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THE EFFECTS OF SADDLE ANGLE/INCLINATION ON LUMBOPELVIC KINEMATICS AND CARDIOMETABOLIC MEASURES

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THE EFFECTS OF SADDLE ANGLE/INCLINATION ON LUMBOPELVIC KINEMATICS AND CARDIOMETABOLIC MEASURES

DISSERTATION

A dissertation submitted in partial fulfillment of the
requirements for the degree of Doctor of Philosophy in the
College of Education
at the University of Kentucky

By

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ABSTRACT OF DISSERTATION

THE EFFECTS OF SADDLE ANGLE/INCLINATION ON LUMBOPELVIC KINEMATICS AND CARDIOMETABOLIC MEASURES

Lower back pain (LBP) is a condition which affects the lumbar portion of the spinal column that can lead to mild to extreme physical pain during seated tasks and has been shown to be prevalent in people who spend long durations sitting particularly in a slumped position or in a position with a large degree of lumbar flexion. LBP can cause regular interruptions in work and in a person's ability to engage in exercise, and in most extreme cases warrants surgical interventions for clinical treatment. While LBP is prevalent in sedentary populations, it is also quite prevalent in cycling populations where athletes frequently train and perform in a seated position with a large degree of lumbar flexion. Bike alterations, primarily adopting a downward inclination of the anterior tip of the saddle, have been a proposed method to increase anterior pelvic tilt and decrease lumbar flexion, which may contribute to decreased incidence of LBP in cyclists. However, alterations to the fit of a bicycle have the potential to impact performance and cardiometabolic measures, and also have a potential to effect men and women differently, as bicycles were traditionally designed with the male anatomy in mind resulting in differences in the way the sexes traditionally position themselves on bicycles when they ride. Therefore, the objective of this study was to investigate the differences in torso, lumbar and pelvic kinematics differences, cardiometabolic differences (VO2 and HR), and sex-based kinematic differences of the torso, lumbar, and pelvis during a synonymous cycling task on a traditional flat (relative to the horizontal) saddle compared to a saddle angle with an anterior inclination of 12.5 degrees.

We performed kinematic and cardiometabolic assessments in recreational and competitive cyclists without existing chronic LBP during an 8-minute cycling task with a fixed work rate with the flat and inclined saddle angles. A bicycle-based GXTmax (graded exercise test) was conducted in order to establish peak VO2 and peak work rate (in watts) to be used for the kinematic and cardiometabolic assessments. Two subsequent rides conducted at a work rate which corresponded with 80% of elicited peak VO2 were performed during which kinematic or cardiometabolic measures were collected. For kinematic differences motion capture of the torso, pelvis and lower limbs was conducted along with perceived rating of LBP. For cardiometabolic differences VO2 ($\mathrm{ml \cdot kg \cdot min^{-1}}$) and HR (bpm) were collected. For sex-based differences the kinematic data was assessed for each sex and then compared via a 2 way ANOVA analysis.

The results showed that in a population of cyclists without existing chronic LBP no significant differences were exhibited as a result of the two saddle angles in lumbar, trunk or pelvic kinematics, perceived LBP, cardiometabolic measures, or kinematics between sexes. These results only directly pertain to short duration, high intensity cycling, and differences may occur if a different cycling task, particularly one of longer duration, were performed. In conclusion, a saddle inclination of 10-15 degrees does not incur any significant kinematic, cardiometabolic or sex-based differences when compared to a flat saddle angle during short duration, high intensity cycling, but further investigation on kinetics in the lumbar spine and lower limbs as a result of these saddle angles is warranted.

KEYWORDS: cycling; saddle angle; kinematics; cardiometabolics; saddle/seat height

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THE EFFECTS OF SADDLE ANGLE/INCLINATION ON LUMBOPELVIC KINEMATICS AND METABOLIC PERFORMANCE

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CHAPTER 1. BACKGROUND

1.1 INTRODUCTION

Bicycle modifications have long been an area of interest within the cycling community, usually in attempts to improve comfort, reduce chance for injury, and/or improve performance. Frequently the fit of the bicycle, which could include size of the frame, orientation of the saddle, handlebars, or seat tube angle, or other factors which affect size and orientation, is modified in ways that attempt to increase performance in competitive cyclists by decreasing drag, or making adjustments to the frame or seat of the bicycle to alter joint kinematics to optimize torque production. Often these modifications are not just made by the individual in an attempt to optimize their sole performance and/or comfort, but so that if the modification is successful it can be marketed. Therefore, in order to understand the impact of bicycle modifications on cycling performance, an evaluation of the currently adopted modifications and their effects on cycling performance should be investigated.

Prevalent types of bicycle modifications include different saddle structures and/or saddle angles to improve comfort and performance (Bressel & Larson, 2003). A common effect of altered saddle angles and designs is a change in the kinematics of the pelvis during cycling. An increasingly common modification made to the saddle attempts to increase the degree of anterior pelvic tilt (APT), as there is some evidence to suggest that increasing APT and the corresponding decrease in lumbar flexion can lead to a lower risk of lower back pain (LBP) in cyclists (Dettori & Norvell, 2005; Marsden & Schwellnus, 2010; Salai et al., 1999). This specific seat modification results in a forward tilted posture with more weight being distributed through the upper extremities and onto the handlebars and thereby, decreasing pressure and shear forces acting on the spine during cycling (Bressel & Larson, 2003; Mestdagh, 1998). However, adopting a saddle position or design which causes a large amount of APT has potential to not only affect comfort and instances of LBP but performance as well (Caddy et al., 2016). There is contention on how this inclined saddle angle will affect performance, as some studies suggest that increased APT correlates with greater peak hip flexion, thereby optimizing the length-tension relationship of the gluteus maximus and hamstrings. Other studies have shown that positions that cause the cyclist to lean forward (such as aerodynamic positions) have the potential to result in higher oxygen expenditure (Gnehm et al., 1997; Jobson, et al., 2008). Modifications to the seat height and seat tube angle (STA) have notable effects on the kinematics and kinetics of the lower limbs as well as cycling efficiency.

There have been few studies conducted which inspect the effects of altered saddle angles on cycling kinematics and performance. More specifically, there exists a need to further study the effects saddle angle can have on the kinematics of the trunk, lumbar spine, pelvis and lower limbs, as well as performance-related measures including metabolic expenditure (VO2) during cycling. Therefore, the purpose of this review was to summarize studies describing the impact of modifying bicycle saddles intended to increase APT and the corresponding biomechanical effects of these modifications on lumbopelvic kinematics during cycling as well as performance parameters (particularly VO2 levels). This summary of scientific evidence will reveal the gaps in the existing literature regarding the impact of increased APT on cycling mechanics, performance and efficiency.

1.2 SEAT ANGLE AND HEIGHT MODIFICATIONS

Anterior inclination of the saddle occurs when the anterior portion of the saddle points has downward tilt and is a means of attaining a cycling position with increased APT when compared to the normal, flat saddle position (at or close to 0 degrees relative to the horizontal) (Salai et al., 1999). Anterior inclination of the saddle is frequently performed to reduce shear forces acting on the vertebral column.

In a 2015 study by Caddy et al., 3 different saddle angles (0, 3 and 6-degrees of anterior inclination) were investigated to see if any significant improvements in high intensity time-trial cycling performance, as a function of augmented power output occurred, with or without reduction of metabolic costs. Other measures included; crank torque kinetics, lower extremity kinematics, and cardiorespiratory values. No significant changes were found in time to complete the 4km ride, power output, cardiorespiratory variables or crank torque values between the three saddle conditions. The significant effects elicited primarily influenced the hip angle with peak hip extension being significantly higher in the 6 degree saddle inclination position when compared to the 3 degree saddle inclination position. Peak hip flexion was also significantly higher during the 6 degree saddle inclination condition compared to the other two saddle conditions. However, hip range of motion (ROM) was similar between all three conditions. The researchers speculated that the increased hip angles in the 6 degree anteriorly inclined saddle position may be due to increased anterior pelvic tilt and leading to greater hip flexion at top dead center (the point of the pedal revolution which corresponds with 12:00 on a clock). While no significant effect of saddle inclination was observed for performance variables, researchers noted that this was only a 4km intensive race, and greater distances and varied intensities should be inspected in the future to better understand the impact of saddle inclination on performance measures during more demanding rides.

A bicycle adjustment that has long been studied and adjusted by cyclists that has a large impact on performance is saddle height. Saddle height is the distance between the top of the saddle and the pedal axis when the pedal is at bottom dead center. Early studies conducted by Nordeen-Snyder (1977) and Shennum & DeVries (1976) examined the effect of bicycle saddle height on oxygen consumption (VO2), carbon dioxide output (VCO2), and ventilation rate (VE) during cycling and cycle ergometry, respectively. It was found that, when compared to the 95% and 105% trochanter height conditions, the 100% of trochanter height condition was the most economical height resulting in the lowest level of oxygen consumption to accomplish the cycling task. Shennum & DeVries found at 100% and 103% of ischium height, the cyclists demonstrated similar VO2 levels and that the V02 levels for these two seat height condition were significantly lower than the V02 levels observed with the seat heights at 106%, 109% and 112% of the ischium height. In addition, the V02 levels observed during the ride at 112% ischium height was significantly higher than all of the other seat height conditions.

