EFFECTS OF CHAINRING DESIGN ON PERFORMANCE IN COMPETITIVE CYCLISTS

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Abstract

Effect of chainring design on performance in competitive cyclists

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The development of noncircular chainrings to improve cycling performance has been in progress since the 1980's and continues apace. The aim of this study was to compare performance time and physiological responses in cycling using a standard circular chainring versus a noncircular chainring developed in 2005: the Rotor Q-Ring. Eight competitive male cyclists were pre-tested using the original circular chainrings and also on the initial week of testing. The intervention consisted of cycling with Rotor Q-Rings for four weeks. Post-testing occurred with the original chainrings for the final week of testing. Testing consisted of a maximal or submaximal graded exercise test followed by a 1 k time trial. Oxygen consumption, carbon dioxide output, heart rate, ventilation, respiratory exchange ratio, and perceived exertion were continuously measured during the tests. Blood lactate concentration was measured during the last 30 s of each three minute stage. Five minutes after the submaximal test, participants performed an "all out" 1 k trial for time as well as maximum and average power. The main findings were: 1) Participants were on average 1.6 seconds faster in the 1 k time trial with Rotor Q-Rings compared to a circular chainrings. 2) There was a significant increase in average power (26.7 watts) and average speed (0.7 kph) during the 1 k time trial with Rotor Q-Rings. 3) Oxygen consumption (during weeks 2-4) and heart rate (weeks 1-3) were significantly lower with Rotor Q-Rings during submaximal testing when compared to circular chainrings. However, in contrast to our hypotheses no benefits were observed for other submaximal dependent measures (i.e., CO_2, VE, RER, RPE, GE, DE, and lactate).

Keywords: cycling performance, chainring, efficiency, cycling power

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Chapter 1: Introduction

Background

"Citus, Altius, Fortius" (Faster, Higher, Stronger) –Olympic motto

Ever since the bicycle's invention in the 1800's, athletes have sought to maximize athletic performance by increasing human speed, strength, and power. Bicycle design and equipment has been studied, developed, tweaked, tested, and modified in an attempt to improve performance. Of particular interest is the design of noncircular chainrings in replacement of the traditional circular chainrings on bicycles. Since the late 1890's there have been many attempts to increase the efficiency of pedaling and reduce the effects of the dead centers (2, 3, 12, 23, 45).

Several different types of chainrings have been developed in hopes of improving cycling performances and/or pedaling efficiency. The purpose of these chainrings is to take advantage of the areas where the most force is applied during the pedal stroke (e.g. 90 degrees), by creating a variable drive radius thereby giving a greater forward momentum to the bicycle. Three primary design factors support this aim: orientation factor, elongation factor, and form factor. The orientation factor is defined as the angle between the centerline of the cranks and the largest diameter of the chainring. The elongation factor (also known as ovalization factor) is defined as the ratio between the largest and smallest diameters of the chainring. This is the gear range of the chainring and is the amount of acceleration and deceleration that is caused during the pedal stroke. The form factor describes the curves shaping the perimeter of the chainring, such as arcs and ovals, angles or flat sections, and ellipses (23).

The more recent types of noncircular designs include the Shimano Bio-Pace chainrings that were developed in the late 1970's and the Harmonic (1994) which was relaunched in 2004 under the brand name O.Symetric (23). However, both had several flaws and have failed mainly due to improper orientation or ovalization and form factor (23, 38, 45). For example, Bio-pace

created a very irregular and uncomfortable pedal stroke which for some users, led to knee pain. Maximum diameter of the non-symmetrical chainring was placed at the dead centers which required more effort to rotate the cranks (12). This design proved unsuccessful, and the chainrings were eventually discontinued. In comparison, O.Symetric was a more effective design than Biopace. This chainring created higher gearing during the pedal down stroke but the large change in ovalization created sudden acceleration changes and increased stress on the knees (12, 23, 44, 45).

