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SADDLE HEIGHT POSITIONING FOR TRIATHLETES USING ROAD CYCLIST METHODS

by

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Thesis

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DEDICATION

To my husband, because without his help, this project would have been a lot harder than it was. And to my parents, for always believing in me.

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ABSTRACT

Triathlon is the combined sport of swimming, cycling, and running. Cycling is normally the longest portion of the race. Therefore, maintenance of comfort and efficiency while maintaining high power output is essential for success in the cycling portion. Several methods are currently used for determination of height for road cyclists. It has yet to be determined if these methods are applicable to triathletes. Because of the different geometry of a triathlon bicycle, the question remains whether road-saddle fitting techniques can be an applied and work for the triathlon bicycle.

This thesis evaluated the participant's current saddle height in addition to four different road-cycling fitting methods with regard to oxygen consumption while in an aerodynamic position on a triathlon-specific bicycle. It was determined that there was no statistically significant difference between the recreational male and female triathletes' current saddle heights or those of the four different methods.

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CHAPTER 1: INTRODUCTION

Introduction

Triathlon consists of three different sport disciplines together in a combined timed event: swimming, cycling, and running. The distances of triathlon races can vary from the shortest race, called a super-sprint which consists of swimming 400-m, cycling 10-km and running 2.5-km, up to the longest triathlon race, Ironman distance, which consists of a 3.8-km swim, a 180-km cycle, and a 42-km run (What is triathlon? n.d.). To complete such an endeavor not only requires immense conditioning due to the physical demands that are placed upon the body in the form of energy requirements but also the essential need to stay mentally focused. To remain focused physically and mentally requires not only energy conservation but also efficiency, the greatest amount of work completed with the least amount of effort (energy expenditure). The majority of a triathlon is spent on the bicycle. Therefore, maximizing power output with the greatest possible efficiency and comfort is a goal for any triathlete.

It might be expected that with the amount of time spent on bicycles during training and racing, recreational, age-group triathletes would have acquired their correct saddle height through trial and error. Even so, these athletes may not be operating at an efficient saddle height.

There are many theories on and practices for obtaining the correct saddle height. Many of the techniques for saddle height adjustment have been around for many years, such as the109% of the inseam method, introduced by Hamley and Thomas in 1967, or the Nordeen-Synder method that was branded as an effective method to adjust saddle height for females in 1977. There are newer methods for saddle height adjustment; two of them consist of the Pruitt position or the Eddie B method, both of which were brought to the bicycle scene in the mid-1980s (Matheny, 1992). Although these saddle height techniques may accomplish saddle height adjustment for road-geometry bicycles, triathlon bicycles are built and situated differently. Not only is the geometry different between the road and triathlon bicycles, but also the body position when racing is varied.

Problem

There are several techniques that are used to fit road cyclists to their bicycles. Among these are the LeMond method, the United States Cycling Federation method, the Nordeen-Synder method, and the 109% of inseam length method. These fitting methods are used to assist cyclists in obtaining efficient position on the bicycle for the greatest power output with minimal energy expenditure while maintaining a comfortable position (Matheny, 1992). Few researchers have focused on bicycle positioning specifically for triathletes (Bentley, Wilson, Davie, & Zhou, 1998; Heil, Wilcox, & Quinn, 1994; Welbergen & Clijsen, 1990). Similarly, most researchers have used a modified stationary cycle ergometer for their data collection and apply their results to road or triathlon bicycles. Finally, only three studies included women (Heil et al., 1994; Billaut, Giacomoni & Falgariette, 2003; Seebauer, Sidler & Kohl, 2003). Therefore, the question remains: Will any of these four road-cyclist fitting methods identify an efficient saddle height for triathletes, who are riding in an aerodynamic position on triathlon-specific bicycles? Additionally, will one specific fitting method of saddle height adjustment demonstrate greater efficiency in power output for males and females alike?

Purpose

The purpose of this study was to determine whether adjustments of saddle height by any of the following four road-cyclist fitting methods, that is, (a) LeMond, (b) the U.S. Cycling Federation, (c) Nordeen-Synder, and (d) 109% of inseam length method, would yield a more efficient position for triathletes using their own bicycles equipped with aerodynamic (aero) handlebars and clipless pedals while monitoring oxygen consumption and heart rate. Moreover, these results were also compared to each participant's current or base saddle height. The researcher attempted to identify the saddle height that would provide the maximum efficiency on a triathlon-specific bicycle.

Hypothesis

The null hypothesis of this study is that there will be no significant difference of performance (oxygen consumption or heart rate) when comparing current saddle height to any of the four road-cycling fitting methods through adjustment made on the saddle height on the triathlon-specific bicycles.

Delimitations and Limitations

Participation was limited to triathletes with their own triathlon-geometry bicycles versus road-geometry bicycles. All participants had been competing in triathlons for the past two years including the current season. Location of the greater trochanter for each participant was obtained in the correct location. If blood samples had been collected during the RCPX pulmonary gas exchange evaluation, anaerobic threshold determinations might have been more reliable.

Assumptions

Any changes in oxygen consumption while participating in the research are due to the changes in saddle height and not previous activities. Calibrations performed at the beginning of each participant's session did not need to be recreated prior to each cycling test. It is believed that accurate and true power output values are obtained through use of a CompuTrainer^{TM}. It was assumed that each participant would complete the various cycling tests at their full potential.

Definition of Terms

Aerobars- Made famous by cyclist Greg LeMond, these handlebars face forward (sometimes shifters are placed here) with pads where the elbows are placed. These bars allow triathletes to maintain a very comfortable aerodynamic position ("Triathlon Glossary," n.d.).

Efficiency- Incorporates the concepts of energy expenditure and work production. Specifically, cycling efficiency is the ratio of the mechanical work performed by the cyclist (propulsive force the distance the body is moved) to the energy expended by the cyclist to do this work as determined by oxygen consumption (VO_2) (Kreighbaum & Barthels, 1996).

Inseam- The measurement taken from the symphysis pubis down to the floor.

Maximal oxygen consumption (*VO_2max*)- A measure of cardiopulmonary fitness. During maximal physical exertion, it is the highest rate of oxygen that can be transported and used.

Oxygen consumption (*VO_2*)- Volume of oxygen (O_2) utilized during exercise.

Peak oxygen consumption (VO_2peak)- The largest amount of O_2 the person is consuming during a specific exercise period.

Power- The amount of work done per unit of time, the product of force and velocity, and/or the ability to exert force quickly (Kreighbaum & Barthels, 1996).

Power output- That power generated by the cyclist realized or measured by the rear wheel of the bicycle.

Respiratory exchange ratio (RER)- The ratio of carbon dioxide produced to oxygen consumed. Determined by the collection of metabolic gases measured indirectly by spirometry. This is the result of dividing the amount of carbon dioxide in the expired air by the oxygen inhaled.

Trochanteric leg length (TLL)- A measurement completed by locating a protuberance of bone on the superior and lateral area of the femur that projects upward, which is called the greater trochanter (Behnke, 2001; Jenkins, 1991). To obtain TLL, a measurement is taken from the greater trochanter to the floor.

Significance of the Study

This study evaluated oxygen consumption of four different road-saddle-height adjustment methods on triathlon-specific geometry bicycles. Triathlon geometry bicycles are designed differently than road geometry bicycles. This allows the triathlete to have less drag and become more aerodynamic. However, this also causes the triathlete's position on the bicycle to be modified, which may compromise efficiency. There are many studies evaluating saddle height of road cyclists. These studies are normally completed on either a modified ergometer or a road bicycle itself. There are very few studies that look at the triathlete's positioning, let alone saddle height on a triathlon geometry-specific bicycle. Because of this, there needs to be further research on saddle height adjustment methods that accommodate this modified positioning.

CHAPTER 2: REVIEW OF LITERATURE

Cycling Seating Positions For Road Bicycles

LeMond and Gordis (1987) stated that one of the single most important factors in determining how the cyclist's will perform is by having the saddle height position carefully established. If a cyclist's saddle height is exceptionally low, the cyclist's legs are unable to use their full muscular force because the legs do not fully extend. This causes the legs to work harder and fatigue more quickly in an attempt to achieve the same speed that they would if the cyclist had the optimal saddle height. On the other hand, if a cyclist's saddle height is exceptionally high, full power in the downstroke of the pedaling motion will not be achieved because the legs are overstretched. In either of these positions, not only is there a risk of injury, but also the full potential of the cyclist's riding or racing abilities is not being achieved. In addition to saddle height adjustment, LeMond and Gordis stated that there are other supplementary measurements that must be taken in order to get the perfect bicycle fit. Those include fore-aft position of the saddle (to allow for the pedaling position to be correct), cycling shoes being placed in the correct position, and the handlebars being set correctly through modification made in the length, angle, and stem height of the handlebars. Finally, it is important that the brake levers be placed in a comfortable position. Keep in mind that this saddle height adjustment is occurring on a road-geometry bicycles.

The LeMond method for measuring overall height was developed by the French coach Cyrille Guimard. This formula assumes that standard-length cranks of 170 millimeter are being used and that the athlete's cycling shoes are assumed to have an average sole thickness of 12.0 mm.

To begin the saddle height adjustment using the LeMond method, an exact inseam measurement of the cyclist is taken. This is completed with the athlete wearing his/her own cycling shorts and a thin pair of socks. Once the inseam measurement is obtained, it is then multiplied by 0.883. This number was established through various tests in addition to the work that was completed on professional cyclists by coach Cyrille Guimard (LeMond & Gordis, 1987). With this number, the saddle is then adjusted to the distance from the bottom bracket axle to the portion of the saddle that is cupped. This adjustment is made through the use of a line that is parallel with the seat tube. Two-to-three additional millimeters will need to be added to the measurement when using a tape measure because the crankset sticks out farther than the saddle.

The United States Cycling Federation (USCF) (Howat, 1993) focused on creating a proper biomechanical relationship between the cyclist and the bicycle. In order to do this, adjustments must be made between the bicycle and where the body interfaces with the bicycle. The three key areas for proper biomechanical position are as follows and are to be adjusted in this order: where the foot hits the pedals, were the crotch is on the saddle, and last, where the hands are on the bars. All of these adjustments are made with the individual sitting on his/her own bicycle in a resistance trainer. This way, the bicycle and athlete are on a stable surface, allowing various measurements to be achieved in a safe manner without additional physical assist. It is recommended that this optimal position is best used for road cyclists in time-trial competitions of less than 60 miles. The main focus of this research is on saddle height adjustment.

The individual's cycling shoes are removed and measured for thickness at the heel and cleat. If there is a difference in the thickness of the sole in these two areas, this is recorded. Next, with the use of a level, the saddle is set perfectly horizontal. With the athlete's hands on the brake hoods, the cyclist completes a basic 10-minute warm-up. From here, the right foot is removed from the shoe, and the right crank is placed downward into a vertical position. The heel is dropped downward toward, but not touching, the pedal and is positioned just above the pedal surface with the leg straight and hips immobile. With the foot in a flat position, a measurement is taken from the bottom of the sole at the heel to the top of the pedal. A clearance of at least 5 mm should be found. If there is a difference in the sole thickness of the cycling shoe, it is added. If the cyclist's pedaling style is one in which he/she pedals with his/her toes pointing down then, another 4 mm is added to this measurement. If the cyclists completes more than 300 miles a week, then the saddle should be lowered between 5 and 8 mm. This will reduce the stress on the knees during rides of longer distances. Even though this may not be as efficient a position, it will reduce the stress placed on the knees. This same procedure is completed with the other leg.

Fiinally, the tilt of the seat needs to be adjusted, which will affect the seat height. The cyclist places this/her right crank arm into the horizontal position. A plumb line is dropped down toward the pedal from the tibial tuberosity. This plum line should be in a neutral position, which is found to be 1 cm behind the pedal axle.