A study conducted by Peveler (2008) was designed to inspect the differences in cycling economy between saddle heights. Optimal saddle heights for cycling have been designated as a saddle height which results in a knee joint angle of 25-35 degrees at bottom dead center (Bini et al., 2011). This optimal saddle height is beneficial in injury prevention as a saddle height which results in greater than 35 degrees of knee flexion can cause anterior knee pain due to excessive patellofemoral joint compression, and a saddle height which results in less than 25 degrees of knee flexion can cause posterior knee pain due to overextension (Hamley & Thomas, 1967). There have been comparisons of anaerobic power production between the saddle heights that result in 25 and 35 degrees of flexion (Peveler et al., 2007), while the study by Peveler (2008) aimed to compare aerobic power and economy through use of graded exercise tests and other cycling tasks in these two specific saddle height conditions. Three different saddle height conditions (25 degree knee angle, 35 degree knee angle, and 109% of inseam height) were randomized and tested during these 15-minute trials. The resistance for each saddle height condition was set to a level at which the subject reached 70% of VO2max on the cycle ergometer. Study participants exhibited significantly less O2 uptake while riding with a seat height that resulted in a 25 degree knee angle compared to the other two seat heights. It was surmised that a seat height which results in a 25 degree knee angle at full extension is likely optimal for performance.

Wilkinson & Kram (2021) investigated the effect of "nose-down saddle tilt", or a downward inclination of the saddle, on cycling efficiency during uphill riding (efficiency was defined as the ratio of mechanical power output to gross metabolic power consumption). It was suggested that tilting the saddle nose down might increase metabolic efficiency during uphill cycling for both recreational and competitive cyclists. Saddle height was adjusted for each subject, though the method used to establish saddle height was not described. Each subject performed four 5-minute trials of seated cycling at 3 W·kg-1 with 5 minutes of rest between each trial. The two saddle conditions tested were parallel (P) to the riding surface (flat saddle) and 8 degrees anterior nose tilt (ND). Oxygen consumption and CO2 production were measured and metabolic power was calculated for each of these conditions. The ND riding condition resulted in a 1.4% increase in mean gross efficiency when compared to the P saddle condition. The study reported that this improvement in efficiency was only tested at 8 degrees of treadmill incline and with 8 degrees of downward saddle tilt, and can only be directly applied to cycling with these specific parameters. This study provided no explanation concerning the mechanism(s) that led to the improvement of gross efficiency. However, prior research by Fonda & Sarabon (2012) suggested that the inclined saddle angle allows for decreased activation of upper appendage musculature (primarily elbow-flexor activity) and may account for the 1.4% overall reduction in metabolic power.

1.3 SEAT TUBE ANGLE MODIFICATIONS

Modification of the seat tube angle (STA) and the reach of the handlebars/position of the rider with respect to the handlebars may have the potential to affect APT and lumbar flexion of the rider during cycling. Silder et al. (2011), conducted a study where the primary goal was to find a seat tube angle that would be optimal for triathletes during the “bike-to-run” transition. Nine cycling trials were randomized and consisted of combinations of 3 different hand positions (aerodynamic with forearms on rests, drop position with hands on the lowest portion of the handlebars, or with hands placed superiorly on the brake hoods) and 3 STAs (73, 76, 79 degrees). The steepest of the STAs (79 degrees) caused a forward tilt position similar to when a cyclist adopts anterior inclination to promote APT, as APT increased an average of 3 degrees for each 3 degree increase in STA. APT was greatly reduced when cyclists switched from the aerodynamic hand position to the “drop” hand position, and was reduced even further when cyclists switched from the “drop” hand position to the brake hood hand position. As STA and APT increased, rectus femoris activity increased significantly during the upstroke of the pedaling revolutions, likely as a result of greater hip flexion when the pedal is at drop dead center (the point of the pedal revolution which corresponds with 6:00 on a clock). The rectus femoris aids in limb recovery and stroke transition from upward to downward motion (Raasch et al., 1997), so the increased activity may aid in ease of turnover rate.

Price and Donne (1997) conducted a study examining the effect of STA on VO2 levels and power efficiency (calculated via work performed and VO2) during submaximal cycling. This study was designed to examine the potential relationship between steeper STAs with greater comfort and improved power production when compared to less steep STA angles. Fourteen experienced male cyclists were recruited and completed a series of 9 submaximal rides with varying seat heights and STAs. Regardless of seat height, as STA increased, mean VO2 levels decreased and power efficiency increased. These results suggest that steeper STAs, which typically result in greater APT, lead to greater economy (lower VO2 levels) and higher power efficiency.

A similar study was conducted by Heil, et al. (1991), where the goal was also to examine claims from the triathlete community that steeper STAs, rather than the “traditional” 72-76 degree STAs allow for greater comfort, improved efficiency, and power production, especially when using aerodynamic handlebars. In their study, 4 different STAs were investigated (69, 76, 83 and 90 degrees) during 10-minute submaximal cycling tests while heart rate, oxygen consumption, ventilation and rating of perceived exertion were measured. Relative and absolute VO2, heart rate (HR), minute ventilation (VE), rating of perceived exertion (RPE), carbon dioxide output (VCO2) and respiratory quotient (RQ) all showed higher levels at a STA of 69 degrees during the cycling task when compared to STAs of 83 and 90 degrees. These results suggest that the steeper STAs (83 and 90 degrees) allowed the cyclists to be more efficient during a constant work rate than the lesser STAs, especially when using the aerodynamic handlebars.

The Sequenzia et al. (2016) study on bicycle saddle geometry was focused on comfort and clinical outcomes, primarily reduction/prevention of neurological pathologies (Alcock’s disease) which may arise from cycling. The primary aim of this study was to develop a variable geometry saddle (VGS) prototype that is capable of reducing the onset of cycling-related pathologies, leading to nerve compression and general discomfort, due to the fit and design of the saddle. The VGS prototype allowed for adjustment of saddle length, saddle nose inclination (from flat to downward 10 degrees) and rear width, and was compared to a regular bicycle saddle with a fixed geometry (FGS). The subjects underwent 4 rides (flat with FGS, 15% incline with FGS, flat with VGS and 15% incline with VGS) at 30-minutes each. Each subject was instructed to adjust the VGS to their “comfort” before each of the trials. The authors found that the cyclists favored a downward inclination of the VGS saddle for both conditions (average of 15 degrees inclination during flat cycling and 25 degrees inclinations during uphill cycling). This preference was not directly related to performance in this study, but suggests that downward saddle inclination is likely to cause a decrease in discomfort in male cyclists, which may in turn result in performance improvements. The design of the VGS could potentially make it easier to study and observe changes in performance related to changes in saddle orientation.

1.4 CONCLUSIONS AND PRACTICAL IMPLICATIONS

The purpose of this literature review was to inspect and compile the results of previous studies that investigated differences in cycling performance outcomes (gases inspired/expired, kinematic and kinetic measures) as a result of seat and saddle alterations (seat height, STA, and saddle angle). The effects of differing seat heights (Holliday & Swart, 2021; Hoof et al., 2012; Peveler et al., 2008; Price & Donne, 1997) have long been studied under a variety of conditions. It is generally agreed that a seat height that is approximately 100% of trochanter height or 109% of inseam height is optimal for performance as these specific seat heights optimize the length-tension relationship in the lower extremity musculature, particularly those which articulate the knee joint, and also results in greater economy when completing a cycling task (Holliday & Swart, 2021; Jobson et al., 2008; Peveler et al., 2007; Price & Donne, 1997). Investigations into STA suggest that steeper angles (≥ 80 degrees) rather than more traditional STA (72-76 degrees) provide greater comfort and performance benefits including lower VO2 levels needed to accomplish the same task and with greater power efficiency (Price & Donne et al., 1997; Silder et al., 2011).

Studies which have inspected the effect of saddle angle on performance and efficiency (Caddy et al., 2016; Wilkinson & Kram, 2021) are still relatively sparse. These prior studies focused on the effects of uphill riding and very small changes in saddle angle (3 and 6 degrees) (Caddy et al., 2016) on cycling performance. However, none of these studies showed any evidence of improved performance or efficiency of task as saddle angle adapted a downward inclination during flat riding. Although, there was evidence that a downward inclination of the saddle to match the incline of a hill (8 degrees downward tilt and 8 degree incline hill) can improve gross efficiency (Wilkinson & Kram, 2021). Other studies which have been conducted to inspect the effects of altering saddle angles have focused on more clinical applications, such as increasing comfort and reducing tendencies of pathologies and chronic pain (Salai et al., 1999, Sequenzia et al., 2016).

Saddle angles which meet the range suggested to decrease lower back pain (10-15 degrees) as well as the corresponding effect on performance have not been investigated. In addition, the effects of different saddle angles need to be investigated further on flat, steady state riding conditions, as previous studies tended to focus on uphill riding. Further research involving metabolic measures as well as biomechanical measures, including joint kinematic and kinetic differences incurred with downward saddle inclination should be conducted on steeper saddle angles and on a greater variety of riding conditions.