The latest noncircular chainring is Rotor Bicycle Component's Q-Ring which was developed in 2005. The designers claim to have the best shape, orientation, and adjustability compared to previous failed chainring designs. Q-Rings create a faster acceleration free of damaging loading peaks and unnatural joint movement (45). Rotor claims to create a better spinning efficiency by extending the time you spend in the power stroke (where 90% of all power is produced) and smoothly accelerating the legs through the critically weak dead centers (e.g., Figure 1: a 53 tooth (T) Q-Ring, around the upper dead-spot is equivalent to a 51T, but as the pedal goes down and more power is applied, the equivalent chainring tooth size reaches a 56T) (41). Rotor also claims these rings increase overall power by 4.1% while reducing blood lactate concentration by 9.1% and lowering fatigue (27, 41). The Q-Rings have been used by many professional and recreational riders, (in 2011 five major teams ride with Rotor components: Garmin-Cervélo, Geox-TMC, Vacansoleil-DCM, Saur-Sojasun and the Specialized Factory Racing team), and the use of these chainrings include many major victories such as Carlos Sastre's big Tour de France win in 2008 (41).

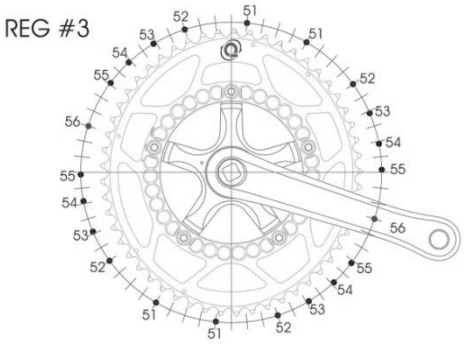


Figure 1: Design of Rotor Q-Ring

Statement of the Purpose

The primary purpose of this study was to examine the effects of a noncircular chainring (Rotor Q-Ring) on performance factors with elite cyclists. Several physiological and biomechanical markers (i.e., dependent measures) were examined including the respiratory exchange ratio (RER), heart rate (HR), ventilation (VE), volume of carbon dioxide expiration (VCO_2), volume of oxygen consumption (VO_2), blood lactate, gross efficiency (GE), delta efficiency (DE), power, and performance time. These are specifically described below.

Research Hypotheses

1. The noncircular chainrings will decrease performance time of elite cyclists in a 1 k time trial when compared to a circular chainring.
2. The noncircular chainrings will increase maximum and average power output of elite cyclists in a 1 k time trial when compared to a circular chainring.
3. The noncircular chainrings will increase maximum and average speed of elite cyclists in a 1 k time trial when compared to a circular chainring.
4. The noncircular chainring will lower blood lactate concentration of elite cyclists in a 1 k time trial when compared to a circular chainring.
5. The noncircular chainring will decrease blood lactate concentration of elite cyclists during a graded exercise test at a constant workload when compared to a circular chainring.
6. The noncircular chainring will decrease heart rate of elite cyclists during a graded exercise test at a constant workload when compared to a circular chainring.
7. The noncircular chainring will increase efficiency (gross and delta efficiency) of elite cyclists during a graded exercise test at a constant workload when compared to a circular chainring.

8. The noncircular chainring will decrease ventilation of elite cyclists during a graded exercise test at a constant workload when compared to a circular chainring.
9. The noncircular chainring will decrease VO_2 of elite cyclists during a graded exercise test at a constant workload when compared to a circular chainring.
10. The noncircular chainring will decrease CO_2 of elite cyclists during a graded exercise test at a constant workload when compared to a circular chainring.
11. The noncircular chainring will decrease the respiratory exchange ratio of elite cyclists during a graded exercise test at a constant workload when compared to a circular chainring.
12. The noncircular chainring will increase the VO_2 max of elite cyclists during a maximal test when compared to a circular chainring.