The simplest and easiest method to use for saddle height adjustment happens to be that proposed by Nordeen-Synder (1977). Nordeen-Synder (1977) used female participants only to determine that a saddle height of 100% of trochanteric leg length (TLL), the measurement taken from the outside of the greater trochanter to the floor, which also calculates out to be 107.1% of the symphysis pubis height, was the most efficient in terms of oxygen consumption when evaluated against 95% and 109% of trochanteric leg length. This saddle height was determined by analyzing oxygen consumption and kinematic patterns of the hip, knee and ankle through the use of filming of these joints for seven seconds. Once TLL is taken, the saddle height is adjusted along the seat tube from the center of the pedal spindle until the saddle height is 100% of TLL or 107.1% of symphysis pubis height.

The last method was evaluated for this study is that proposed by Hamley and Thomas (1967), who examined three main points: saddle to pedal distance, upper body positioning while riding, and movement of the ankle. Among 100 cyclists, 109% of the symphysis pubis height was the most efficient saddle height during a power output test. There was a greater change in heart rate than in oxygen uptake when the upper body was in various positions. A lower heart rate and oxygen uptake was noted during high work-loads when the participants were in the racing position with a *grip and pull* action of the hands. A straight line was measured from the pedal-axle surface to the saddle surface to equal that of the 109% of symphysis pubis height to obtain the correct saddle height according to this method. Therefore, the name of this fitting is called the 109% of inseam method.

Bike Specifics

Most studies accomplished their research using a modified Monark cycle ergometer (Heil et al., 1994; MacIntosh, Neptune, & Horton, 1999; Marsh & Martin 1996; Welbergen & Clijsen, 1990 not bicycles. In the cases where bicycles were used, they were road-geometry bicycles. Results of these various studies are then generalized to individuals who race on road-geometry bicycles or triathlon-specific bicycles, which are designed slightly differently.

Road and triathlon bicycle frames are similar in look; however, there are several differences between the two bicycles, and one of the most visible is the handlebar.

Figure 1. Aerodynamic position and aerodynamic handlebars.

Triathletes use aerodynamic handlebars (aero bars) (see Figure 1). These aero bars allow the triathlete to decrease upper body cross-section area and improve aerodynamics. Road cyclists will race with aero bars during time trials; however, aero bars cannot just be placed on a road bicycle, due to the positional changes that occur in the body as a whole. Placing aero bars on a road bicycle changes the geometric relationship between the cyclist and bicycle. To compensate for the use of these bars, bicycle manufactures modify the seat tube angle to about 78 degrees on triathlon bicycles, whereas on a road bicycle the average seat tube angle is 73 degrees (see Figure 2). Of course, there are other bicycle frames that have greater or lesser degrees of seat tube angles. This five-degree adjustment allows the diaphragm to have a greater opening through the additional space between the thigh and torso while in an aerodynamic position. This triathlon-specific geometry forces the bottom bracket to be set further back on the bicycle, opening up the torso-femur angle and allowing the triathlete's feet to be placed farther back on the pedals. A triathlon bicycle also has the specific feature of having a shorter top and head tube, allowing for more efficiency in the aero position because of the diminished frontal surface area.

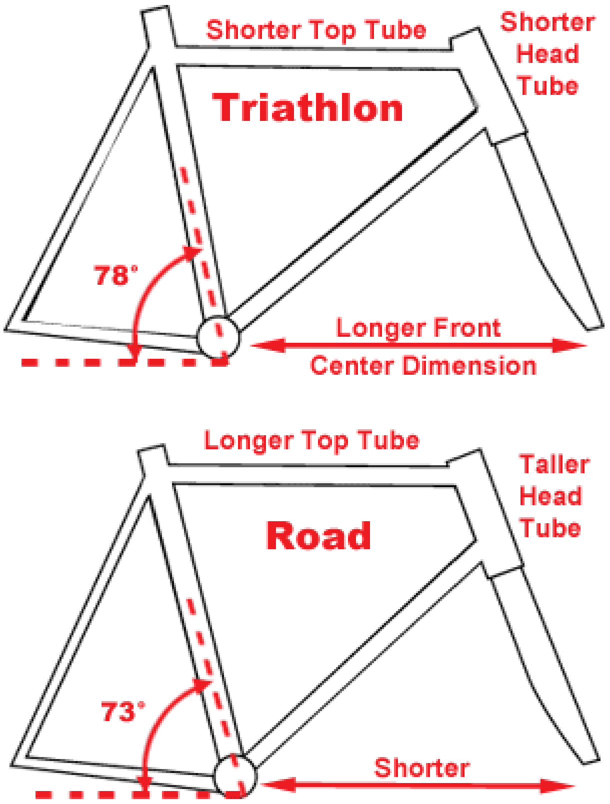

Figure 2. Triathlon versus road bicycle geometry.

Many triathlon bicycles use 650-cm or 26-inch wheels in place of the 700-cm wheels used on road bicycles. Smaller wheels on certain triathlon bicycles serve a twofold purpose. First, because of the angle of the seat tube, 78 degrees, there is a decrease in the area for a 700-cm rear wheel to fit, therefore introducing a 650-cm wheel. Second, because the wheel is smaller, there is a decrease in the quantity of spokes, which ultimately decreases the amount of drag introduced from the wheel while racing. (Demerly, n.d.).

Because of the differences between a road and a triathlon geometry bicycle, it is obvious that there needs to be specific research on triathletes' power output using their own triathlon-specific bicycles. However, specific biomechanics of the lower extremity need to be addressed first.

Skeleton

It is important to comprehend how the body works to produce basic movement and, more specifically, force. There are two divisions of the adult human skeleton, the axial and appendicular. The extremities that extend from the axis of the body are considered to be the appendicular skeleton. This consists of the pectoral (shoulder) girdles, upper extremities, pelvic (hip) girdle, and lower extremities. The axis of the skeleton system allows for the appendicular skeleton to "hang onto" the axis and thus allow movement to occur with the use of muscles (Tortora & Grabowski, 2000).

Of the 206 bones that make up the human skeleton, 62 of them make up the lower extremity, including the pelvis and hip. The three main joints of the lower extremity are the hip, knee, and ankle. The hip coxal joint is considered a ball-and-socket joint and is multiaxial (polyaxial). Due to the nature of bicycling, this study is focused on the movement of the hip in the sagittal plane, flexion and extension, which has a range of motion (ROM) from 0° to 120° (Trombly, 1989). From here the distal end of the femur attaches to the tibia and patella to form the knee joint.

The knee joint is the largest joint in the body and is composed of two articulations between the opposed lateral and medial condyles of the tibia and femur. The ROM of knee flexion and extension in the sagittal plane is from 0° to 135°, and movement is limited by the various muscles, tendons, and the synovial capsule itself (Trombly, 1989; Luciano, Vander, & Sherman, 1978; Tortora & Grabowski, 2000).

The ankle joint is considered a hinge, or ginglymus, joint and is connected to the distal portion of the fibula. The range of motion of this joint varies from person to person, but in the sagittal plane it is generally between 0º to 20º for dorsiflexion and 0º to 50º for plantar flexion (Trombly, 1989). The proximal ends of the metatarsals articulate at the tarsal bones of the foot. It is the metatarsals that attach the complete lower extremity to the crank pedal of the bicycle, where all force is applied to cause motion that began at the hips.

Muscles

The skeletal joints are the basis for the muscles to attach and produce movement and force, which produces power. In order to pedal a bicycle, the lower extremities must coordinate the various muscles to produce force. Yet, it takes more than just one muscle to cause the required segmental energetic exchanges (Zajac, 2002). Muscles work together in a synergistic manner. This means that various muscles cause segmental exchanges through deceleration of some muscles and acceleration of others. The segmental energetic exchanges of one muscle is not sufficient to cause the segmental energetic exchange; therefore, co-functional muscle activity may be required. In order for the crank of the bicycle to move, energy must be delivered to it. These crank forces are developed through tangential muscles that are not necessarily energy-producing themselves. By the co-functioning of these various muscles, various segments produce force. Ultimately, this force leads to work output.

There are other times when muscles are co-excited and work synergistically but not co-functionally. This is caused when another muscle produces energy that is required for the execution of the task; however, the target segment is unable to receive it because the force does not accelerate the segment. In order for this energy to reach the target segment, there must be acceleration or deceleration of mechanical energy (Zajac, 2002).

Anthropometrics

Identification of specific landmarks on the body will allow for specific measurements, such as the inseam and TLL, to be taken, and positioning of the saddle height can begin using any of the fitting methods. A human height of 177.8-cm is considered to be average. This includes an estimated shank and thigh length of 43.6-cm segment. A man who is 162.6-cm has a shank and thigh segment length of 39.9-cm. This is a great contrast to a man who is 193.0-cm with a shank and thigh segment length of 47.4-cm (Gonzalez & Hull, 1989). Although the height and segment lengths varied among the different men, the same percentage to total height is calculated to 53.3%, with an average foot height assumed. This can be used as a height reference for an average, a tall, and an undersized man. Kreighbaum and Barthels (1996) identified the mean segment lengths of the thigh, leg, and foot combined as being equal to 52.15% for the males and 54.85% of total body height for females However, these are segment lengths and not specifically TLL or inseam.

To obtain these various measurements, certain landmarks on the body need to be located. According to Tortora and Grabowski (2000), anterior to the hollow side of the hip is where the prominence of the greater trochanter is felt and seen. Once the greater trochanter is felt and located, the trochanteric leg length measurement is taken from the lateral budge to the floor while the participant is standing (see Figure 3). To confirm this location of the greater trochanter, Behnke (2001) stated can be felt on the leg being tested if it is internally rotated toward the other leg.

The LeMond and 109% of inseam require inseam measurement for adjustment the saddle heights. The inseam measurement is taken from the floor to the symphysis pubis while the participant is standing in thin socks (LeMond & Gordis, 1987) (see Figure 3). This is how LeMond suggested obtaining the inseam measurement. On an uncarpeted floor, the athlete faces a wall and a hardcover book that is five inches long and an inch and a half thick is placed between the athlete's legs to simulate the riding saddle. With the front and back covers of the book perpendicular to the ground, enough pressure is applied to simulate riding. On the wall, a mark is made at the top edge of the book. From here this measurement is taken from the floor to the mark to give the cyclist his/her inseam measurement. The 109% inseam method does not give specifics on how to obtain the inseam measurement.

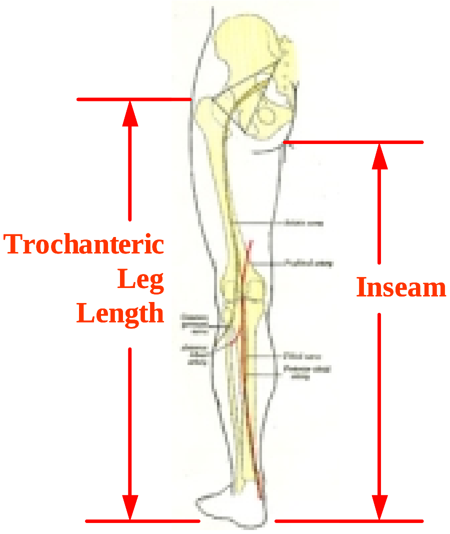

Figure 3. Anthropometric leg measurements.

Cadence

Four variables that affect the lower extremity during constant power output include seat height, crank arm length, longitudinal foot position on the pedal, and seat tube angle (Gonzalez & Hull, 1989). Knowing that the lower extremity is a chain of joint angles that connects the pelvis to the foot position on the crank, one can see that any variation in geometry of the lower extremity would influence the kinematic linkage, which would ultimately affect the intersegmental loads. These are all termed *biomechanical variables* because of their influence on kinematic and intersegmental loads. However, there is an additional biomechanical variable, and that is the rate at which the cyclist pedals: *cadence*.