Bicycle modifications are a common way for cyclists to attempt to increase comfort, reduce risk of injury, and/or positively impact cycling performance. Many previous studies have inspected STA and seat height yet the overall impact of these seat modifications on comfort and performance during cycling is still not well understood. One limitation of the prior research is a lack of understanding of the combined impact of these seat modifications on biomechanical and physiological outcomes during cycling. An in-depth kinematic analysis and measurement of metabolic expenditures incurred as an effect of an altered saddle position will help expand upon the current scientific knowledge needed to assess and understand the impact of seat modifications on lower extremity mechanics and overall performance during cycling.

Based on the results of this literature review the following key points and suggestions have been surmised:

-The cycling population has a long history of modifications made to the design of the bicycle in an attempt to find out which modification(s) works best for the individual while optimizing performance, improving comfort and reducing risk of injury during cycling.

-Prior research has led to standards such as proper seat height and optimal seat tube angles for different conditions (i.e. uphill vs flat riding), and further experimentation with a range of saddle inclinations could lead to better understanding and perhaps eventual normative seat positions for riding under different conditions.

-Changing saddle inclination could potentially become a low effort, no cost modification to the bicycle which improves comfort and decreases the chance of inducing chronic pain without sacrificing an individual’s metabolic economy while riding.

ACRONYM GLOSSARY

- Anterior Pelvic Tilt: APT
- Body Mass Index: BMI
- Center of Gravity: COG
- Graded Exercise Test: GXT
- Heart Rate: HR
- Lower Back Pain: LBP
- Range of Motion: ROM
- Rating of Perceived Exertion: RPE
- Respiratory Exchange Ratio: RER
- Seat Tube Angle: STA

CHAPTER 2. SAGITTAL PLANE LUMBAR, TRUNK AND PELVIC KINEMATICS AT DIFFERENT SADDLE INCLINATIONS

2.1 INTRODUCTION

It has been suggested that an anterior pelvic tilt (APT) position is optimal for reduction of low back pain (LBP) in cyclists (Salai et al., 1999). Changing the saddle angle so that there is downward inclination of the anterior portion of the saddle leads to increased APT and reduced shear forces acting on the lumbar spine (Dettori & Norvell, 2005; Marsden & Schwellnus, 2010), suggesting that this saddle angle may be a preventive measure for reducing onset of LBP in cyclists. In addition, changing the saddle angle to an anterior inclination of 10-15 degrees, compared to a horizontal saddle position, is associated with a decrease in self-reported LBP in cyclists (Asplund et al., 2005). Compared to core-strengthening and flexibility interventions, as well as purchasing a new bicycle frame or refitting a bicycle, modifying the saddle angle position is a very quick and inexpensive process yet the impact of this anteriorly tilted saddle position on lumbar mechanics in cyclists while riding on a bicycle is not well understood.

Traditionally, cyclists ride their bicycles with a relatively flat saddle position, which may result in altered lumbar joint loading patterns compared to non-cyclists. Prolonged lumbar flexion by the rider is needed in order to remain seated on the saddle and to maintain contact with the handlebars with a fairly neutral pelvic angle yet causes large tensile forces on the lumbar spine (Salai, et al 1999; Stone & Hull, 1995). Mechanical creep of the spine has also been attributed to the constant force imposed by prolonged lumbar flexion and the mechanical loads generated by the legs being transferred through the flexed spine (Hoof, et al, 2012; Muyor, et al, 2011). Prior work assessing the impact of anterior saddle inclination on torso/lumbar kinematics during cycling as well as the corresponding impact on reducing LBP are limited. Increased anterior saddle inclination was shown to decrease lumbar tensile forces and potentially resulted in less strain on the lower back (Salai, et al, 1999). This study also assessed the effects of riding with a 10 – 15 degree downward saddle inclination, over a 6-month time frame, on reducing self-reported LBP in cyclists with prior incidence of LBP requiring clinical treatment (Salai, et al, 1999). This intervention resulted in 72% of these cyclists reporting they no longer had LBP and an additional 20% reporting a significant reduction in LBP. Despite the information provided by these previous studies, there have been no assessments of the impact of a downward saddle inclination on joint and segmental kinematics while cycling.

Understanding the effects of a downward saddle inclination of 10 – 15 degrees on torso, lumbar and pelvic kinematics during cycling will provide an understanding of the potential impact of a downward saddle inclination on kinematic alterations that may lead to the reduction in LBP. Therefore, the purposes of this study were to directly inspect the differences in torso, lumbar and pelvic kinematics between a traditional saddle inclination (flat relative to the horizontal) and a 12.5 degree downward inclination of the saddle while cycling b) monitoring self-reported lower back pain and rating of perceived exertion.

2.2 METHODS

2.2.1 Participants

A total of 20 subjects were recruited for this study (11 men) through a series of flyers posted on University of Kentucky's campus, local bike shops and local gyms, as well as word of mouth. Participants were all 18-55 year old individuals who had previous or current experience riding a bike (recreational to professional levels were accepted), exercised a minimum of 3 times per week (30 minutes per day), and were currently free from diagnosed lower back pain and/or lower limb surgeries. Additional subject inclusion criteria were body mass index (BMI) ≤ 35 kg/m^2 and did not experience lower limb injury during the 6 months prior to participation.

2.2.2. Testing Sessions

Three testing sessions conducted in the University of Kentucky Biodynamics Lab were required for each subject. Each testing session was separated by a minimum of 48 hours, but the 3 testing sessions were completed within two weeks. Subjects were instructed to refrain from engaging in any strenuous exercise 24 hours prior to each testing session.

Testing Session 1 (Consent and Pre-Screening, Anthropometric Measures, Maximal Graded Exercise Test

During the first testing session, subjects provided written informed consent for participation in accordance with the policies and procedures of the University of Kentucky's Office of Research Integrity, completed the Physical Activity Readiness Questionnaire for Everyone (PARQ+) (NASM PAR-Q, 2020) as a pre-participation safety screening tool, and completed a customized physical activity questionnaire.

While wearing lightweight clothing and no shoes, measures of total body mass (kg) using a calibrated scale (ETEKCITY) and standing height (m) was determined using a stadiometer (HEALTH O METER, Continental). These measures of mass and height were used to calculate each participant's BMI. Inseam length was measured by inserting a folder between the thighs and with the top portion of the folder in contact with the participant's pelvic floor. The distance from the top of the folder to the ground was measured and multiplied by 1.09 to assess proper saddle height for the ensuing testing procedures. Saddle height was visually inspected while the subject warmed up for the graded exercise test (GXT) to ensure that there was no knee abduction or lateral flexion of the torso, which would indicate too short or too long of a saddle height, respectively.

The subject was then instructed to warm up on a stationary bicycle ergometer (Monark pendulum ergometer) with the approximate saddle height and cadence (70rpm) that would be used for the ensuing maximal graded exercise test (GXTmax) and submaximal rides during testing sessions 2 and 3. A 5-10 min warm-up was required prior to the GXTmax while maintaining the approximate cadence of 70rpm with a resistance of 0.5-1.0 kiloponds (kp). Once the warm-up was completed, the subject was prepared for the GXTmax designed to determine peak oxygen consumption (VO2peak; ml·kg·min^{-1}). The GXTmax was completed using an indirect calorimetry testing system (Parvo Medics TrueOne 2400 Metabolic Measurement System) and the same bicycle ergometer used for the warm-up period. During the GXTmax, the flywheel resistance was progressively increased at 2 minute workload stages, while maintaining a constant cadence of 70 rpm (metronomeonline.com), oxygen consumption (VO2), heartrate (HR; Polar with chest strap), and ratings of perceived exertion (RPE) of the chest (aerobic system), legs (musculature) and "overall" (combination of chest and legs) were determined. The initial stage of the test began with resistance of 0.5 kp and increased 0.5 kp at each stage until testing termination. Metabolic data was collected continuously by the metabolic unit, providing averages of VO2 in ml·kg·min^{-1} every 15 seconds which were converted to one minute averages post-testing. During the final minute of each stage, the respiratory exchange ratio (RER), and ratings of perceived exertion (RPE) were recorded. Heart rate was recorded in the last 10 seconds of each stage using a chest strap heart monitor. Ratings of perceived exertion were recorded using the original (6–20) Borg Scale (Borg, 1982). Participants were instructed to remain in contact with the seat for the entirety of the ride. The test was terminated when the subject could not continue due to fatigue or inability to maintain a cadence of 70rpm. Maximal effort and the attainment of VO2peak was verified by the subject meeting or exceeding predicted max HR or meeting or exceeding an RPE of 17 for the "overall" measure. The final RPE measure was determined immediately after termination of the test. After completing the GXTmax, each participant was encouraged to complete a short, self-directed cool-down period.