Significance

To our knowledge, this is the first study to investigate the use of noncircular chainrings compared to circular chainrings during a four week adaptation period. While other studies have examined the effects of various non-circular chainrings or non –traditional crank systems, this study will give further insight into the effects of these chainrings on cycling performance and provide insight on equipment design and further research.

Definition of Terms

The following terms and abbreviations are defined as used in the study:

Dead centers: Also known as "dead spots," the dead centers occur when one of the pedals is up (at top dead center) and the other is down (at bottom dead center), creating a power vacuum due to the cancellation of the tangential component of the forces on the pedals. This occurs at 0 and 180 degrees in the pedal stroke (25).

Efficiency: measure of effective work performed and most commonly expressed as the percentage of total energy expended that produces external work (6).

Gross mechanical efficiency (GE): at each 3-minute workload, the ratio of work accomplished to energy expended. GE (%) = [work rate (J/sec)/energy expended (J/sec) x 100%; Energy expenditure (J/sec) = ([3.869 x VO_2] + [1.195 x VCO_2]) x (4.186/60) x 1000 (7).

Delta Efficiency (DE): the ratio of the change in work accomplished and the change in energy expended = Change in Wx100/Change in E (7).

Maximal oxygen uptake (VO_2 max): The maximal amount of oxygen consumed, limited by oxygen delivery and subject to central and peripheral cardiovascular capacity limitations and tissue oxygen demand (7).

Respiratory exchange ratio (RER): Ratio of volume of oxygen to volume of carbon dioxide, used for estimating what fuel (carbohydrate or fat) is being utilized as energy. Values due to non-metabolic CO_2 range from 0.70 to 1.0, although can exceed 1.0 during maximal exercise (36).

Rate of perceived exertion (RPE): This is assessed using Borg's Scale. The 6-20 point scale was displayed on an 8.5" x 11" sheet of paper with the numbers and words describing intensity. Each workload stage the participant would point to a corresponding number to report their subjective levels of intensity (36).

Assumptions

1. The participants performed to the best of their ability during each testing session.
2. The participants followed the pre-test requirements (fasted, hydrated, well rested, followed same exercise routines), that were given to them before initial testing.
3. The participants gave honest responses of RPE and training routines.

Chapter 2: Literature Review

The purpose of this review is two-fold. First, to describe the basic biomechanical aspects of the bicycle and rider system and how muscular force is transmitted though the bicycle for the purpose of locomotion. This background highlights the underlying principles that could be manipulated for the purpose of increasing performance for competitive cyclists and triathletes. Second, this review will also describe works involving the effects of noncircular chainrings or altered crank systems on various physiological and biomechanical measures, and compare that to the latest design of a noncircular chainring, Rotor Bicycle Component's Q-Ring.

The human neuromuscular and musculoskeletal systems involve complex intrinsic properties and become more complex with interactions between different equipment, environments, and alterations to these systems. Human locomotion is characterized by cyclical movements that require muscles to generate mechanical power to overcome external resistive forces (e.g., friction, gravity, and inertia). Muscle power is the product of muscle force and contraction velocity, each of which is influenced by intrinsic muscle properties (33). The primary intrinsic determinants of muscle force and work output during the pedal stroke involve the force-velocity relationship; power-velocity relationship; and the kinetics of muscle activation/deactivation (force-time relationship). These properties have an influence on muscle force, power, efficiency, and metabolic capacity which in turn can affect an athlete's overall performance. Altering these properties in a positive direction will create new adaptations in the nervous system and will in theory increase performance. After a period of training (as soon as two to four weeks) muscle adaptations of the neural system can occur (18, 41). Although there may need to be an adaptation period for maximum benefits, slight adaptations can occur starting with as little as 20 pedal strokes (32).

Force-Velocity and Power-Velocity Relationship

The force-velocity relationship describes the force production with shortening or lengthening of the muscle fiber. The ability of a muscle to produce force decreases as shortening velocity increases, whereas when the muscle is lengthened the force increases with increasing speeds of lengthening until a certain speed is reached and then the force becomes constant. Viewing the actions of the muscle at the fiber level, one would see that as the velocity of shortening increases, cross-bridge formation decreases and therefore tension developed by the muscle decreases (see Figure 2) (34).