Cadence is dependent on the length of the crank arm (Gonzalez & Hull, 1989). Pedal rate and crank arm length are inversely related. Gonzalez and Hull (1989) found that all five variables (seat height, crank arm length, longitudinal foot position on the pedal, and seat-tube angle) are interrelated and that number of variables cannot be reduced. As the height of the cyclist’s seat increases, so will crank arm length and the position of the foot on the pedal. At the same time, pedaling rate and seat tube angle will decrease.

Because saddle height is based on either the athlete’s inseam or TLL, accuracy in obtaining these measurements is crucial. Pedaling rate varies during cycling according to terrain, fatigue, and the experience of the cyclists. Patterson and Moreno (1990) found that for recreational male cyclists, maintaining 100 watts (W), the preferred pedaling rate was 94.5-revolutions per minute (rpm), as compared to 98.3 rpm at 200 W.

Marsh and Martin (1996) found comparable results when evaluating experienced cyclists, less-trained non-cyclists, and runners. At the 100-W level, cyclists' pedaling rate was 96.6 rpm, whereas runners cycled at 92.0 rpm. The less-trained non-cyclists had a preferred pedaling rate of 77.4 rpm. At 200 W, the cyclists had rpms of 93.1, and the runners cycled at 91.8 rpm. This is slightly lower than what Patterson and Moreno (1990) found at the 200-W levels.

In spite of this, the preferred pedaling rates in trained individuals is still higher than the most economical cadences. At 200 W, 59.9 and 62.9 rpm were the most economical cadences for the cyclists and runners, respectively (Marsh & Martin, 1996). These researchers also identified that as the wattage increased from 75 to 175 W, the preferred cadence decreased linearly from 80 to 65 rpm in the less-trained non-cyclists. Ultimately, Patterson and Moreno (1990) discovered that not only did optimum pedaling rate depend on the ability to apply force to the crank arm of the pedals but also on the general coordination of the cyclist. However, they did not specifically measure oxygen uptake.

Power Output

When Welbergen and Clijsen (1990) evaluated body positioning on power output and VO_2max, it was found in the standard sitting position, trunk near vertical position, 100% of TLL produced the maximal power output. This was significantly different when compared to the standard racing position: trunk is near horizontal and recumbent forward (trunk prone) and backwards positions (supine trunk). More specifically, there was a 4.5% higher maximal power output in the standard sitting position than in the standard racing position. When VO_2max was addressed, standard sitting position had the highest mean value, 100%, whereas the other positions were between 97% and 95%. But this difference was not significant. This suggests that power output may be significantly affected by trunk angle, but VO_2max is not.

A significant relationship between peak power output and VO_2peak (L/min) was identified in recreational triathletes (Bentley et al., 1998). A correlation was identified between VO_2peak (ml/kg/min), peak power output, and the overall time spent cycling during the cycling portion of an Olympic triathlon. However, this correlation was not a significant one. This may be because the peak power output test was completed on a cycle ergometer and the cycling test was during an actual race on the participants' own bicycles.

Cycle Ergometer Modifications

Heil et al. (1994) studied men and women, cyclists and triathletes. Each participant in the study used his/her own cleats and pedals on the modified cycle ergometer that was equipped with a narrow racing seat, drop handlebars, and 172.5-mm aluminum alloy cranks. The seat-tube angle, saddle, and stem height were adjusted to each participant's comfort level for the VO_2peak testing. During the submaximal testing, the cycle ergometer was modified further with a seat post that allowed for various seat-tube angle positions, from 69º to 90º, with the addition of clip-on aero handlebars. The various adjustments to the seat-tube angles and adjustment of the seat height and handlebar stem were also performed on the participants' personal bicycles. However, angles of the seat and aero bars were adjusted to each participant's comfort level.

Welbergen and Clijsen (1990) used a cycle ergometer that was modified with racing-type saddle, handlebars, and toeclips. The influence of body position on maximal performance in cycling of male cyclists, triathletes, and recumbent cyclists was evaluated, and specific measurements were taken. All participants used cleated shoes with the seat-tube angle set at a standard 21º, and the seat height was set at 100% of their trochanteric height for the cyclists and triathletes. The standard racing position consisted of the trunk near horizontal, with the participants' arms flexed and their hands on the lower part of the handlebars, whereas during the standard sitting position, the trunk was near vertical, with the arms almost in full extension when the handlebars were turned upwards.

Nordeen-Snyder (1977) found that when the saddle height was adjusted to that of 100% of the trochanteric leg length, VO_2 had the lowest value when compared to 95% and 105% of trochanteric leg length. This seating method is called the Nordeen-Snyder method, and it is the saddle height adjustment that Patterson and Moreno (1990) used. The distance from the greater trochanter to the floor determines this saddle height. From here a measurement is taken along the axis of the seat tube, from the top of the saddle to the lower position of the pedal, and this is then adjusted to equal the leg length.

Cooke, Whitacre, and Barnes (1997) used a modified and unmodified cycle ergometer only with male participants. During the set-up, the researchers adjusted the saddle height by allowing for 15º of bend at the knee joint and for approximately 45º of bend at the ankle. There was no discussion of seat-tube angle or use of aerobars.

Billaut et al. (2003) adjusted the saddle height for each participant and used toe clips; however, they did not state what protocol was used for the adjustments. Neptune and Herzog (2000) set up a conventional road-racing bicycle to match each participant's own bicycle's geometry. After the adjustments were made, the bicycle was then placed on an electronically braked CompuTrainer^{TM} ergometer to complete the study. Yet, there was no mention of whether or not these participants used their own seats, toeclips, clipless pedals, and shoes. There was no mention of the specific individual set-up or modification of the mechanically braked cycle ergometer in the studies completed by Bentley et al. (1998), MacIntosh et al. (1999), Marsh and Martin (1998), or Seebauer et al. (2003).

Physiological Responses

Triathletes are in an aero position while riding for most, if not all of the race, so physiological responses in this position are important. Hamley and Thomas (1967) compared heart rate and workload response while the upper body was in two different positions. They found that heart rate was affected more than oxygen consumption by the two different positions on the handlebars. It was revealed that while the participants were in an upright stance, with no support from the upper body, the heart rate began at a lower rate but increased more as the work-rate increased. While in the grip-and-pull stance on the handlebars with full extension of the upper body, the heart rate began at a higher rate than in the upright position. Nonetheless, as the workload increased, the heart rate did not elevate to as high in the upright position.

When Nordeen-Synder (1977) correlated TLL to mean VO_2 (L/min), 100% TLL demonstrated the lowest value at 1.61 L/min. The mean VO_2 was 1.69 L/min at 95% TLL and 1.74 L/min at 105% TLL. This suggests that 100% TLL is more efficient than the other two saddle heights.

Burke and Jin (1996) identified that Ironman triathlon finishing time could be predicted by two physiological factors: VO_2max and skinfold tests. The less weight an athlete carries, the more efficient the oxygen uptake. Of the 36 finishers evaluated, the first 12 finishers had a VO_2max of 68.7 ± 7.2 ml/kg/min and a weight of 72.1 ± 4.4 kg, and the next 12 finishers had a VO_2max of 67.4 ± 10.4 ml/kg/min and a weight of 74.0 ± 9.3 kg. The final 12 finishers had a VO_2max of 52.1 ± 10.4 and a weight of 74.8 ± 7.8 kg. This indicates that the athletes with less mass had higher VO_2maxes and had better finishes.

Heil et al. (1994) found that cardiorespiratory (CR) variables increased when riding at seat-tube angles of 69º and decreased when riding at seat-tube angles of 83º. When heart rate (HR) was evaluated at the various seat-tube angles, it was found that HR was significantly lower at a seat-tube angle of 76º (150.3 ± 12.2 bpm) when compared to an angle of 69º (152.9 ± 11.1 bpm). This HR declined even further, although not significantly, from 69° to 149.6 ± 13.0 at the 83° angle and 149.9 ± 12.8 at the 90° angle. They found that VO_2 was significantly lower at 83º (3.09 ± 0.65 l/min) and 90° (3.10 ± 0.65 l/min) compared to 69º (3.17 ± 0.65 l/min).

Gender Differences

It is important to identify any differences in recovery on workload between the genders because this study completed five sub-max power outputs in the same visit. It was established during two consecutive short power-output bouts, eight seconds each, that all the subjects were able to reach the peak power output and that the women recovered the same as men when given 30 seconds of rest. Additionally, after the women attained the peak power output, it was noted that there was a greater decline in power output after the peak power was met (Billaut et al., 2003). Men still produced a higher peak power output, 37.2% more than women, when lower limb lean volume and lean body mass were corrected.

When Cooke et al. (1997) looked at fatigue levels relative to peak power output during high-intensity cycle sprinting using only men, they found that within 3.5 seconds, peak power was reached at 880 W, then declined by 30.6% within 6.7 seconds. Additionally, there was no significant difference in the peak power output, time to peak power output, time to fatigue for fatigue index, or fatigue rate when there were only 20 minutes of rest between bouts one and two or between bouts two and three, completed 48 hours later.

Only female subjects were used in Nordeen-Synders's 1977 research, where each subject rode for 8-9 minutes at 60 rpm and at three various saddle heights: 95%, 100%, and 105% TLL. Between each of these tests there was a 10-minute rest break.

There are few studies that evaluate a triathlete's response to various positions on the bicycle. All of the studies cited have used cycle ergometers. Some of these studies state the modifications made during the respective studies, but other studies do not. Saddle height has been researched; however, none of the studies evaluated saddle height specifically with the participant in the aerodynamic position on a triathlon geometry bicycle. Heil et al. (1994) evaluated seat-tube angle while the participants were in an aerodynamic position but not saddle height.

Because the sport of triathlon is relatively new and growing in participation, current research needs to occur in this new genre of cycling. Although most of the participants in triathlons are younger males, many females are joining the sport. Because females differ physically from males, identifying whether their physical response to various adjustments are the same or different than those of males is vital to the ability of females to compete at the same levels as males. If differences are identified, further studies need to be completed to identify the causes. These recreational, age-grouper triathletes are not always young or in the fitness category of Olympians. At the same time, they want to perform to the best of their abilities. Sometimes a small, easy adjustment, such as saddle height, may be the determining factor for their staying with the sport and, more important enjoying it. Therefore, identifying the response to saddle height adjustments while in an aerodynamic position will provide data they will be able to use to increase their performance.

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

Because triathlons last between 2 and 17 hours in length, energy needs to be conserved and distributed throughout the event. One way to assist in facilitating this is having an efficient saddle height while in the aerodynamic position. There have not been any studies evaluating how saddle height affects the efficiency of triathletes and their specific bicycles in the aerodynamic position. The purpose of this study is to identify and evaluate how saddle height affects efficiency of triathletes using triathlon-specific bicycles while in an aerodynamic position.