Testing Sessions 2 and 3: Constant Load Testing with Seat Position Randomization

Testing sessions 2 and 3 each consisted of four, 8-minute rides yet biomechanical and metabolic assessments performed during these 2 testing sessions were randomized. During testing sessions 2 and 3 each subject completed identical bicycle testing protocol rides, in which the second and fourth rides during testing sessions 2 and 3 were performed at a power level equal with 80% of the work rate of the previously determined VO2peak from the GXTmax. The first and the third rides during testing sessions 2 and 3 served as acclimatization for the seat position (flat or 12.5 degrees anterior incline) with the order of the seat position being randomized within each testing session. A minimum 10-minute break was provided between rides 2 and 3 during each testing session to aid with recovery. The two seat positions assessed in this study included a flat (parallel to the ground) and an anteriorly inclined (10-15 degree downward inclination of the saddle nose), measured via an inclinometer (eOUTIL digital angle gauge). A Velotron bike system using a Giant large (55.5cm) men's road bike frame and RacerMate battery operated magnet system (for resistance) was used for kinematic data. Cadence was controlled via the same online metronome system as the GXT while resistance was controlled via the magnet system of the Velotron. The only three bike parameters that were subject to alterations were the saddle height (determined by subject height and inseam length), saddle inclination (flat or 10-15 degrees on inclination), and handlebar position (depending upon comfort of the subject).

Three-dimensional segment position data were obtained using a 15-camera motion camera system (Motion Analysis, Rohnert Park, CA) at a capture frequency of 240Hz. A modified Cleveland Clinic marker set consisting of 46 reflective markers was utilized in this study. Markers were placed on the right and left acromion processes, sternum and the C7 vertebrae to track trunk position. Pelvic tracking was performed using markers placed bilaterally on the iliac crests, anterior (ASIS) and posterior (PSIS) superior iliac spines. Markers were placed bilaterally on the lateral and medial femoral epicondyles and malleoli. Rigid body clusters, consisting of 4 markers each, were placed on the lateral aspects of the thighs and shanks. Foot segment tracking was performed using markers placed bilaterally at the superior and inferior heel, lateral heel, first, second and fifth metatarsal heads. A 3-second static shot was captured and then the calibration markers at the sternum, ASIS, medial and lateral femoral condyles, and malleoli were removed.

After the calibration markers were removed, the subject established a comfortable hand hold position on the handlebars, which was marked with textured tape to remind the subject not to change their hand position or grip while cycling. During the second and fourth test rides, a series of 10-second data captures were obtained in 1-minute increments after completing the initial 30 seconds of the ride, resulting in eight data captures during the test ride. The eighth data capture was used for analysis as this was hypothesized to be the time frame in which fatigue had the largest effect on cycling mechanics. In addition, the same Borg RPE scale was used to obtain a self-reported LBP.

Visual3D (C-Motion Inc., Boyds, MD) was used to create an 8-segment musculoskeletal model consisting of the torso, pelvis, bilateral thighs, shanks, and feet. All marker position data were filtered using a 4th order, low-pass Butterworth filter with a cut-off frequency of 6Hz. Trunk and pelvic segment positions were described in reference to the global coordinate system whereby the x-direction was oriented medial-lateral, y-direction was oriented anterior-posterior and the z-direction was oriented superior-inferior.

All segment positions were normalized to the static calibration trial. Our primary kinematic variables of interest were the peak torso flexion, lumbar flexion and anterior pelvic tilt, whereby a negative value indicated torso flexion, lumbar flexion and anterior pelvic tilt as well as ROM for the aforementioned segments. Lumbar flexion was defined as torso position minus pelvis position in the sagittal plane (Vazirian et al., 2017). The established stance phase was one pedal revolution of the right foot. The beginning of the phase was established as the highest position of the center of gravity (COG) of the right foot and the ending phase was established as the next highest position of the COG of the right foot. These data were normalized to 101 points (0-100%) per revolution and 10 pedal revolutions of the final kinematic capture (collected at 7:30 during the 8 minute ride) were analyzed for each subject.

2.2.3. Statistical Analyses

All data were assessed for normality using a Shapiro Wilks test. Within-group differences in kinematics were assessed using a paired t-test or Wilcoxon test as necessary. All statistical analyses were performed in SPPS with a corresponding alpha-value of 0.05.

2.3 RESULTS

The average age and BMI of the participants was 29.2 years and 26.5kg/m^2. The trunk, lumbar and pelvic positions and ROMs as well as self-reported LBP (Table 2.1) were similar between the flat and inclined saddle conditions ($p > 0.05$). The group average profiles during the stance phase of the cycling task for the torso, lumbar and pelvic angular positions are shown in Figures 2.1 – 2.3.

2.4 DISCUSSION

Our study compared the effect of two saddle angles, a traditional flat relative to the horizontal saddle angle and a saddle angle with anterior downward inclination of 10-15 degrees, on trunk, lumbar, and pelvic kinematics during cycling. No significant differences were found in sagittal plane torso, lumbar or pelvic kinematics between saddle conditions.

The lack of kinematic differences may suggest that lumbar forces while cycling with these two different saddles conditions may be similar. In addition, the lack of kinematic differences despite a change in saddle position was not associated with any significant changes in self-reported incidence of LBP within our study cohort. These study results indicate no effect of our tested saddle conditions on lumbar mechanics or LBP.

Although our study results indicate a lack of differences in sagittal plane torso, lumbar or pelvic segment positions, prior work indicated differences in lumbar flexion as an impact of varying saddle positions. In a previous study where lumbar flexion and self-reported LBP decreased when adopting a saddle angle with 10-15 degrees of declination minimal joint/segmental kinematics were reported (Salai, et al, 1999). In addition, self-reported LBP was investigated outside of a laboratory setting with the subjects in that previous study using their own custom fitted bikes (Salai, et al, 1999). These lack of similarities between the previous work and our study may be due to the use of a short-term, high intensity cycling on a single bike within our study, and the corresponding kinematic data inspected were collected near the end of the ride when potential fatigue had been induced.

Our study has potential limitations which should be considered when assessing the results of this study. One primary limitation was that the only adjustments that could be conducted on the bicycle used in our study, was the height of the seat and inclination of the saddle. In addition, all our study participants did not report current or prior history of LBP. The tested saddle conditions in our study may be more sensitive in detecting kinematic differences in cyclists with self-reported LBP and should be investigated in future studies. Future work should also include varying intensities, assess joint kinetics and lumbar spine forces via computational modeling to understand potential alterations in lumbar and joint loading during cycling.

2.5 CONCLUSION

In conclusion, this study found no significant evidence that a saddle with a downward incline of 10-15 degrees significantly alters lumbar, trunk or pelvic kinematics or perceived LBP in individuals who are free from chronic LBP. It should be noted that these results only pertain to short-term, high intensity cycling, and alterations may be observed during cycling tasks that are of a longer duration and lower intensity.

Table 2.1: Results are reported as mean ± standard deviation for both saddle conditions. Negative joint angles represent trunk flexion, lumbar flexion, and anterior pelvic tilt. All angles are measured in degrees. Self-reported lower back pain (LBP) was gauged on a Borg scale of 6-20.

	Flat Saddle	Inclined Saddle	p
Trunk Flexion	-41.14 ± 6.34	-40.66 ± 6.2	0.88
Lumbar Flexion	-18.06 ± 6.38	-18.60 ± 8.99	0.66
Anterior Pelvic Tilt	-23.34 ± 5.93	-22.3 ± 7.03	0.33
Trunk ROM	5.91 ± 2.58	6.02 ± 3.18	0.91
Lumbar ROM	8.62 ± 3.07	8.35 ± 3.03	0.70
Pelvic ROM	6.41 ± 3.13	5.76 ± 3.06	0.23
Self-Reported LBP	7.25 ± 2.49	6.9 ± 1.8	0.28

Figure 2.1: Trunk angles in the sagittal plane during the stance phase (pedal rotation) of cycling with a flat saddle angle (blue line) and a saddle with downward inclination (orange line). Negative joint angles represent trunk flexion.

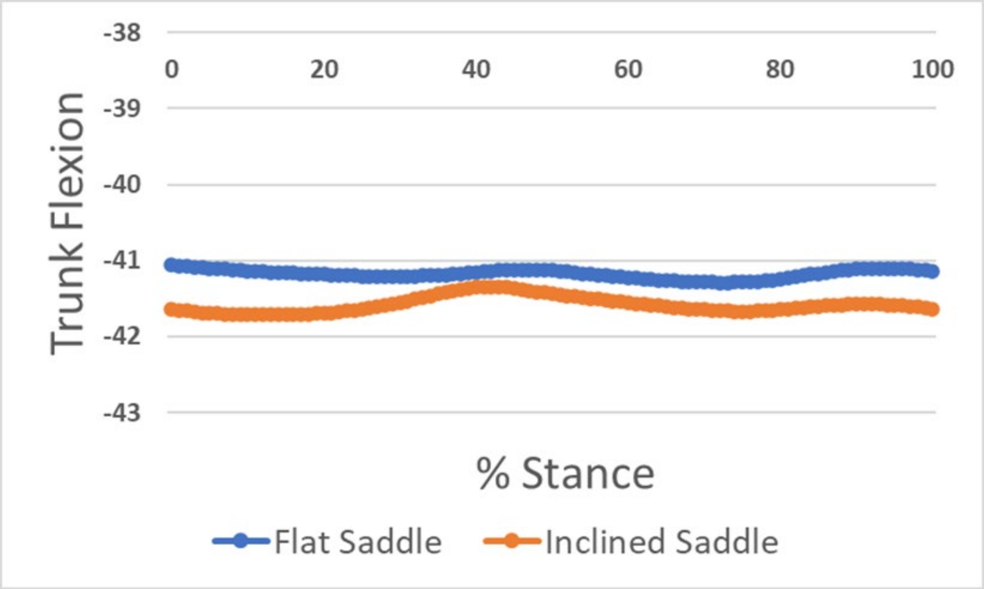


Figure 2.2: Lumbar angles in the sagittal plane during the stance phase (pedal rotation) of cycling with a flat saddle angle (blue line) and a saddle with downward inclination (orange line). Negative joint angles represent lumbar flexion.