Power is the rate of doing work, and is expressed as the product of force and velocity (7). The tensile force produced by a muscle multiplied by the velocity of the shortening of the muscle produces a final power output. As velocity increases, power increases to a maximum between 20-35% of maximum shortening velocity, and then decreases with further increasing speeds (24). With any given muscle group the greatest power output is elicited by an optimum speed of movement. Based on the power-velocity curve (see Figure 3), cyclists would maximize power in a gear and cadence that would allow them to spin the crank efficiently so that the muscle's velocity of shortening is in the range of producing maximum power output (34).

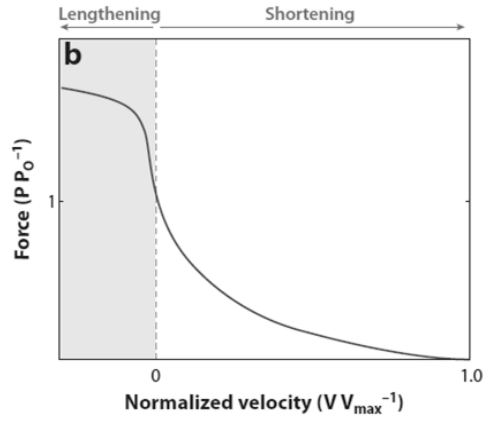


Figure 2: Force-Velocity Relationship

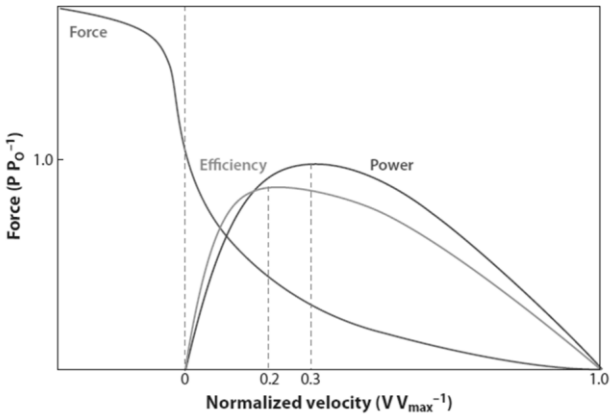


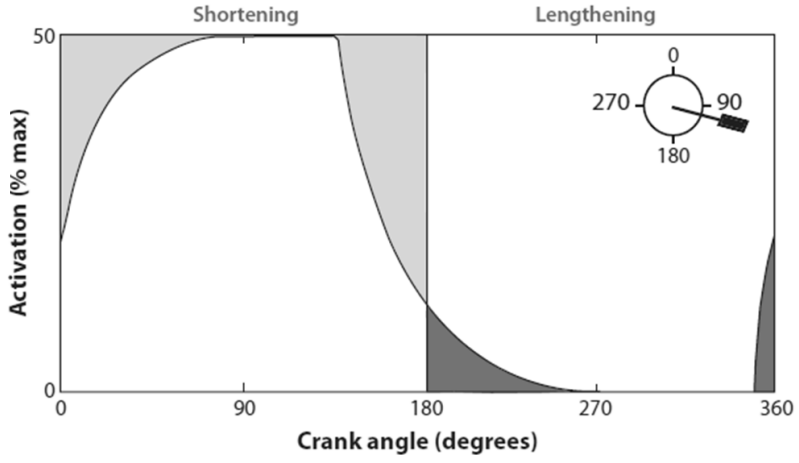
Figure 3: Power-Velocity Relationship

Activation/Deactivation Relationship

Activation and deactivation dynamics are another important muscle property that describes the delay between the development of muscular force and relaxation. (The force-time relationship refers to the delay in muscle tension after activation). Muscles require time to relax (deactivation) and time to develop tension (muscle activation). These delays are mainly due to calcium dynamics and cross-bridge attachment and detachment (33). During repetitive activities such as cycling, force-time effects may constrain muscular performance, imposing limitation on maximal force production. At the beginning and end of the shortening phase, actual force is decreased because of incomplete activation (24). Therefore, maximal power increases when there in an increase in the duration of the portion of the movement cycle spent shortening. With the leg extended for 58% of the pedal stroke (compared to shortening and lengthening for 50% each with circular chainrings), Martin reported a 4% increase in average power and an 8% increase in instantaneous power in a maximal cycling computer model (25). Another model they created found a 70% shortening cycle increased power during the leg extension by 44% (24). Similar results were found by Askew and Marsh who reported that power was 40% greater when the muscle shortened for 75% of the cycle time (1).

With circular chainrings, there is a delay in muscle activation which potentially causes a loss in power during the downstroke (power phase) (32). With elliptical chainrings the delay can

Figure 4: Muscle activation through one pedal revolution



be altered to occur earlier in the pedal stroke, therefore maximizing positive work and minimizing negative work (see Figure 4). Relationships such as these have been shown to have positive influences on the neural control and optimal performance in human movement during work loop techniques and simulations in animal preparations (34, 38).

