itself.

## Appendix B. Static joint angle measurements

### Minimum hip flexion angle

The participant was instructed to pedal three revolutions before stopping at top dead centre, or the '12 o' clock' position. The heel was assessed to ensure that it did not change. The first inclinometer measurement will be taken by positioning the inclinometer over the centre of the greater trochanter with the extension arm positioned towards the lateral condyle of femur. The second measurement was taken by positioning the inclinometer on the posterior surface of the lower lumbar vertebrae with the red reference dot perpendicular to the iliac crests. The minimum hip flexion angle was calculated from these two measurements

by applying plane geometry formulas.

### Knee flexion angle

The participant was instructed to pedal three revolutions before stopping at bottom dead centre, or the '6 o'clock' position. The heel was assessed to ensure that it did not change. The inclinometer was positioned at the top of the greater trochanter with the extension arm positioned at the lateral condyle of femur for the first measurement. The second measurement was taken with the positioning of the inclinometer on the lateral malleolus with the extension arm positioned towards the head of fibula. The knee flexion angle was calculated from these two measurements by applying plane geometry formulas.

### Ankle flexion angle

The participant was instructed to pedal three revolutions before stopping at bottom dead centre, or the '6 o'clock' position. The heel was assessed to ensure that it did not change. The inclinometer was positioned at the centre of the lateral malleolus with the extension arm positioned towards the head of fibula for the first measurement. The second measurement was taken with the positioning of the inclinometer on the lateral malleolus with the extension arm positioned parallel to the 5<sup>th</sup> metatarsal. The ankle flexion angle was calculated from these two measurements by applying plane geometry formulas.

### Minimum shoulder flexion angle

The participant was instructed to pedal three revolutions before stopping at top dead centre, or the '12 o' clock' position. The heel was assessed to ensure that it did not change. The inclinometer was positioned at the lateral aspect of the centre of the humeral head approximately 2.5 cm below the acromion process with the extension arm positioned in line to the lateral epicondyle for the first measurement. The second measurement was taken with the positioning of the inclinometer on the first four thoracic vertebrae with the red reference dot perpendicular to the centre of the humeral head. The shoulder flexion angle was calculated from these two measurements by applying plane geometry formulas.

### Elbow flexion angle

The participant was instructed to pedal three revolutions before stopping at top dead centre, or the '12 o' clock' position. The heel was assessed to ensure that it did not change. The inclinometer was positioned over the lateral epicondyle of the humerus with the extension arm positioned over the centre of the humeral head to determine the first measurement. The second measurement was taken by positioning the inclinometer over the lateral epicondyle of the humerus with the extension arm positioned over the longitudinal axis of the radius. The longitudinal axis of the radius was determined by the position of the acromion process and the styloid process of the radius. The elbow flexion angle was calculated from these two measurements by applying plane geometry formulas.

## References

1. Silberman MR, Webner D, Collina S, et al. Road bicycle fit. *Clin J Sport Med.* 2005; 15(4):271–276. <https://doi.org/10.1097/01.jsm.0000171255.70156.da>.
2. Gonzalez H, Hull ML. Multivariable optimization of cycling biomechanics. *J Biomech.* 1989;22(11–12):1151–1161. [https://doi.org/10.1016/0021-9290\(89\)90217-0](https://doi.org/10.1016/0021-9290(89)90217-0).
3. Bisi MC, Ceccarelli M, Riva F, et al. Biomechanical and metabolic responses to seat-tube angle variation during cycling in tri-athletes. *J Electromyogr Kinesiol Off J Int Soc Electrophysiol Kinesiol.* 2012;22(6):845–851. <https://doi.org/10.1016/j.jelekin.2012.04.013>.
4. Umberger BR, Scheuchenzuber HJ, Manos TM. Differences in power output during cycling at different seat tube angles. *Med Sci Sports Exerc.* 1998;30(5):81.