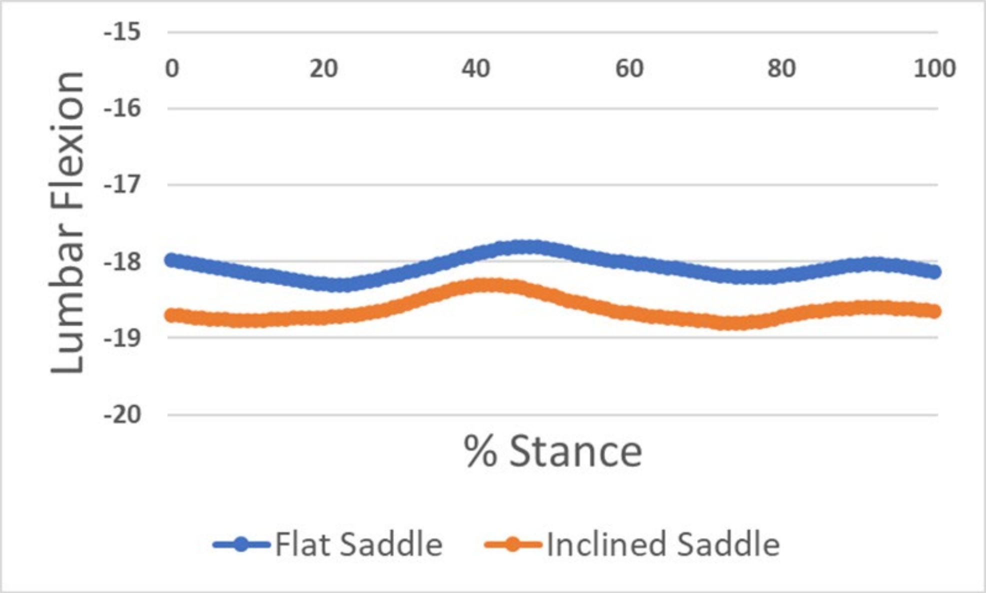
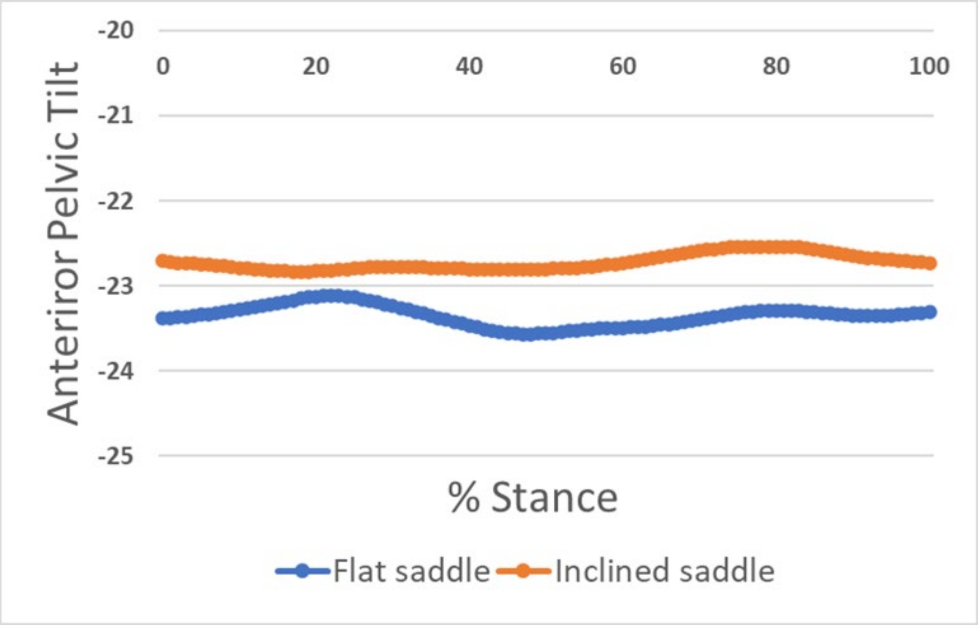


Figure 2.3: Pelvic angles in the sagittal plane during the stance phase (pedal rotation) of cycling with a flat saddle angle (blue line) and a saddle with downward inclination (orange line). Negative joint angles represent anterior pelvic tilt.



CHAPTER 3. THE EFFECT OF DIFFERENT SADDLE INCLINATIONS ON CARDIOMETABOLIC MEASURES

3.1 INTRODUCTION

Oftentimes bicycle modifications are made in an effort to improve performance by increasing aerodynamics or to alter joint kinematics and position on the bicycle to optimize torque production, with the goal being to decrease energy used to accomplish the same cycling task. Common bicycle modifications to improve comfort and performance during cycling are often centered around the saddle and may include alterations to saddle structures, seat tube angles, saddle heights, and/or saddle angles. Changes in saddle orientation have a direct effect on how an individual is positioned upon the bicycle frame and can cause large shifts in torso and pelvis kinematics, which can in turn affect joint angles of the lower limb and cycling performance. (Bressel & Larson, 2002) One major effect of saddle modifications on a bicycle is the effect on anterior pelvic tilt (APT), whereby increasing APT leads to a corresponding decrease in lumbar flexion, which can lead to a lower risk of lower back pain (LBP) in cyclists (Salai et al., 1999; Dettori & Norvell, 2005; Marsden & Schwellnus, 2010). This specific seat modification of 10-15 degrees downward inclination results in a forward tilted posture as a result of increased anterior pelvic tilt and decreased lumbar flexion, with more weight being distributed through the upper extremities and onto the handlebars and thereby, decreasing pressure and shear forces acting on the spine during cycling (Bressel & Larson, 2002; Mestdagh, 1998).

However, adopting a saddle position or design which causes a large amount of APT has the potential to not only increase comfort and decrease LBP, but affect performance as well (Caddy et al., 2016). There is controversary concerning how this inclined saddle angle will affect performance, as some studies suggest that increased APT correlates with greater peak hip flexion, thereby optimizing the length-tension relationship of the gluteus maximus and hamstrings (Hoof et al., 2012; Muyor et al., 2011). Other studies have shown that positions which cause the cyclist to lean forward (such as aerodynamic positions) have the potential to result in higher oxygen expenditure (Gnehm, et al, 1997; Jobson, et al, 2008). Modifications to the seat height and seat tube angle (STA) have notable effects on the kinematics and kinetics of the lower limbs as well as cycling efficiency, and has led to established standards on seat height by the scientific and cycling communities (Nordeen-Snyder, 1977; Shennum & Devries, 1976).

There have been few studies conducted which inspect the effects of altered saddle angles on performance as determined by changes in cardiometabolic measures (VO2 and HR). Specifically, there is a need to further examine the effects that a change in saddle angle can have on performance-related measures including metabolic expenditure (oxygen utilization) during cycling. Therefore, the purpose of this study was to examine the metabolic- and performance-based differences that occur when cycling with a traditional saddle inclination (flat relative to the horizontal) and a 10 – 15 degree saddle inclination through continuous metabolic, heart rate (HR) monitoring and rating of perceived exertion (RPE). It was hypothesized that there would be no significant differences in VO2 levels, HR, or RPE between the two saddle conditions when comparing the same cycling task.

3.2 METHODS

3.2.1 Participants

A total of 20 subjects were recruited for this study (11 men, 9 women) through a series of flyers posted on University of Kentucky's campus, local bike shops and local gyms, as well as word of mouth. Participants were all 18-55 year old individuals who had previous or current experience riding a bike (recreational to professional levels were accepted), exercised a minimum of 3 times per week (30 minutes per day), and were currently free from diagnosed lower back pain and/or lower limb surgeries. Additional subject inclusion criteria were body mass index (BMI) $\leq 35 \text{kg/m}^2$ and did not experience lower limb injury during the 6 months prior to participation.

3.2.2 Testing Sessions

Three testing sessions conducted in the University of Kentucky Biodynamics Lab were required for each subject. Each testing session was separated by a minimum of 48 hours, but the 3 testing sessions were completed within two weeks. Subjects were instructed to refrain from engaging in any strenuous exercise 24 hours prior to each testing session.