Muscle work, Energy, Power, and Efficiency

In general, muscle efficiency is the ratio of mechanical work output to metabolic energy input (6). The relationship of muscle efficiency and shortening velocity is similar to the power-velocity relationship (see Figure 3). As a cyclist's shortening velocity increases, so does the rate of energy consumption. Efficiency peaks at about 20% of the muscle's maximum shortening velocity and then begins to decrease (33). Peak muscle efficiency and power output do not occur at the same shortening velocity; therefore a velocity somewhere in between is optimal as can be seen in Figure 3 (34).

Cyclists can maximize speed and power by taking advantage of the previously mentioned relationships and achieving optimal shortening velocity of muscle fibers. Using muscle-actuated models and simulation of the pedal stroke, research has found optimal conditions to improve performance through equipment design (13, 14, 15, 17, 21, 23, 38, 39, 40, 42, 46). Circular chainrings have a relatively constant crank angular velocity, whereas elliptical rings have a sinusoidal crank angular velocity (Figure 5) (33). An altered angular velocity during the pedal stroke has the potential to provide improved conditions for increasing power and performance. Computer models identified an eccentric chainring that increased average crank power by 3% relative to a circular chainring (38). During the downstroke of the pedal cycle (power phase), the eccentric chainring causes a decrease in angular velocity resulting in a longer power phase and therefore more work production. The foot continues through the pedal stroke going through the

dead spot centers at an increased angular velocity and therefore minimizing negative work during deactivation.

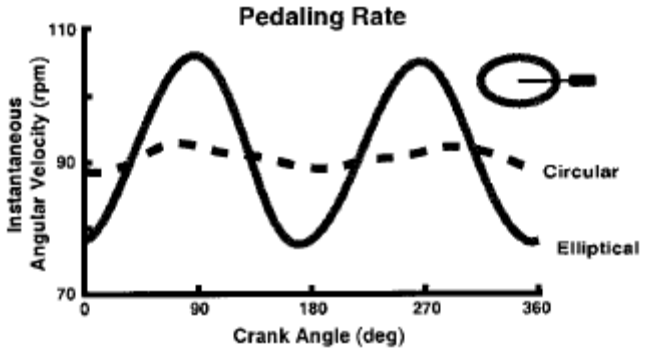


Figure 5: Pedaling rate

Among the many determinants of success in cycling, the ability to effectively rotate the chainrings is worthy of greater inspection. Maximum power output (developed primarily about the hip and knee joints) is reached when the tangential component of the force applied is greatest. Maximum torque is exerted when the crank is positioned midway between top and bottom dead centers (90 degrees from top dead center). The "dead spot" occurs when one of the pedals is up and the other is down, creating a power vacuum due to the cancellation of the tangential component of the forces on the pedals (25). The use of newly designed equipment (such as Rotor's Q-Rings) can alter the previously discussed relationships and in theory improve performance.