Table 1. Participant Characteristics, Mean (SD)

Parameter	All	Males	Females
Age	37.9 (8.4)	39.6 (8.6)	35.3 (8.1)
Height, (cm)	172.5 (6.6)	176.4 (4.5)	166.5 (4.3)
Weight, (kg)	72.5 (12.5)	78.4 (9.7)	63.6 (11.5)
Years Competing	7.1 (7.8)	7.7 (8.4)	6.3 (7.7)
Bike Training, (hrs/wk)	5.5 (4.2)	6.4 (4.4)	4.6 (4.4)
VO_2peak, ml/kg/min	54.6 (7.3)	56.2 (8)	52.3 (6.1)
VO_2peak, l/min	3.9 (0.9)	4.4 (0.8)	3.3 (0.5)
Vepeak, l/min	132.2 (27.4)	135.1 (25.9)	128.3 (31.4)
VT, L	3.1 (0.6)	3.3 (0.7)	2.8 (0.3)
RQpeak	1.1 (0)	1.1 (0.1)	1.1 (0)

Participants

Nine male and six female recreational triathletes from the Ann Arbor Triathlon Club volunteered as participants. The participants had been competing in the sport of triathlon for an average of 7.1 ± 7.8 years, including the current season; they had an average age of 37.9 ± 8.4, years, an average weight of 72.5 ±12.2 kg, and an average height of 172.5 ± 6.6 cm. A month prior to the study, the participants' average hours of riding per week was 5.5 ± 4.2 (see Table 1). Procedures were reviewed and approved by the Eastern Michigan University Human Subjects Review Committee. Informed consent was obtained from all the participants prior to their entry into the study. All participants met the inclusion and exclusion requirements of having been injury free for the past three months, having been racing for the past two years including the current season, and having and using aerodynamic bars and clipless pedals on their triathlon-specific bicycles while racing.

Procedures

Pre-visit requirements. Through a website, all participants signed up for two sessions that were at least 48 hours apart. Additionally, all participants completed a medical history form (see Appendix A). All participants were asked not to partake in any long-duration or high-intensity physical activity for at least 24 hours prior to both of their sessions.

First session. During the first session (FS), Informed Consent (See Appendix B) was obtained, and participants were instructed on the exercise testing protocols and procedures and were provided answers to any questions. Each participant's medical history form was reviewed, and a basic interview was completed with the use of a Saddle Height Power Interview Form (see Appendix C). Specific measurements were obtained with the participant wearing his/her cycling shorts, shirt, and socks. The characteristics gathered from each participant were as follows: the participant's age, height in centimeters (cm), weight in kilograms, inseam length (cm), and trochanteric leg length (cm). Inseam length was obtained by having each participant place a 4-foot level between his/her legs and holding onto the front and back of the level in addition to pulling the level up snug to simulate the saddle. A steel tape measure was used to obtain the inseam measurement from the floor to the top of the level once the level was level. To obtain the

TLL, the researcher located the bony prominence on the outside of the participant’s right greater trochanter. Once the researcher had located it, the participant was instructed to place his/her weight through his/her left leg and turn his/her right foot in and out. He/she was also asked to slowly abduct his/her right leg to confirm the correct location of the greater trochanter. From the confirmed location, a measurement was made from the floor to the top of the researcher’s left thumb.

Determination of saddle heights. Once the inseam and trochanteric leg-length data were collected, the various saddle heights were calculated for each of the participants. Taking the inseam and multiplying that number by 0.883 completed the LeMond method saddle height calculation. This specific measurement should be taken from the bottom bracket axel to the center of the cupped portion of the saddle. The 109% inseam method used the inseam measurement and multiplied it by 1.09. This method required measurement from the center of the pedal spindle to the cupped portion of the saddled. The USCF method used the trochanteric leg length and multiplied it by 0.96. For this saddle height, this measurement is taken from the bottom bracket to the cupped portion of the saddle. Nordeen-Synder also used the trochanteric leg-length measurement for the saddle height fitting. This number was then multiplied by 1.00. This saddle height is measured from the center of the pedal spindle to the cupped portion of the saddle. All saddle height measurements were then standardized on the distance from the center of the bottom bracket to the cupped portion of the saddle by subtracting the crank arm length from the methods that were referenced against the center of the pedal spindle. Therefore, all measurements were taken from the center of the bottom bracket to the cupped portion of the saddle. An additional 0.3-cm was subtracted from all saddle height measurements to account for cycling shoe and clipless pedal systems (LeMond & Gordis, 1987).

Bicycle specifics that were gathered consisted of the name of the bike manufacturer, bike size (cm), wheel size millimeters (mm), crank arm length (mm) (measured and read from the crank arm's backside), and pedal type, as well as the type of cycling shoes. Current saddle height (cm) measurement was taken using a 4-foot level and a tape measure. With the assistance of another person, the level was placed in the cup of the saddle and leveled. Next, a steel tape measure was placed in the center of the crank arm bolt and held securely while the research assistant holding the level also held the tape measure so that the primary investigator could read the measurement. The saddle was marked, and the measurement was recorded. Last, the number of years the participant had been competing in triathlons, the number of hours a week spent cycling his/her triathlon bicycle in the past month, and whether he/she had been professionally fitted for the current bicycle and by whom were recorded.

The rear wheel of the participant's bicycle was mounted onto the CompuTrainer^{TM} with the use a quick-release skewer that was installed onto the rear wheel, if needed, to fit the bicycle properly into the CompuTrainer^{TM}. The front wheel was placed onto a tire support so that the bicycle was level. The CompuTrainer^{TM} was securely attached to a platform that was 921 cm long, 182 cm wide, and 5.6 cm thick. The Polar heart-rate monitor was put on by the participant, and a self-paced 10-minute warm-up was completed in any riding position. During the warm-up, a gearing ratio was self-selected by the participant and recorded by the researcher. Following the manufacturer's recommendations, the CompuTrainer^{TM} was calibrated after the warm-up.

Rolling resistance calibration was completed for each participant. The calibrations were approximately 2.00 lb and were all within ±0.10 lb.

Prior to beginning the VO_2peak testing, each participant was fitted with a Polar heart-rate monitor, Model S510 (Polar Electro Oy), to collect heart-rate data. After a 10-minute, self-paced warm-up on the CompuTrainer^{TM}, the participant was ready to begin the testing. It was determined that all subjects were comfortable with a cadence between 85 and 90 rpm. Therefore, all participants completed all testing at 85 rpm. Expired gases (O_2 and CO_2) and ventilation (VE) were collected and measured through the use of a mouthpiece that was held in place by a headpiece that each participant wore during all of the testing.

Vmax series 29 and Vmax Program Manager software (version 5.0) (Sensor Medics Corporation, Yorba Linda, CA) was used to determine peak oxygen consumption (VO_2Peak), anaerobic threshold (AT), and respiratory exchange ratio (RER) and to measure ventilation (VE) and expired gases (O_2 and CO_2). Using a 3-L syringe and known concentrations of gas (O_2 and CO_2), calibration of the Sensor Medics system was completed according to the manufacturer's recommendations before each participant's test session.

Figure 4. Session one RCPX testing.

After the calibrations and warm-up were completed, a continuously ramped cardiopulmonary exercise test (RCPX) began (see Figure 4). The bicycle gearing for the testing was selected by each participant and recorded by the researcher so that he/she could maintain a cadence of approximately 85-rpms without shifting gears. A headpiece was placed on the participants head, and the mouthpiece was placed into the participant's mouth and adjusted so that it was in a horizontal position while the participant was in aerodynamic position for the test. A nose clip was then applied. Once the participant felt comfortable with the headpiece/mouthpiece attachment and verified that the gas analyzer was collecting the expired gas, the test began.

All participants began and ended the test in aerodynamic position. The male participants began the RCPX testing at 150 watts (W) and had a continuous increase of

20W every minute with the exception of one male, who used the female participants' protocol because of his fitness level. The female participants began the RCPX testing at 100 W and increased by 10 W every minute until the participant reached volitional exhaustion. Volitional exhaustion was determined by one of the following: (a) the participant dropped ten rpm from his/her self-selected cadence; (b) the respiratory exchange ratio (RER) was equal to or greater than 1.1; (c) the heart rate was within 10 beats per minute (bpm) below or above the participant's age-predicted maximum heart rate (220-age); or (d) oxygen consumption plateaued with increased power output as evidenced by a change of 2.1 ml/kg or less. All participants were given verbal encouragement and informed when the workload would be increased throughout the RCPX.

Heart rate was recorded every minute during the RCPX. Expired gases were continuously monitored breath by breath, and a 20-second average of breath-by-breath data was used to determine the VO_2peak.

Power output was recorded every minute. Once the participant had reached volitional exhaustion, the CompuTrainer^{TM} power reduced to the starting amount (i.e., 150 W for males and 100 W for females) for at least 3 minutes or until the participant felt he/she had recovered from the test.

Second session. The second session (SS) occurred, on average, four days after the FS, during which each participant completed five randomized saddle height tests. All of the tests were completed on the participant's same bicycle in the same gearing ratio and maintained the same 85 rpm as during the FS. The same Polar heart-rate monitor and headpiece were used to collect breath-by-breath expired gases. These saddle heights were determined by the previously stated methods: LeMond, the U.S. Cycling Federation, Nordeen-Synder, and 109% of inseam length. All participants began the second session with their saddle heights at their current positions for the first test, and the other four saddle heights tests were completed in a random order.

Each test lasted 9 minutes and was conducted at a power interpreted as 70% of each particpant's VO_2peak attained in his/her RCPX. The CompuTrainer^{TM} and gas analyzer were calibrating after placing the Polar heart-rate monitor on and the head/mouth piece was donned. The initial 3 minutes of the test were used to get the participant into a warmed-up steady state. This was completed at 150 W for the male participants and 100 W for the female participants. Beginning the next 3 minutes, the power was increased to a point that resulted in 70% the participant's specific VO_2peak during the RCPX. During the final 3 minutes, the power was decreased to the initial level so that the participant had an active recovery while still in the aero position. While completing each test, the participant was cooled by a floor fan, and after each test, the participant had a 10-minute rest break that was completed off the bicycle, and he/she was provided with water. During the 10-minute rest break, the saddle height was adjusted for the next specified fitting method.

Statistical Analysis

For this study, VO_2 efficiency was analyzed against the five various saddle heights. At the first session, the RCPX was completed, and the expired gases, O_2 and CO_2, were continuously collected, with averages taken every 20 seconds throughout the entire test. Heart rate was taken every minute. For the randomized four saddle height tests, O_2 and CO_2 averages were taken breath by breath, and heart rate was recorded every 3 minutes during the test, including at the beginning and end of each test. Results of the tests are expressed as mean and standard deviation.

Last, to identify whether a significant correlation was detected between saddle height and VO_2, an X, Y plot graph was generated. The plot graph evaluated normalized VO_2 against normalized saddle height. Each saddle height was divided by the average of the four saddle height fitting methods for a given participant in order to obtain his/her normalized saddle height.

Statistical analyses were performed through the use of Microsoft Excel 2002 Analysis Tools (Microsoft Corp.). Minitab Statistical Software (version 11.12) (Minitab, Inc., State College, PA) was used to complete analysis of power of a test. Statistical significance was set at $p < 0.05$. Pearson correlation coefficient (r) with the significance level at $\alpha < 0.05$ identified statistical significance between the various methods.

CHAPTER 4: RESULTS

Anthropometric Measurements

The ratio of the trochanteric leg length to the inseam was averaged across all participants, 1.1 ± 0.03 The male participants had an average ratio of 1.11 ± 0.04, whereas the females had an average ratio of 1.11 ± 0.03. The differences were not statistically significant. See Table 2 for the detailed and specific data.

Table 2

Anthropometric Leg Measurements

Subject	**Sex**	**Height (cm)**	**Trochanteric Leg Length (cm)**	**Inseam (cm)**	**TLL/IS**
1	M	182.9	90.8	81.9	1.109
2	F	167.6	84.3	78.6	1.073
3	M	182.0	94.0	87.6	1.073
4	M	172.0	92.5	82.5	1.121
5	F	173.5	91.5	80.8	1.132
6	F	163.0	89.0	77.6	1.147
7	M	173.5	92.8	78.2	1.187
8	M	173.5	93.5	82.4	1.135
9	M	171.0	88.5	80.1	1.105
10	F	163.0	88.0	78.6	1.120
11	F	163.0	85.0	77.9	1.091
12	M	174.0	89.0	79.5	1.119
13	F	169.0	87.7	79.5	1.103
14	M	180.0	95.5	84.5	1.130
15	M	179.0	90.0	86.0	1.047

	Avg	**StDev**
All	1.113	0.034
F	1.111	0.027
M	1.114	0.039

Saddle Height Determination

All but one of the participants stated that they had been fitted for their current seat height by one of the area’s local bike shops. All but 3 out of the 15 participants had been fitted when they purchased their current triathlon-specific bicycle. Because of the differences in measuring techniques used for the various fitting methods, measurements were standardized, and participants were measured from the center of the bottom bracket to the cupped portion of the saddle. Because all participants utilized clipless pedals, 3-mm was subtracted for all participants (see Table 3).