Testing Session 1 (Consent and Pre-Screening, Anthropometric Measures, Maximal Graded Exercise Test)

During the first testing session, subjects provided written informed consent for participation in accordance with the policies and procedures of the University of Kentucky's Office of Research Integrity, completed the Physical Activity Readiness Questionnaire for Everyone (PARQ+)(NASM PAR-Q, 2020) as a pre-participation safety screening tool, and completed a customized physical activity questionnaire.

While wearing lightweight clothing and no shoes, measures of total body mass (kg) using a calibrated scale (ETEKCITY) and standing height (m) was determined using a stadiometer (HEALTH O METER, Continental). These measures of mass and height were used to calculate each participant's BMI. Inseam length was measured by inserting a folder between the thighs and with the top portion of the folder in contact with the participant's pelvic floor. The distance from the top of the folder to the ground was measured and multiplied by 1.09 to assess proper saddle height for the ensuing testing procedures. Saddle height was visually inspected while the subject warmed up for the graded exercise test (GXT) to ensure that there was no knee abduction or lateral flexion of the torso, which would indicate too short or too long of a saddle height, respectively.

The subject was then instructed to warm up on a stationary bicycle ergometer (Monark pendulum ergometer) with the approximate saddle height and cadence (70rpm) that would be used for the ensuing maximal graded exercise test (GXTmax) and submaximal rides during testing sessions 2 and 3. A 5-10 min warm-up was required prior to the GXTmax while maintaining the approximate cadence of 70rpm with a resistance of 0.5-1.0 kiloponds (kp). Once the warm-up was completed, the subject was prepared for the GXTmax designed to determine peak oxygen consumption (VO2peak; $ml \cdot kg \cdot min^{-1}$). The GXTmax was completed using an indirect calorimetry testing system (Parvo Medics TrueOne 2400 Metabolic Measurement System) and the same bicycle ergometer used for the warm-up period. During the GXTmax the flywheel resistance was progressively increased at 2 minute workload stages while maintaining a constant cadence of 70 rpm (metronomeonline.com) oxygen consumption (VO2), heartrate (HR; Polar with chest strap), and ratings of perceived exertion (RPE) of the chest (aerobic system), legs (musculature) and "overall" (combination of chest and legs) were determined. The initial stage of the test began with resistance of 0.5 kp and increased 0.5 kp at each stage until testing termination. Metabolic data was collected continuously by the metabolic unit, providing averages of VO2 in ml·kg·min^{-1} every 15 seconds which were converted to one minute averages post-testing. During the final minute of each stage, the respiratory exchange ratio (RER), and ratings of perceived exertion (RPE) were recorded. Heart rate was recorded in the last 10 seconds of each stage using a chest strap heart monitor. Ratings of perceived exertion were recorded using the original (6–20) Borg Scale (REF; Borg, 1982). Participants were instructed to remain in contact with the seat for the entirety of the ride. The test was terminated when the subject could not continue due to fatigue or maintain a cadence of 70rpm. Maximal effort and the attainment of VO2peak was verified by the subject meeting or exceeding predicted max HR or meeting or exceeding an RPE of 17 for the "overall" measure. The final RPE measure was determined immediately after termination of the test. After completing the GXTmax, each participant was encouraged to complete a short, self-directed cool-down period.

Testing Sessions 2 and 3: Constant Load Testing with Seat Position Randomization

Testing sessions 2 and 3 were conducted in a random order. During Testing Session 2 and 3 each subject completed identical bicycle testing protocol rides. Each ride consisted of four 8 min rides. Rides 2 and 4 were performed at a wattage which coincided with 80% of the work rate of previously determined VO2peak from the GXTmax. The first and the third 8 min rides served as acclimatization for the seat position that was also randomly presented within each testing session. The two seat positions used to determine kinematic and metabolic differences included the seat position "flat" (horizontal to the floor testing room floor) and "anteriorly inclined" (10-15 degree downward inclination of the saddle nose, measured via inclinometer and were randomized. During the performance testing session, cardiometabolic measures (VO2, HR, efficiency) were determined during the 4 consecutive 8 min rides at an intensity corresponding with an 80% of the previously determined VO2peak from the GXTmax. During Testing Session 3 an identical biking protocol was used; however, kinematic measures were completed instead of the cardiometabolic measures. Kinematic and cardiometabolic measures were completed during separate testing sessions because the metabolic cart would have obstructed the multi-camera system in the lab during motion capture of the kinematic data collection.

A minimum 10-minute break was required between rides 2 and 3 to aid recovery. During performance testing, cardiometabolic measures were determined using the same metabolic system and heartrate monitors used during the GXTmax procedures. The metabolic system was calibrated immediately preceding the arrival of each subject. The subject first established a comfortable hand hold position on the handlebars, which was marked with textured tape to remind the subject not to change their position or grip on the handlebars during the constant load ride. The subject then completed the first 8 min constant load ride using the randomized seat position. After the first 8-minute ride was complete, the metabolic mask was affixed to the subject and another 8-minute ride at the predetermined constant load was completed. After the second 8-minute ride was completed, the mask was taken off and lightly cleaned while the subject engaged in a minimum of 10 minutes of passive recovery. After passive recovery, the saddle angle was changed to the remaining position and the third 8 min ride began. Once the third ride concluded, the metabolic mask was once again affixed for the fourth and final 8 min constant load ride of this testing session. During the data collection rides (2 and 4), in addition to VO2 measures, HR and RPE (chest, legs, and "overall") were recorded every 2 minutes. In addition, the subjects were asked to self-report their low back pain using the same 6 to 20 RPE scale to avoid confusion during intensive exercise, if any existed. Once the final 8-minute ride was completed, the metabolic mask was removed from the subject and a cool down on the bike was recommended.

VO2 and HR measures were converted to one minute averages for assessment. VO2 was assessed as a measure of milliliters of oxygen per kilogram of body mass per minute of work ($ml \cdot kg \cdot min^{-1}$) while HR was assessed as beats per minute (BPM). These results were analyzed from the perspective of absolute measure and as a percentage of the peak established from the GXTmax. RPE of chest, legs and overall were obtained every two minutes during the ride, however only "overall" was analyzed as it was a combination of both chest and legs and was thought to most accurately represent the subjects' perceived effort.

3.2.3 Statistical Analyses

All data were assessed for normality using a Shapiro Wilks test. Within-group differences in VO2-parameters, HR and RPE scores were assessed using a paired t-test or Wilcoxon test as necessary. All statistical analyses were performed in SPPS with a corresponding alpha-value of 0.05.

3.3 RESULTS

The average age and BMI of the participants was 29.2 years and 26.5 kg/m^2. The peak VO2, HR and "overall" RPE varied from person to person based on age, sex, and current level of fitness (Table 3.1).

Peak VO2s, HR, and "overall" RPE elicited by the submaximal constant load sessions (Table 3.2) were similar between the flat and inclined saddle positions ($p > 0.05$).

3.4 DISCUSSION

Our study compared the effect of two saddle angles, a traditional flat relative to the horizontal saddle angle and a saddle angle with anterior downward inclination of 10-15 degrees, on submaximal VO2 levels, HR, and RPE. No significant differences were found in VO2, HR or RPE between saddle conditions which suggests no statistically significant alterations in performance between these two saddle positions, nor do they have any significant effect on an individual's perception of effort.

Our study results indicate a lack of differences in cardiometabolic measures or perceived effort, which has been reported in previous studies which reported the effect of differing saddle angles and pelvis positions of performance outcomes (Caddy, et al, 2016; Welbergen & Clijsen, 1990), however previous studies used shallower saddle angles and higher intensity cycling to measure these parameters. Our study did inspect short duration, high intensity cycling despite being submaximal. It is possible that a longer duration, lower intensity test may elicit more pronounced differences in the cardiometabolic and RPE measures inspected. Another factor which could influence cardiometabolic measures during cycling is air resistance, which was not a factor in our study since all cycling was performed in a stationary fashion in an indoor laboratory. It is possible that the change in saddle position could have an effect on the aerodynamics of the rider, which in turn could have an effect on VO2, HR and RPE during submaximal cycling.

Our study has potential limitations which should be considered when assessing the results of this study. One primary limitation is that only one intensity (80% of peak VO2 work rate) was inspected. If lower intensities were also inspected there may have been more significant differences in cardiometabolic measures during cycling tasks. Another potential limitation was that this study was conducted in a laboratory setting in which aerodynamics had no effect on energy expenditure. Future work should include varying intensities and duration, as well as field tests (such as track riding with a portable VO2 system) so that the effects of fluid friction (air resistance) and, to a lesser extent, rolling friction may be observed on cycling-based performance.

3.5 CONCLUSION

In conclusion, this study found no evidence of differences in cardiometabolic measures when comparing a flat saddle angle to a saddle angle with a downward incline of 10-15 degrees during a high intensity 8 minute cycling task. It should be noted that these results only pertain to short term, high intensity cycling in a laboratory setting, and alterations may be observed during cycling tasks that are of a longer duration and lower intensity.