5. Bosak A, Green J, Crews T, et al. The comparison of maximal oxygen consumption between seated and standing leg cycle ergometry: a practical analysis. *Sport J*. 2007; 10(3):1–10.
6. de Vey Mestdagh K. Personal perspective: in search of an optimum cycling posture. *Appl Ergon*. 1998;29(5):325–334. [https://doi.org/10.1016/S0003-6870\(97\)00080-X](https://doi.org/10.1016/S0003-6870(97)00080-X).
7. Too D. Biomechanics of cycling and factors affecting performance. *Sports Med*. 1990; 10:286–302. <https://doi.org/10.2165/00007256-199010050-00002>.
8. Ter Keurs HEDJ, Iwazumi T, Pollack GH. The sarcomere length-tension relation in skeletal muscle. *J Gen Physiol*. 1978;72(4):565–592. <https://doi.org/10.1085/jgp.72.4.565>.
9. Ericson MO, Nisell R. Efficiency of pedal forces during ergometer cycling. *Int J Sports Med*. 1988;9:118–122. <https://doi.org/10.1177/036354658601400407>.
10. Heil D, Wilcox A, Quinn C. Cardiorespiratory responses to seat tube angle variation during steady-state cycling. *Med Sci Sports Exerc*. 1995;27(5):730–735.
11. Price D, Donne B. Effect of variation in seat tube angle at different seat heights on submaximal cycling performance in man. *J Sports Sci*. 1997;15(4):395–402. <https://doi.org/10.1080/026404197367182>.
12. Baum BS, Li L. Lower extremity muscle activities during cycling are influenced by load and frequency. *J Electromyogr Kinesiol*. 2003;13(2):181–190. [https://doi.org/10.1016/S1050-6411\(02\)00110-4](https://doi.org/10.1016/S1050-6411(02)00110-4).
13. Dorel S, Drouet JM, Couturier A, et al. Changes of pedaling technique and muscle coordination during an exhaustive exercise. *Med Sci Sports Exerc*. 2009;41(6): 1277–1286. <https://doi.org/10.1249/MSS.0b013e31819825f8>.
14. Hug F, Dorel S. Electromyographic analysis of pedaling: a review. *J Electromyogr Kinesiol*. 2009;19(2):182–198. <https://doi.org/10.1016/j.jelekin.2007.10.010>.
15. O'Bryan SJ, Brown NAT, Billaut F, et al. Changes in muscle coordination and power output during sprint cycling. *Neurosci Lett*. 2014;576:11–16. <https://doi.org/10.1016/j.neulet.2014.05.023>.
16. Saunders MJ, Evans EM, Arrgrímsson S a, et al. Muscle activation and the slow component rise in oxygen uptake during cycling. *Med Sci Sports Exerc*. 2000;32(12): 2040–2045. <https://doi.org/10.1097/00005768-200012000-00012>.
17. Verma R, Hansen EA, de Zee M, et al. Effect of seat positions on discomfort, muscle activation, pressure distribution and pedal force during cycling. *J Electromyogr Kinesiol*. 2016;27. <https://doi.org/10.1016/j.jelekin.2016.02.003>.
18. Jorge M, Hull ML. Analysis of EMG measurements during bicycle pedalling. *J Biomech*. 1986;19(9):683–694. [https://doi.org/10.1016/0021-9290\(86\)90192-2](https://doi.org/10.1016/0021-9290(86)90192-2).
19. Bressel E, Cronin J. Bicycle seat interface pressure: reliability, validity, and influence of hand position and workload. *J Biomech*. 2005;38(6):1325–1331. <https://doi.org/10.1016/j.jbiomech.2004.06.006>.
20. Holliday W, Fisher J, Theo R, et al. Static versus dynamic kinematics in cyclists: a comparison of goniometer, inclinometer and 3D motion capture. *Eur J Sport Sci*. 2017;17:1–14. <https://doi.org/10.1080/17461391.2017.1351580>.
21. Pauw K De, Roelands B, Geus B De, et al. Guidelines to classify subject groups in sport- science research. *Int J Sports Physiol Perform*. 2013;8(2):111–122. <https://doi.org/10.1123/ijspp.8.2.111>.
22. Whaley M, Brubaker P, Otto R. Preparticipation Health screening and risk stratification. In: Whaley M, Brubaker P, Otto R, eds. *ACSM's Guidelines for Exercise Testing and Prescription*. Lippincott Williams & Wilkins; 2007:26.
23. World medical association world medical association declaration of Helsinki: ethical principles for medical research involving human subjects. *J Am Med Assoc*. 2013; 310(20):2191–2194. <https://doi.org/10.1001/jama.2013.281053>.
24. Lamberts RP, Swart J, Noakes TD, et al. A novel submaximal cycle test to monitor fatigue and predict cycling performance. *Br J Sports Med*. 2011;45(10):797–804. <https://doi.org/10.1136/bjism.2009.061325>.
25. Albertus-Kajee Y, Tucker R, Derman W, et al. Alternative methods of normalising EMG during cycling. *J Electromyogr Kinesiol*. 2010;20(6):1036–1043. <https://doi.org/10.1016/j.jelekin.2010.07.011>.
26. Ricard MD, Hills-Meyer P, Miller MG, et al. The effects of bicycle frame geometry on muscle activation and power during a Wingate anaerobic test. *J Sports Sci Med*. 2006; 5(1):25–32.
27. Silder A, Gleason K, Thelen DG. Influence of bicycle seat tube angle and hand position on lower extremity kinematics and neuromuscular control: implications for triathlon running performance. *J Appl Biomech*. 2011;27(4):297–305. <https://doi.org/10.1123/jab.27.4.297>.
28. Bini R, Hume P, Croft J. Effects of saddle height on pedal force effectiveness. *Procedia Eng*. 2011;13:51–55. <https://doi.org/10.1016/j.proeng.2011.05.050>.
29. Ericson M, Nisell R, Arborelius U, et al. Muscular activity during ergometer cycling. *Scand J Rehabil Med*. 1985;17:53–61.
30. Sanderson DJ, Amoroso AT. The influence of seat height on the mechanical function of the triceps surae muscles during steady-rate cycling. *J Electromyogr Kinesiol*. 2009; 19(6):e465–e471. <https://doi.org/10.1016/j.jelekin.2008.09.011>.
31. Hayot C, Domalain M, Bernard J, et al. Muscle force strategies in relation to saddle setback management in cycling. *Comput Methods Biomech Biomed Eng*. 2013;16: 106–108. <https://doi.org/10.1080/10255842.2013.815937>.