Table 3

Saddle Heights Determined From Anthropometric Measurements

				LeMond	USCF		N-S		1.09 * IS	
	Height (cm)	TLL (cm)	Inseam (cm)	TOS-COBB (cm)	TOS-COPS (cm)	TOS-COBB (cm)	TOS-COPS (cm)	TOS-COBB (cm)	TOS-COPS (cm)	TOS-COBB (cm)
1	182.9	90.8	81.9	72.0	86.0	70.0	90.5	73.0	89.0	71.5
2	167.6	84.3	78.6	69.1	79.8	64.0	84.0	66.8	85.4	68.1
3	182.0	94.0	87.6	77.1	89.0	73.0	93.7	76.2	95.2	77.7
4	172.0	92.5	82.5	72.5	87.6	71.6	92.2	74.7	89.6	72.1
5	173.5	91.5	80.8	71.0	86.6	70.9	91.2	74.0	87.8	70.5
6	163.0	89.0	77.6	68.2	84.3	68.5	88.7	71.5	84.3	67.0
7	173.5	92.8	78.2	68.8	87.9	71.9	92.5	75.0	84.9	67.4
8	173.5	93.5	82.4	72.5	88.5	72.8	93.2	76.0	89.5	72.3
9	171.0	88.5	80.1	70.4	83.8	68.0	88.2	71.0	87.0	69.8
10	163.0	88.0	78.6	69.1	83.3	67.6	87.7	70.5	85.4	68.1
11	163.0	85.0	77.9	68.5	80.5	65.0	84.7	67.7	84.6	67.6
12	174.0	89.0	79.5	69.9	84.3	68.3	88.7	71.2	86.4	68.9
13	169.0	87.7	79.5	69.9	83.0	67.5	87.4	70.4	86.4	69.4
14	180.0	95.5	84.5	74.3	90.4	74.4	95.2	77.7	91.8	74.3
15	179.0	90.0	86.0	75.6	85.2	69.2	89.7	72.2	93.4	75.9

*TOS - Top Of Saddle
*COBB - Center Of Bottom Bracket, and
*COPS - Center Of Pedal Spindle

VO_2peak Determination

VO_2peak was determined in the RCPX test during the FS. The average VO_2peak of all participants was 54.6 ± 7.3 ml/kg/min. The male participants had an average VO_2peak of 56.2 ± 8.0 ml/kg/min. The female participants had an average VO_2peak of 52.3 ± 6.1 ml/kg/min.

The power during RCPX testing was measured to determine the test conditions for the seat height method evaluation. The average peak power output in watts determined at VO_2peak for all participants was 271.3 ± 70.9, M = 296.7 ± 71.6, F = 233.3 ± 54.7. The power at 70% of VO_2peak in watts for all participants averaged 190 ± 50.1. For the males, it was 207.8 ± 50.4. For the females, it was 163.3 ± 39.3. The participants' average HR at VO_2peak was 175.3 ± 12.4 bpm. The female participants had the highest average HR at 181.2 ± 10.4 bpm, whereas the male participants had the lowest average HR at 171.3 ± 12.5 bpm (see Table 4).

Table 4

VO_2peak Results and Subsequent Power

	VO_2peak (ml/kg/min)	**HR @ VO_2pk (bpm)**	**Power @ VO_2peak (watts)**	**70% of Power @ VO_2peak (watts)**
1	51.2	176	290	200
2	57.3	184	260	180
3	60.9	175	350	250
4	41.4	164	160	110
5	47.9	172	270	190
6	62.3	170	200	140
7	64.5	177	370	260
8	62.8	148	390	270
9	62.5	175	310	220
10	50.9	194	190	130
11	48.1	192	170	120
12	50.5	173	250	180
13	47.4	175	260	180
14	56.2	161	270	190
15	63.4	193	330	230
All	55.2 (7.4)	175.3 (12.4)	271.3 (70.9)	190 (50.1)
M	55.4 (8.2)	171.3 (12.5)	296.7 (71.6)	207.8 (50.4)
F	54.8 (6.8)	181.2 (10.4)	233.3 (54.7)	163.3 (39.3)

VO_2 at Saddle Height

Each saddle height fit method evaluation was completed during a 9-minute test; the first 3 minutes served as a warm up for the participant and time to get his/her HR to a steady state. The next 3 minutes were the actual evaluation at 70% of the power at VO_2 peak. The data shown in Table 5 are the average VO_2 taken during the last minute of the bout, minutes 5 through 6. The final 3 minutes was a cool-down period. The range of this data indicates the difficulty in comparing the participants within a given fit method (See Figure 5.). The average VO_2 at the current saddle height for the 15 participants varied from 29.38 to 51.36 ml/kg/min at 70% of power at VO_2peak. This is too great a range within a given fit method to compare among the participants. Therefore, the measured VO_2 differences at the different saddle heights or fitting methods or for a particular participant do not demonstrate any real difference.

Table 5

Average (SD) VO_2 (ml/kg/min) at 70% of Power Based on Saddle Height

	Base	**LeMond**	**USCF**	**N-S**	**1.09 * IS**
1	41.62 (2.9)	41.88 (1.61)	43.35 (2.25)	41.98 (2.54)	40.43 (2.57)
2	43.99 (2.42)	45.91 (2.78)	42.72 (1.63)	41.36 (2.51)	42.93 (2.13)
3	51.11 (2.59)	49.36 (2.52)	49.13 (2.18)	49.02 (2.06)	48.05 (2.33)
4	29.38 (1.21)	28.25 (1.91)	28.45 (0.96)	28.69 (1.74)	27.88 (1.63)
5	39.66 (1.64)	39.04 (1.42)	38.31 (1.45)	38.89 (1.53)	38.36 (1.51)
6	48.89 (2.61)	46.26 (2.63)	47.47 (2.54)	47.64 (2.55)	46.49 (2.64)
7	48.36 (1.83)	50.18 (2.7)	50.09 (2.78)	50.99 (3.21)	47.74 (2.04)
8	49.88 (1.68)	54.78 (1.55)	54.67 (2.02)	53.89 (1.42)	52.86 (1.7)
9	45.29 (2.44)	42.7 (1.96)	43.57 (2.33)	43.26 (2.15)	42.77 (2.76)
10	42.59 (1.49)	43.66 (1.35)	43.76 (1.88)	45.98 (1.42)	44.84 (1.98)
11	38.96 (1.84)	39.69 (1.96)	38.56 (2.19)	38.66 (2.72)	38.47 (2.34)
12	45.88 (3.23)	47.83 (3.57)	47.54 (3.13)	44.03 (2.94)	48.83 (2.19)
13	51.36 (2.61)	48.06 (2.33)	49.69 (2.22)	51.23 (1.77)	48.63 (2.31)
14	48.36 (1.83)	50.09 (2.78)	50.99 (3.21)	47.74 (2.04)	50.18 (2.7)
15	44.46 (1.5)	45.66 (1.48)	47.21 (2.12)	46.37 (1.76)	46.57 (2.26)

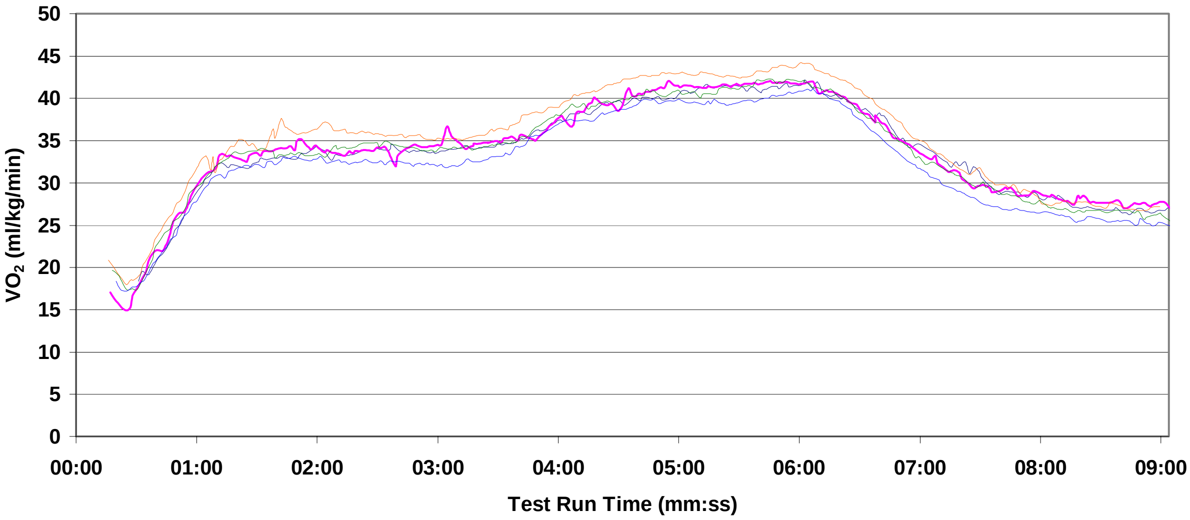

Figure 5. VO_2 breath-by-breath for a single participant during saddle height fit method evaluation testing.

Due to the variation in VO_2 results from participant to participant, the participant's average VO_2 during each of the saddle height tests was divided by the participant’s VO_2peak to obtain his/her normalized VO_2. Multiplying this ratio by 100% will produce it as a percentage. The normalized VO_2 for the current saddle height (base) had a mean of 81.2 ± 6.8%. The 109% of inseam length method had an average normalized VO_2 of 80.6 ±7.8%. Following closely was the Nordeen-Synder method at 81.0 ± 6.4%. The LeMond method had an average of 81.5 ± 7.1%. The United States Cycling Federation (USCF) method demonstrated a normalized VO_2 at 81.8 ± 7.2%. When data for male and female participants are separated, the males demonstrated that their current saddle height had the lowest, best, average normalized VO_2 of the five saddle heights tested (see Table 6). This finding is the opposite of that for the females, whose self-selected position was least effective in terms of normalized VO_2.

Table 6

Normalized VO_2 Based on Saddle Height Fit Method

	All		Men		Women	
Method	Avg	StDev	Avg	StDev	Avg	StDev
Base	81.2%	6.7%	80.0%	6.9%	83.0%	6.7%
LeMond	81.5%	7.1%	81.0%	8.4%	82.4%	5.3%
USCF	81.8%	7.2%	82.0%	8.0%	81.5%	6.5%
N-S	81.0%	6.4%	80.4%	5.9%	82.0%	7.6%
1.09 * IS	80.6%	7.8%	80.1%	8.9%	81.3%	6.5%

The same normalization method and significance level were used to evaluate the testing order for any significant effect. The first test was the participant's current saddle height (base); it revealed VO_2 efficiency of 81.2% ± 6.2. The fourth test had an average VO_2 of 80.9% ± 6.8. The second test averaged 81% ± 6.9 and was followed closely by the third test at 81.1% ± 7.6. The last test, test number 5 averaged 81.9% of VO_2 ± 7.2, but again no differences were significant (see Table 7).