Table 3.1: Peak Cardiometabolic and RPE measure averages from the GXTmax

	Average peak
VO2 (ml·kg·min^{-1})	42.32 ± 7.3
HR (bpm)	184.4 ± 7.3
“Overall” RPE (6-20)	18.5 ± 0.76

Table 3.2 : Absolute cardiometabolic and RPE measure averages from constant load testing

	Flat Saddle	Inclined Saddle	p-value
Absolute VO2 (ml·kg·min^{-1})	35.07 ± 6.15	35.04 ± 6.05	0.81
Relative VO2 (%)	82.86 ± 1.79	82.81 ± 2.35	0.87
HR (bpm)	165.9 ± 6.5	165.9 ± 6.76	1.0
‘overall’ RPE (6-20)	16.45 ± 0.94	16.6 ± 1.19	0.42

CHAPTER 4. SEX BASED LUMBOPELVIC DIFFERENCES INCURRED BY DIFFERENT SADDLE ANGLES

4.1 INTRODUCTION

Due to the difference in anatomical build, men and women position themselves differently on a traditional bicycle, with the female athlete potentially being less comfortable as the bicycle was originally designed with the male anatomy in mind (Ingole et al., 2015). One notable difference is that men tend to ride with a slightly more flexed (inclined) torso position (Ingole, et al 2015). Perineal pain has been shown to be a more common side effect of cycling in women compared to men, to the point where bladder infections and tissue breakdown of the anterior perineum can occur as a result of abnormal pressure on female cyclist's bladder (Bressel & Larson, 2003). Previous studies have proposed the idea that forward (anterior) pelvic tilt could be a bicycle modification that decreases these perceptions and side effects of perineal pain and pressure. However there is contention in the literature on whether this effect is a result of the change in positioning as result of anterior inclination or if pressure is relieved as a result of more of the person's mass being supported by the upper limbs via the handlebars (Salai, et al, 1999; Bressel & Larson, 2003).

One explanation for the increased anterior perineal pressure and pain in female cyclists is that women tend to have more of a natural anterior pelvic tilt, along with a wider distance between the ischium when compared to men, increasing bone on saddle contace (Mestdagh, 1998). Men, however, have shown a tendency to ride with a more neutral pelvic position (less anterior inclination) which could be attributable to an anatomically more neutral pelvic angle in males (Mestdagh, 1998). A previously suggested optimal fit for a bicycle regarding the female anatomy may involve a saddle angle with slight anterior inclination to minimize rubbing contact on the anterior portion of the pelvis along with slight changes to the saddle which minimizes contact between the saddle and the sensitive portions of the female anatomy (Bressel & Larson, 2003).

Understanding the differing effects of a downward saddle inclination of 10-15 degrees on torso, lumbar and pelvic kinematics on female and male cyclists will help provide an understanding of the potential differences this saddle angle may have when it comes to factors which may decrease instances of LBP in men vs women. While no evidence was found that men and women experience different rates of back pain (Piotrowska et al., 2017; Dettori & Norvell, 2006) it is possible that the kinematic differences elicited by the downward inclination of the saddle may have different potential for affecting kinematic factors which may contribute to LBP. Therefore the purposes of this study were to directly inspect the differences in torso, lumbar and pelvic kinematics between a traditional saddle inclination (flat relative to the horizontal) and downward saddle inclination of 10 – 15 degrees in men and women cyclists. It was hypothesized that women would exhibit greater anterior pelvic tilt and less lumbar flexion during both flat and inclined saddle positions compared to men yet there would be no interaction effect of sex and saddle condition on cycling kinematics.

4.2 METHODS

4.2.1 Participants

A total of 20 subjects were recruited for this study (11 men) through a series of flyers posted on University of Kentucky's campus, local bike shops and local gyms, as well as word of mouth. Participants were all 18-55 year old individuals who had previous or current experience riding a bike (recreational to professional levels were accepted), exercised a minimum of 3 times per week (30 minutes per day), and were currently free from diagnosed lower back pain and/or lower limb surgeries. Additional subject inclusion criteria were body mass index (BMI) ≤ 35 kg/m2 and did not experience lower limb injury during the 6 months prior to participation.

4.2.2 Testing Sessions

Three testing sessions conducted in the University of Kentucky Biodynamics Lab were required for each subject. Each testing session was separated by a minimum of 48 hours, but the 3 testing sessions were completed within two weeks. Subjects were instructed to refrain from engaging in any strenuous exercise 24 hours prior to each testing session.

Testing Session 1 (Consent and Pre-Screening, Anthropometric Measures, Maximal Graded Exercise Test)

During the first testing session, subjects provided written informed consent for participation in accordance with the policies and procedures of the University of Kentucky's Office of Research Integrity, completed the Physical Activity Readiness Questionnaire for Everyone (PARQ+)(NASM PAR-Q, 2020) as a pre-participation safety screening tool, and completed a customized physical activity questionnaire. While wearing lightweight clothing and no shoes, measures of total body mass (kg) using a calibrated scale (ETEKCITY) and standing height (m) was determined using a stadiometer (HEALTH O METER, Continental). These measures of mass and height were used to calculate each participant's BMI. Inseam length was measured by inserting a folder between the thighs and with the top portion of the folder in contact with the participant's pelvic floor. The distance from the top of the folder to the ground was measured and multiplied by 1.09 to assess proper saddle height for the ensuing testing procedures. Saddle height was visually inspected while the subject warmed up for the graded exercise test (GXT) to ensure that there was no knee abduction or lateral flexion of the torso , which would indicate too short or too long of a saddle height, respectively.

The subject was then instructed to warm up on a stationary bicycle ergometer (Monark pendulum ergometer) with the approximate saddle height and cadence (70rpm) that would be used for the ensuing maximal graded exercise test (GXTmax) and submaximal rides during testing sessions 2 and 3. A 5-10 min warm-up was required prior to the GXTmax while maintaining the approximate cadence of 70rpm with a resistance of 0.5-1.0 kiloponds (kp). Once the warm-up was completed, the subject was prepared for the GXTmax designed to determine peak oxygen consumption (VO2peak; $ml \cdot kg \cdot min^{-1}$). The GXTmax was completed using an indirect calorimetry testing system (Parvo Medics TrueOne 2400 Metabolic Measurement System) and the same bicycle ergometer used for the warm-up period. During the GXTmax, the flywheel resistance was progressively increased at 2 minute workload stages, while maintaining a constant cadence of 70 rpm (metronomeonline.com), oxygen consumption (VO2), heartrate (HR; Polar with chest strap), and ratings of perceived exertion (RPE) of the chest (aerobic system), legs (musculature) and "overall" (combination of chest and legs) were determined. The initial stage of the test began with resistance of 0.5 kp and increased 0.5 kp at each stage until testing termination. Metabolic data was collected continuously by the metabolic unit, providing averages of VO2 in ml·kg·min^{-1} every 15 seconds which were converted to one minute averages post-testing. During the final minute of each stage, the respiratory exchange ratio (RER), and ratings of perceived exertion (RPE) were recorded. Heart rate was recorded in the last 10 seconds of each stage using a chest strap heart monitor. Ratings of perceived exertion were recorded using the original (6–20) Borg Scale (REF; Borg, 1982). Participants were instructed to remain in contact with the seat for the entirety of the ride. The test was terminated when the subject could not continue due to fatigue or maintain a cadence of 70rpm. Maximal effort and the attainment of VO2peak was verified by the subject meeting or exceeding predicted max HR or meeting or exceeding an RPE of 17 for the "overall" measure. The final RPE measure was determined immediately after termination of the test. After completing the GXTmax, each participant was encouraged to complete a short, self-directed cool-down period.

Testing Sessions 2 and 3: Constant Load Testing with Seat Position Randomization

Testing sessions 2 and 3 each consisted of four, 8-minute rides yet biomechanical and metabolic assessments performed during these 2 testing sessions were randomized. During testing sessions 2 and 3 each subject completed identical bicycle testing protocol rides, in which the second and fourth rides during testing sessions 2 and 3 were performed at a wattage which coincided with 80% of the work rate of the previously determined VO2peak from the GXTmax. The first and the third rides during testing sessions 2 and 3 served as acclimatization for the seat position (flat or 10 – 15 degree anterior incline) with the order of the seat position being randomized within each testing session. A minimum 10-minute break was provided between rides 2 and 3 during each testing session to aid with recovery. The two seat positions assessed in this study included a flat (parallel to the ground) and an anteriorly inclined (10-15 degree downward inclination of the saddle nose), measured via an inclinometer (eOUTIL digital angle gauge). A Velotron bike system using a Giant large (55.5cm) men's road bike frame and RacerMate battery operated magnet system (for resistance) was used for kinematic data. Cadence was controlled via the same online metronome system as the GXT while resistance was controlled via the magnet system of the Velotron. The only three bike parameters that were subject to alterations were the saddle height (determined by subject height and inseam length), saddle inclination (flat or 10-15 degrees on inclination), and handlebar position (depending upon comfort of the subject).