Table 7

Normalized VO_2 Based on Testing Order

Order	Avg	StDev
1	81.2%	6.7%
2	81.0%	6.9%
3	81.1%	7.6%
4	80.9%	6.8%
5	81.9%	7.2%

The maximum HR during each of the saddle height evaluation tests was recorded for each participant. These five maximum heart rates were averaged for all participants. On average, for all participants, the maximum HR was 151.5 ± 16.1 (see Table 8 and Table 9). On average, the male participants' maximum HR was 150 ± 15.1, and female participants' maximum HR was 153.7 ± 18.7. When HR was evaluated according to test order, on average, all of the participants and the males as a group demonstrated the lowest HR, 150.5 ± 16.8 bpm and 148.3 ± 15 bpm, respectively. Yet, for the females, test order two and three demonstrated the lowest, at 153 ± 20.4 and 153 ± 20.9 bpm, respectively.

Table 8

Maximum Heart Rate During Various Saddle Height Testing at Power Equivalent to 70% of VO_2*peak Measured in RCPX Based on Test Order*

			Test Order		
Subject	**1**	**2**	**3**	**4**	**5**
1	160	161	158	160	158
2	163	167	166	166	160
3	163	160	160	159	161
4	143	138	138	139	142
5	137	138	137	137	140
6	134	130	129	131	147
7	120	123	124	123	124
8	148	148	146	144	145
9	164	164	168	171	170
10	163	165	164	161	161
11	134	133	135	134	138
12	164	161	164	161	160
13	140	140	138	133	142
14	161	165	165	160	164
15	178	181	180	178	174
All	151.5 (16)	151.6 (16.9)	151.5 (17)	150.5 (16.8)	152.4 (13.8)
Male	150.3 (15.9)	150.7 (15.5)	150.4 (15.2)	148.3 (15)	150.3 (13.7)
Female	153.2 (17.7)	153 (20.4)	153 (20.9)	153.7 (20.3)	155.5 (14.6)

Table 9

Maximum Heart Rate During Seat Height Testing at Power Equivalent to 70% of VO_2peak Measured in RCPX Based on Seat Height Fit Method

	Seat Height Method				
Subject	**Base**	**LeMond**	**USCF**	**N-S**	**1.09 * IS**
1	160	161	158	160	158
2	163	160	167	166	166
3	163	160	159	161	160
4	143	138	139	142	138
5	137	137	140	138	137
6	134	129	131	147	130
7	120	124	123	124	123
8	148	148	146	144	145
9	164	164	168	171	170
10	163	165	164	161	161
11	134	133	135	138	134
12	164	160	161	164	161
13	140	133	142	140	138
14	161	160	164	165	165
15	178	178	174	181	180
All	151.5	150	151.4	153.5	151.1
	(16)	(16.3)	(15.7)	(15.6)	(17)
Male	150.3	149.3	150.2	150.8	149.4
	(15.9)	(15.4)	(14.5)	(14.6)	(14.9)
Female	153.2	151	153.2	157.5	153.5
	(17.7)	(19.1)	(18.5)	(17.5)	(21)

CHAPTER 5: DISCUSSIONS, INFERENCES, SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FURTHER RESEARCH AND ACTION

Discussion

Because all but one of the participants had been fitted by a local bicycle shop to arrive at their current saddle heights, it is unclear what criteria were used to fit the cyclists for their bicycles. Some of the unknowns are whether the participants were fitted for their triathlon-specific bicycles while in an aero position, what method was used to determine their current saddle heights, and what was the knowledge of the bicycle shop. While triathlete participants were in aerodynamic position, four different road-cycling fitting techniques, in addition to their current saddle heights, were evaluated to identify which fitting technique provided the most efficient riding position for triathlon-specific bicycles. No statistically significant differences were observed between the participants' initial saddle heights and those of the four different methods.

Evaluation of the saddle height fit methods was conducted at 70% of the power generated at VO_2peak. So, it was expected that the oxygen consumption of similar magnitude would be elicited. In spite of this, an oxygen consumption of approximately 80% of VO_2peak was observed (see Figures 6 & 7). The reason for this discrepancy is unclear. When the order in which the fitting methods were completed was evaluated, it was still identified that there was no statically significances noted when comparing normalized VO_2 from the first to the fifth test (see Figures 8 & 9).

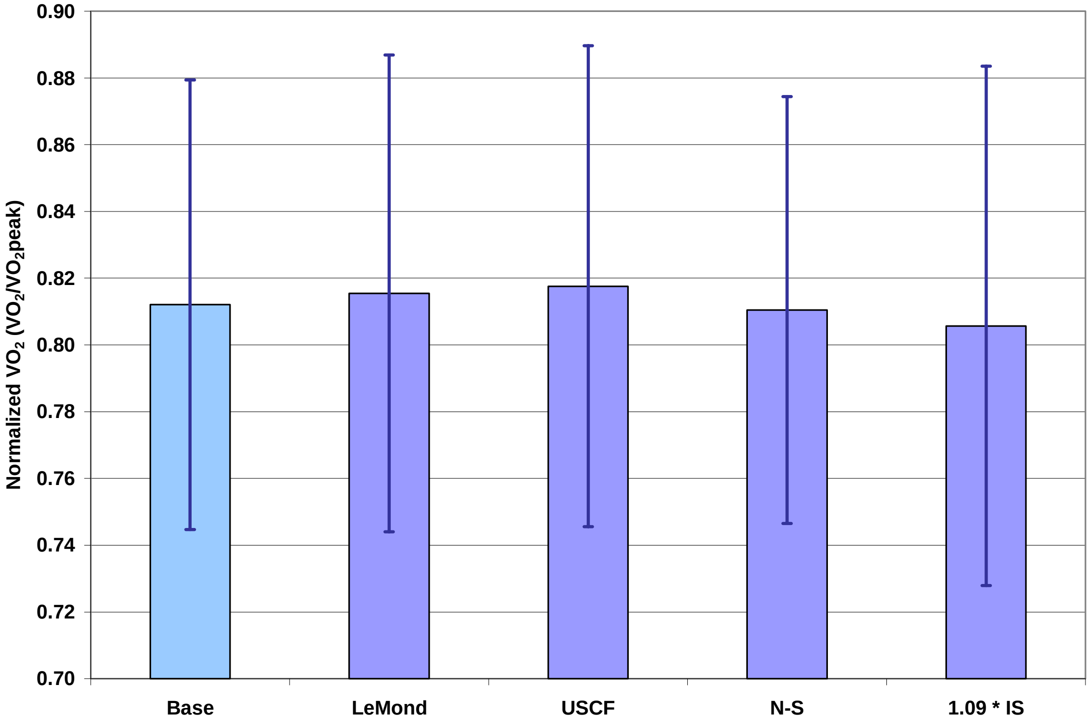

Figure 6. Normalized VO_2 by fitting method.

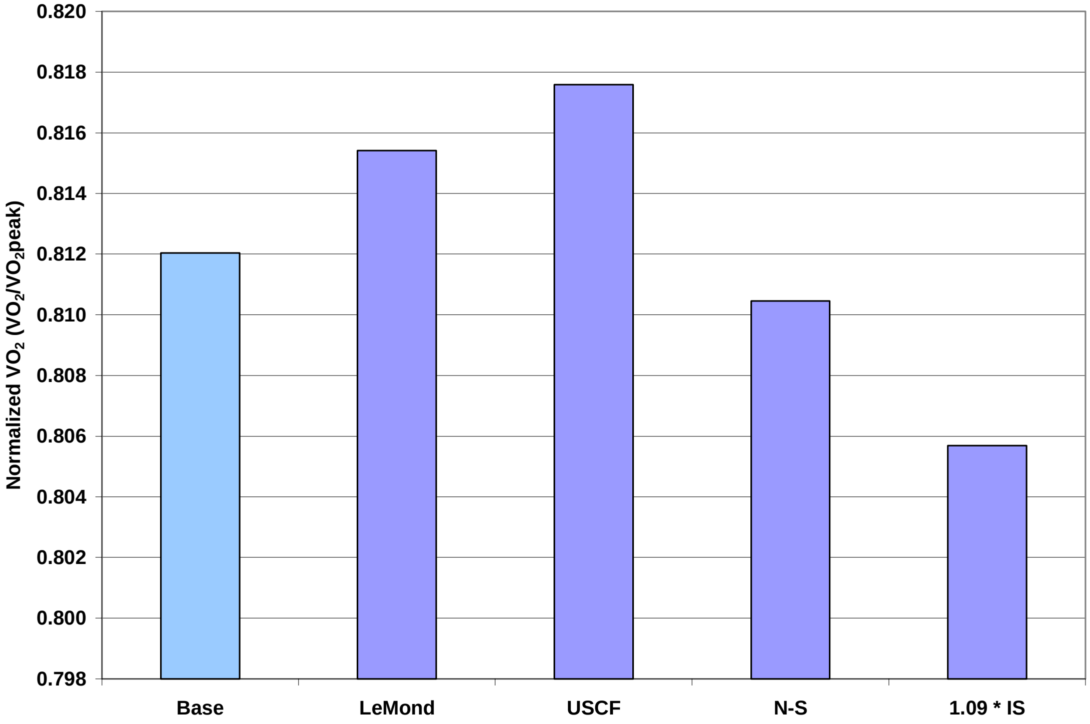

Figure 7. Normalized VO_2 by fitting method.

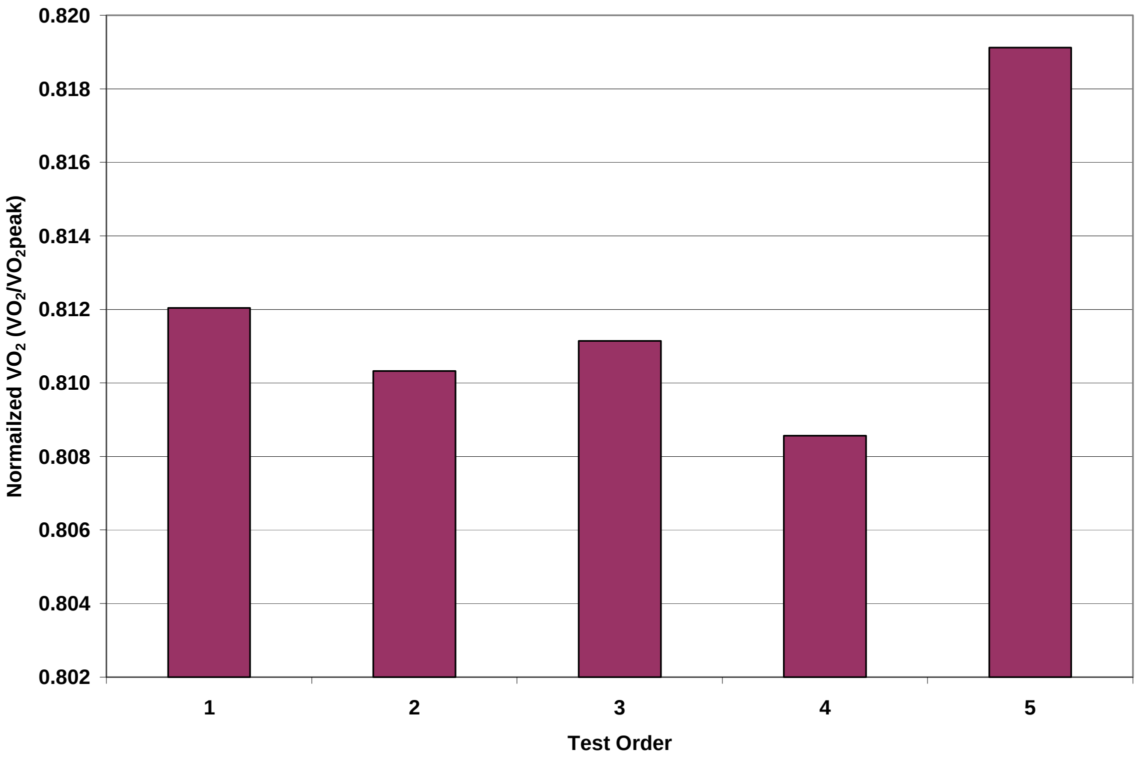

Figure 8. Normalized VO_2 by test order.