Three -dimensional segment position data were obtained using a 15-camera motion camera system (Motion Analysis, Rohnert Park, CA) at a capture frequency of 240Hz. A modified Cleveland Clinic marker set consisting of 46 reflective markers was utilized in this study. Markers were placed on the right and left acromion processes, sternum and the C7 vertebrae to track trunk position. Pelvic tracking was performed using markers placed bilaterally on the iliac crests, anterior (ASIS) and posterior (PSIS) superior iliac spines. Markers were placed bilaterally on the lateral and medial femoral epicondyles and malleoli. Rigid body clusters, consisting of 4 markers each, were placed on the lateral aspects of the thighs and shanks. Foot segment tracking was performed using markers placed bilaterally at the superior and inferior heel, lateral heel, first, second and fifth metatarsal heads. A 3-second static shot was captured and then the calibration markers at the sternum, ASIS, medial and lateral femoral condyles and malleoli were removed .

After the calibration markers were removed, the subject established a comfortable hand hold position on the handlebars, which was marked with textured tape to remind the subject not to change their hand position or grip while cycling. During the second and fourth test rides, a series of 10-second data captures were obtained in 1-minute increments after completing the initial 30 seconds of the ride, resulting in eight data captures during the test ride. The eighth data capture was used for analysis as this was hypothesized to be the time frame in which fatigue had the largest effect on cycling mechanics. In addition, the same Borg RPE scale was used to obtain a self-reported LBP. Visual3D (C-Motion Inc., Boyds, MD) was used to create an 8-segment musculoskeletal model consisting of the torso, pelvis, bilateral thighs, shanks and feet. All marker position data were filtered using a 4th order, low-pass Butterworth filter with a cut-off frequency of 6Hz. Trunk and pelvic segment positions were described in reference to the global coordinate system whereby the x-direction was oriented medial-lateral, y-direction was oriented anterior-posterior and the z-direction was oriented superior-inferior. All segment positions were normalized to the static calibration trial. Our primary kinematic variables of interest were the peak torso flexion, lumbar flexion and anterior pelvic tilt, whereby a negative value indicated torso flexion, lumbar flexion and anterior pelvic tilt as well as ROM for the aforementioned segments. Lumbar flexion was defined as torso position minus pelvis position in the sagittal plane (Vazirian et al., 2017). The established stance phase was one pedal revolution of the right foot. The beginning of the phase was established as the highest position of the center of gravity (COG) of the right foot and the ending phase was established as the next highest position of the COG of the right foot. These data were normalized to 101 points (0-100%) per revolution and 10 pedal revolutions of the final kinematic capture (collected at 7:30 during the 8 minute ride) were analyzed for each subject.

4.2.3 Statistical Analyses

In order to assess sex-based differences in cycling mechanics, all kinematic data were assessed using a two-way analysis of variance (ANOVA). All statistical analyses were performed in SPSS (v28.0, Armonk, NY) with a corresponding alpha-value of 0.05.

4.3 RESULTS

No differences were found based upon sex or saddle conditions between male and female subjects. In addition there were no differences in the interaction between sex and saddle conditions on kinematics (Table 4.1).

4.4 DISCUSSION

No statistically significant differences occurred in any of the kinematic comparisons made in this study Men showed greater overall “peak” positions for both lumbar and pelvis positions, regardless of the condition, however these peaks did not exceed the women’s peaks by more than 1.6 degrees. These study results indicate no effect of our tested saddle conditions on sex-based kinematic differences in the lumbar portion of the spine or the pelvis.

Despite previous data in which women rode with greater anterior pelvic tilt (Ingole et al., 2015, Bressel & Larson, 2003; Mestdagh, 1998) our results exhibited males riding with a greater degree of APT during both saddle conditions, which also led to men riding with greater lumbar flexion under both saddle conditions. This may have been due to the limited access of bicycle frames, and the frame being used for this study was not suited for smaller people. On average, the female subjects in this study were of smaller stature (1.66 meters) than that of men (1.78 meters, which could explain why the kinematics of this study vary from those in which different sized bicycle frames were accessible. Additionally, due to this discrepancy between frame size and the average stature of female subjects it is possible that they rode positioned further forward on the saddle, which may impact pelvic positioning, and this could also account for the greater variation in pelvic and lumbar position in women as it may have been more difficult for them to establish a comfortable riding position.

Our study has potential limitations which should be considered when assessing the results of this study. The primary limitation was the limited access to differing bike frames, and the bike frame that was used for kinematic data collection was not well suited for individuals of shorter stature.

4.5 CONCLUSION

In conclusion, this study found no significant evidence that a bicycle saddle with a downward incline of 10-15 degrees incurs any significant differences in lumbopelvic kinematics when comparing men to women. It should be noted that no significant differences in lumbopelvic kinematics were observed during cycling with a flat saddle angle and that these results only pertain to short-term, high intensity cycling and that the cycling tasks were completed with only one size and make of bike frame. Alterations may be observed during lower intensity cycling tasks, or with bicycle frames that better fit cyclists of a shorter stature.

Table 4.1: Trunk, lumbar and pelvic kinematics comparison based on sex. All angles are measured in degrees.

	Males Flat Saddle	Males Incline Saddle	Females Flat Saddle	Females Inclined Saddle	Sex (p-value)	Saddle Condition (p-value)	Sex by Saddle Condition (p-value)
Trunk Flexion	-45.3 ± 3.62	-45.2 ± 4.92	-42.4 ± 7.88	-42.2 ± 6.68	0.12	0.94	0.99
Lumbar Flexion	-23.4 ± 6.09	-23.7 ± 9.50	-21.2 ± 6.30	-22.1 ± 8.49	0.45	0.82	0.92
Anterior Pelvic Tilt	-26.9 ± 5.87	-25.5 ± 7.12	-25.8 ± 6.35	-25.2 ± 7.97	0.73	0.63	0.86
Trunk ROM	6.24 ± 2.63	5.39 ± 2.69	5.51 ± 2.62	6.79 ± 3.71	0.72	0.82	0.26
Lumbar ROM	8.30 ± 3.27	7.47 ± 2.66	9.02 ± 2.95	9.42 ± 3.26	0.18	0.82	0.53
Pelvic ROM	6.84 ± 2.86	5.19 ± 2.10	5.88 ± 3.53	6.45 ± 3.97	0.88	0.59	0.27

CHAPTER 5. CONCLUSION

5.1 CONCLUSION

This dissertation compared how two differing saddle angles (flat relative to the horizontal vs. 10-15 degrees anterior declination) during a short duration high intensity cycling task affect: 1) overall trunk, lumbar and pelvic kinematics and perceived lower back pain, 2) cardiometabolic measures (VO2 and HR) as well as rating of perceived exertion and 3) trunk, lumbar and pelvic kinematics in men vs. women. Previous studies have inspected the effects of similar and identical saddle angles on lumbar kinematics as well as perceived LBP, however studies inspecting this degree of saddle inclination have been limited to studies where very little laboratory conducted cycling tasks are conducted, and/or results were obtained through subjects self-reporting their data.

In past studies, changes in kinematics of the torso and pelvis when riding with a saddle angle of 10-15 degrees declination have been shown to decrease lumbar flexion to an extent which has potential to reduce overall shear forces in the lumbar spine and potentially decrease perceptions of LBP. However this saddle angle elicited no significant differences in these measures in this study.

Cardiometabolic measures as well as RPE showed no significant differences when comparing saddle angles while accomplishing the same cycling task. These results have been observed in previous studies, though previous studies have used shallower saddle angles (<10 degrees declination) and have focused on maximal intensity rides. The results of this study suggest that a steeper angle of 10-15 degrees with a submaximal high intensity workload does not incur significant kinematic differences to affect any of the measured performance parameters significantly.

Kinematics of the torso, lumbar spine and pelvis were similar between males and females regardless of saddle angle. Previous studies have exhibited that women tend to ride with a more anteriorly inclined pelvic tilt during normal cycling, however no significant difference was found between sexes in lumbar flexion or the segments which affect lumbar flexion (torso and pelvis) in flat or inclined saddle riding. However, these results may have been affected by the lack of bicycle frames available and the frame being too large for some of the female participants.

In conclusion, no kinematic, cardiometabolic or sex-based differences were found in this study as a result of saddle angle. While some riders may prefer a saddle angle with a downward inclination, there is no evidence from this study that suggests such a saddle angle will have any positive or negative effects on lumbar kinematics, perceived back pain, cardiometabolic measures or rating of perceived exertion when accomplishing synonymous cycling tasks.

5.2 FUTURE WORK

This study sought to expand upon prior studies inspecting the effects of differing saddle angles (specifically those with downward inclination) on kinematics of the lumbar spine and cardiometabolic measures. Future work should focus on including kinetic measures (shear forces) in conjunction with kinematics, and should include a more focused subject demographic in regards to prior and current cycling experience. Greater diversity in the selection of bicycle frames should also be included, and inspection of cycling tasks which more closely resemble real world cycling tasks (longer duration, shorter intensity) might also elicit more substantial differences in kinematics and cardiometabolic measures as increasing the duration may induce more fatigue in the lumbar region of the spine.

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