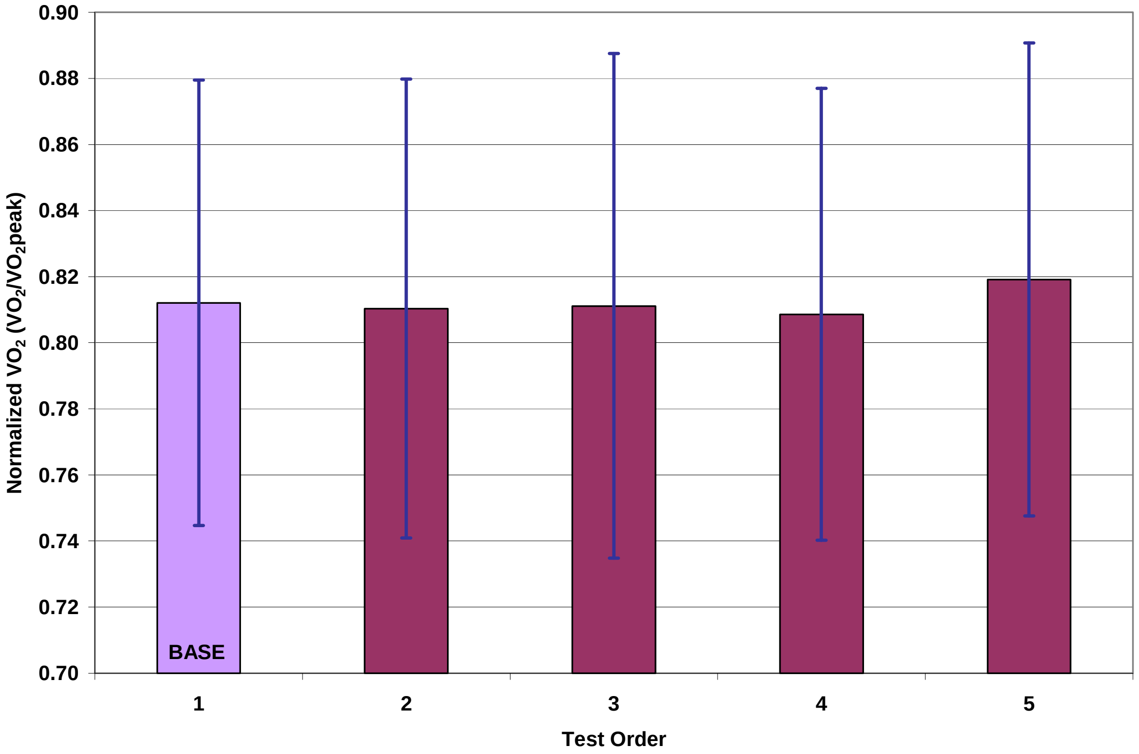

Figure 9. Normalized VO_2 by test order.

Fit methods versus gender. When comparing normalized between fit methods, the number represents a percentage of the participants' VO_2peak; thus, a lower number indicates more efficient results. The test results from the saddle height evaluation demonstrated that the 109% inseam method elicited the lowest normalized VO_2 for all participants grouped together (80.6 ± 7.8%) (see Table 6), but this difference was not statistically significant. Because the results are not statistically significant, the investigator can only compare results and cannot state that any method is more efficient than another. When the participants were separated by gender, the average VO_2 for 109% inseam method was still the lowest for the females. However, the results for males were lowest at their initial saddle height.

When other results were compared, the United Stated Cycling Federation (USCF) method provided the highest normalized VO_2 for all the participants as a group at 81.8 ± 7.2%. This indicates that the USCF method might be less efficient, but the lack of statistical significance does not support this conclusion. When the results are evaluated by gender, the males still had higher average normalized VO_2 using the USCF method: 82.0 ± 8.0%. The female participants' highest average normalized VO_2 was at their initial, or base, saddle heights with normalized VO_2 at 83.0% ± 6.7%.

Because the gender-specific results do not agree with each other or with the results when all participants are grouped together, there may be gender-specific issues. In the Nordeen-Synder (1977) research, only female participants were used, and it was concluded that 100% of trochanteric leg length (TLL) was the most efficient through analysis of oxygen consumption and kinematic factors. During this study, the 100% TLL method elicited the second-lowest efficient VO_2 as a function of saddle height out of the five fitting methods tested for the female participants.

Nordeen-Synder (1977) only identified participants as students and did not provide specific anthropometric or VO_2peak data for any of the participants. This makes it difficult to interpret why Nordeen-Synder was able to achieve conclusive results; whereas the current study was not. In this study, many of participants were slightly older, 37.9 ± 8.4 years old, and were athletes with VO_2peak values higher than those of untrained subjects. With well-trained athletes who exhibit high VO_2 efficiencies, test subjects masking any effects may absorb slight variations in test conditions, like minor seat-height changes. This reasoning would suggest that testing should be completed on untrained or elite athletes yet healthy individuals.

Heart rate measurements. When heart rate was evaluated against the various tests, it was determined that on average, the heart rate (beats per minute) was the lowest for the combined group during the LeMond method at 150.0 ± 16.3 (bmp). Comparing heart rate on basis of gender revealed little difference between males, 149.3 ± 15 bpm, and females, 151.0 ± 19.1 bpm, especially considering the large variation in the results. These results do not agree, in general, with the VO_2, results (see Table 10). The lowest heart rate does not necessarily agree with the lowest (more efficient) normalized VO_2. This suggests that the results between the fit methods are too similar to suggest that one is better than another (see Figure 10).

Table 10

Comparison of Efficiency Indicators (most to least) by Fit Method

Fit Method	Normalized VO_2 Rank	Heart Rate Rank
Base	3	4
Lemond	4	1
USCF	5	3
Nordeen-Snyder	2	5
109% Inseam	1	2

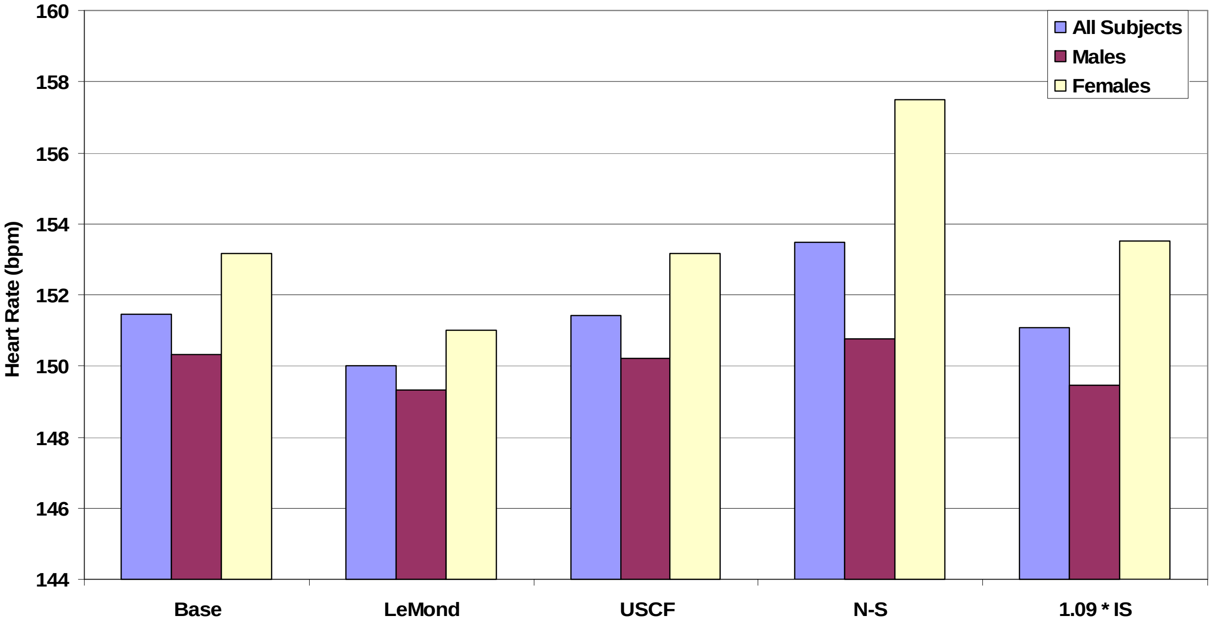

Figure 10. Heart rate by seat height method.

Saddle heights. The initial saddle heights of all participants averaged 72.5 ± 4.0 cm. The male participants had an average initial saddle height of 74.9 ± 3.2 cm, and the females had an average saddle height of 69.1 ± 1.9-cm. The four saddle height fit methods varied from the lowest saddle height at 64.0-cm to the greatest at 77.7-cm when measured from the center of the bottom bracket (COBB) (see Figure 11). This is a difference of 13.7-cm. By gender there is only a difference of approximately 10-cm for either gender. One of the USCF references suggests that a range of 2-cm would yield equivalent results (USCF, 1993) although it is not known if that 2-cm range applies to females as well as males. However, the results of this study suggest that a range of as much as 10-cm in saddle height, with all other bicycle fit variables unchanged, yields equivalent results. It is unknown why these results came to be. It may be because these participants used triathlon-geometry-specific bicycles. Or it may be due the aerodynamic position used during testing. Alternatively, the data may suggest that there is a 10-cm window for fitting seat height without sacrificing efficiency. Age and fitness level should also be considered as explanations for the data. The participants in this study were older and perhaps not as fit as those used in other studies

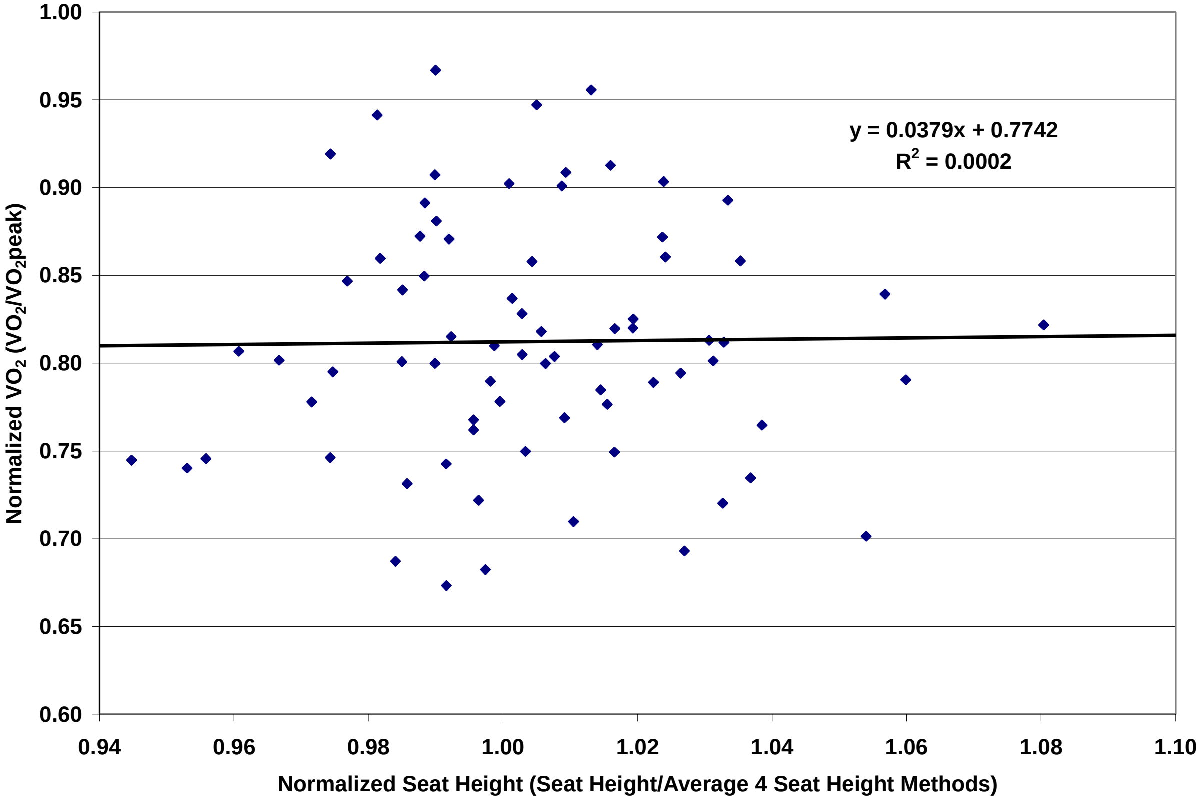

Figure 11. Normalized VO_2 versus normalized seat height.

Subject demographics. The physical characteristics of participants in this study may have been a factor in the results. There were a total of 15 participants; nine were males and six were females. The average age of these participants was 37.9 ± 8.4 years old. Not only were these participants older when compared to participants in other studies, but both male and female participants were used. The participants whom Bentley et al. (1998) and Marsh and Martin (1996) used in their studies were all males with average ages of 24.0 ± 4.2 and 25.1 years old, respectively. Nordeen-Synder (1977) used all females who were between 18 and 31 years old. Last, the study completed by Burke and Jin (1996) had the oldest average age for subjects, at 32.4 ± 7.8 years old. Their study had 37 males and 3 females; therefore, the female participants' data was included with the males.

When this study evaluated body mass against that in the other studies (Bentley et al., 1998; Heil et al., 1994; Burke & Jin, 1996), the average body mass in kilograms was 72.5 ± 12.5. Gonzalez and Hull (1989) gave the average weight of a man as 72.5-kg. Needless to say, on average this body mass is comparable with that in the other studies.

Last, VO_2peak (ml/kg/min) was examined. For the participants used in this study, the average VO_2peak (ml/kg/min) was 54.6 ±7.3. This average was on the lower end of what other researchers identified; Marsh and Martin (1996) reported the highest VO_2max of all the studies at 70.7 ± 4.1 ml/kg/min for cyclists and 72.5 ± 2.2 ml/kg/min for the runners. On the other hand, less-trained non-cyclists in their study had a VO_2max of 44.2 ± 2.8 (ml/kg/min). It was noted that the less-trained non-cyclists were cycling at higher percentages of their VO_2max and demonstrated a rapid rise in their VO_2 with increased cadence and power-output changes. The fact that participants in this study had a slightly higher VO_2peak average than the less-trained individuals in the aforementioned study may help to explain why the participants had VO_2 results at 80% of their VO_2peak versus the 70% of VO_2peak that it was expected. Bentley et al. (1998) reported VO_2peak of 64.7 ± 5.2 ml·kg·min-1. Again, these were 10 recreational triathletes who were all male. The nine males in this study had a VO_2peak of 56.2 ± 8.0 (ml/kg/min). Heil et al. (1994) reported a VO_2peak of 62.2 ± 8.3 ml·kg·min-1, and Burke and Jin (1996) reported VO_2max of 63.2 ± 11.7 (ml/kg/min), which are both higher than the participants in this study. Although Nordeen-Synder (1977) used all female subjects, the subjects' specific VO_2peak characteristics were not given.

Anthropometric measurements. The average male was determined to be 72.5-kg in mass and have a height of 177.8-cm (Gonzalez & Hull, 1989). In this study, the average mass of the males was 72.5-kg, yet the height of the male participants was 176.4-cm. This indicates that the males in this study were 1.4-cm shorter than the average-height male. However, it is believed that this would not cause the results of the data to alter significantly. There was no statistically significant difference in the inseam or TLL between the sexes. However, in this study, the TLL data for the male participants were 52% of the mean segment length and 52.6% for the female participants. Kreighbaum and Barthels (1996) the lower extremity segment length, thigh, leg, and foot, was 52.15% for the males and 54.85% for females.

Power of a Test

The power of a test is the probability of correctly rejecting the null hypothesis when it is false. It is also the likelihood that a significant difference will be identified if it exists. The power is calculated from the number of measurements, or the population for a given effect, the variability (SD) of the population, the level of significance, and the difference between the effects. Minitab Statistical Software (version 11.12) (Minitab, Inc., State College, PA) completed the power calculation. For the normalized VO_2 when testing the various seat heights, the population for each treatment was the number of participants, 15. The level of significance, α, was 0.05. The variability of the population, or the standard deviation of the normalized VO_2, was 0.07. The minimum difference between the methods was 0.3% of VO_2peak, and the maximum difference was 1.2% of VO_2peak. The minimum difference resulted in a power of 0.0532, and the maximum difference resulted in a power of 0.1018. Both of these values indicated a relatively low power (Vincent, 1999).

The same calculation can be used to predict the population required to meet the power desired. Minitab Statistical Software (version 11.12) was also used to perform these calculations. Assuming a power of 0.8 at the maximum difference between fit methods, the number of participants required would be 268. At a lower power of 0.5 at the maximum difference, the number of participants required drops to 131. As the difference that is desirable to detect decreases, the number of participants required increases significantly. At the minimum difference and a power of 0.8, the number of participants required is 4274.

This calculation indicates that given the variability in the testing, there is a low probability of being able to detect a difference if one exists. Unfortunately, it is impractical to test more than 100 participants in an effort to detect a statistically significant difference.

Conclusions

In conclusion, there was no statistical significant difference in oxygen consumption or heart rates when the five various saddle height fitting methods were evaluated with a triathlon-specific bicycle while in aerodynamic position. This held true when evaluating the participants at their current saddle height as well.

Cycling races as a sport have been around since 1891 (LeMond & Gordis, 1987). Triathlon is a relatively new sport, developed in 1974 (What is triathlon?, retrieved on May 07, 2004). During the introduction of triathlon, road bicycles were used for racing. As the sport of triathlon evolved, triathletes attempted to become more aerodynamic and with that, their bicycles needed to do the same. Through research, the triathlon bicycle has evolved for the sport of triathlon. However, research identifying efficient positioning in terms of power output, efficiency, and oxygen consumption or heart rate when using the triathlon bicycle, is scarce. Researchers need to focus not just on high-level, elite triathletes but also on those recreational, age-group triathletes who know they will never be Olympians yet still want to perform at their highest abilities. This provokes questions. Are there specific modifications that need to be made to the triathlon bicycle for female athletes in particular? What is the difference in heart rate and oxygen consumption of triathletes in an aerodynamic position versus the traditional "pull and grip" position when using a triathlon bicycle?

Many questions remain about what is considered an efficient position and how to achieve it. As one question is answered, there are endless questions that arise and need to be addressed. It is hoped that through future research, more questions will be answered than not and the sport of triathlon will continue to evolve.

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APPENDICES

Appendix A: Personal Medical History Survey

Personal Medical History Survey

Name_________________________________ Local Phone__________________________

Local Address____

Today's Date__________________ Birth date___________________ Age__________Sex________

Weight_________ Height__________

1. *Have you ever been diagnosed as having any of the following (if there is a family history of any of the following, please check the Family History column)?*

		Never	In Past	Presently	Family History
a.	Heart Disease	_____	_____	_____	_____
b.	Rheumatic Fever	_____	_____	_____	_____
c.	High Blood Pressure	_____	_____	_____	_____
d.	Hemophilia	_____	_____	_____	_____
e.	Other Vascular Disorders	_____	_____	_____	_____
f.	Diabetes	_____	_____	_____	_____
g.	Kidney Disease	_____	_____	_____	_____
h.	Liver Disease	_____	_____	_____	_____
i.	Asthma	_____	_____	_____	_____
j.	Allergies (in general)	_____	_____	_____	_____
k.	Chronic Bronchitis	_____	_____	_____	_____
l.	Other Respiratory Illness	_____	_____	_____	_____
m.	High Serum Lipids	_____	_____	_____	_____
n.	Anemia	_____	_____	_____	_____
o.	Low Blood Sugar	_____	_____	_____	_____
p.	Neuro-Musculo-Skeletal Problems	_____	_____	_____	_____
q.	Prostate Hypertrophy	_____	_____	_____	_____

2. *Please indicate any surgery that you have undergone and the approximate date(s*):

____

____

3. *Please indicate recent illnesses or major injuries that you have had & the approximate date(s):*

____

____

4. *Please list any and all medications that you are presently taking:*

Medication	Dosage	Dosage per day
_____________________	________________	________________
_____________________	________________	________________

5. *Do you smoke?* _________ *Packs per day* _____________

6. *Describe your present cycling program (amount per day, days per week, and the length of time you have been training at this level):*

Cycling	Minutes/Day	Days/Week	Weeks of Training
__________________	_________	________	____________
__________________	_________	________	____________

The information provided above is correct to the best of my knowledge:

_________________________ ____________________

Signature Date

Inclusion Decision: Accept Reject

Appendix B: Eastern Michigan University College of Education Approval of Research Involving Human Subjects

Eastern Michigan University
Ruth Boughner Laboratory of Applied Physiology
Informed Consent for Research Involving Human Subjects

Title of Project:
SEAT HEIGHT POSITIONING FOR TRIATHLETES USING ROAD CYCLIST METHODS

Principal investigator: Steven J. McGregor, Ph.D.
(734) 487-7120 ext. 2726

I,________________________________, hereby give my consent to participate in the research study entitled "Seat height positioning for triathletes using road cyclist methods" details which have been provided to me above, including anticipated benefits, risks and potential complications.

I fully understand that I may withdraw from this research project at any time without prejudice. I also understand that I am free to ask questions about any techniques or procedures that will be undertaken.

I understanding that in the unlikely even of physical injury resulting from research procedures that the investigators will assist in the subjects in obtaining medical care; however payment for the medical care will be the responsibility of the subject. The Eastern Michigan University will not provide financial compensation for medical care.

Finally, I understand that the information about me obtained during the course of this study will be kept confidential unless I consent to its release.

____
Participants Signature Date

I herby certify that I have given an explanation to the above individual of the contemplated study and its risks and potential complications.

____
Principal Investigator

Appendix C: Saddle Height Power Interview Form

Saddle Height Power Interview Form

Personal Information	**Last Name**
	First Name
	Sex
	Age
	Height (cm)
	Weight (kg)
	Trochanteric Leg Length (cm)
	Inseam (cm)
	LeMond (cm)
	USCF (cm)
	N-S (cm)
	1.09 * IS (cm)
	Years Comp
	Bike Training (hrs/wk)
Bicycle Information	**Bike Manuf**
	Bike Size (cm)
	Wheel Size (mm)
	Crank Arm Length (mm)
	Saddle Height (cm)
	Pedal Type
	Shoe Type
	Profsnl Fit/Adj (Y or N)
VO_2 Peak Testing	**Front Gear**
	Rear Gear
	Cadence (rpm)
	VO_2 Peak (ml/kg/min)
	VO_2 Peak Power (watts)
	70% VO_2 Peak Power (watts)
	VO_2 @ 70% Peak (ml/kg/min)
Test Order	**LeMond**
	USCF
	N-S
	1.09 * IS
Current	**Heart Rate (bpm)**
	VO_2 (ml/kg/min)
LeMond	**Heart Rate (bpm)**
	VO2 (ml/kg/min)
USCF	**Heart Rate (bpm)**
	VO2 (ml/kg/min)
N-S 100%	**Heart Rate (bpm)**
	VO2 (ml/kg/min)
109% IS	**Heart Rate (bpm)**
	VO2 (ml/kg/min)