Eccentric and noncircular chainring research

Previous research has shown mixed results between noncircular and circular chainrings (1, 3, 4, 5, 9, 10, 12, 13, 22, 12, 13, 14, 15, 22, 23, 28, 38, 39, 40, 42, 46). There are several studies that have been published comparing the use of these eccentric chainrings, but to our knowledge there is only one published study by Martinez et al. that has looked at the Rotor Q-Rings and their effect on performance and metabolic cost (28). Martinez's study found a

reduction in lactate production, a lower heart rate, and increased power output at 90% of VO_2 max during a graded exercise test. Before Rotor Q-Rings were developed there were many attempts at developing an eccentric chainring and/or crank design in hopes of improving cycling performance and/or pedaling efficiency (23). Biomechanical and physiological research has been conducted on these designs, again showing mixed results (23). However, these theories and research designs can be looked at to study the effects of Rotor Q-Rings. The following sections look at these biomechanical and physiological responses from previous research.

I. Biomechanical Responses:

Cycling efficiency/economy

Gross mechanical efficiency has been defined as ratio of work done to the total metabolic cost (6). This variable can provide insight into the effects due to different equipment used, in our case, between different types of chainrings. Several studies also computed delta efficiency to analyze greater changes. Delta efficiency can be defined as the change in power over the change in metabolic rate with increasing work rate (6). Using this equation eliminates the use of resting metabolic rate and therefore eliminates any variation in changes of the subjects baseline energy cost caused by work rate. Economy is another measure that analyzes the cyclist's VO_2 per unit of power output. This is defined as the amount of oxygen per liter per unit of energy transferred to the bicycle (7). An increased in efficiency would lower the rate of oxygen uptake at any given power output or speed, and be advantageous for longer duration exercise/performance (10).

Slight increases in cycling efficiency, up to 3%, were found when eccentric chainrings were used in comparison to a circular system (15, 34, 38, 42, 46). At exercise intensities between 60 and 90% of VO_2 max, an increase in delta efficiency with Rotor cranks (42). Using an O.Symetric chainring, Horavis found lower net crank torque, higher max torque, and verified a theoretical mechanical benefit (12). In contrast, Rodriguez-Marroyo found no improvements in

aerobic cycling efficiency (measured via gross mechanical efficiency and the cycling economy) using a Rotor pedaling system (40).

Crank Torque

Horavis et al., found significant differences between torque production from a noncircular O.Symetric chainring (OC) and circular chainring (CC), during submaximal cycling testing (12). The results showed that the OC produced lower net crank torque at top and bottom dead center, and higher torque at during the downstroke phase. OC also had a significant increase in the instantaneous pedaling rate during top and bottom and decrease during the downstroke. This indicates that the crank moves at a slower rate during the effective activation phase (i.e., more time spent in the effective phase) (12). Theoretically, this can lead to benefits in competitive settings. For example Hue et al., found significant difference in cycling performance (faster time) during an all out 1-km using an eccentric chainring (that increases crank length during downstroke), but no significance in any physiological variables (13). They attributed the increase in performance to the possible higher torque production during the downstroke resulting from the greater crank length. On the other hand, Hansen et al., found that there were similar profiles between a noncircular chainring (Biopace) and circular chainring. No significant differences were found between peak torque, min torque, and crank angle at peak torque (10).

Power Output

Power output is the product of torque and pedal velocity (24). Torque is determined by the effective force applied perpendicular to the crank arm and by crank arm length. The maintenance of a constant effective force would optimize torque, and hence, power production (3). However, biomechanical constraints result in an uneven production of torque in a nearly sinusoidal manner with minimal torque being produced at the top and bottom dead center points of the crank cycle (33). Any optimization of this crank cycle would necessarily lead to higher net

torque and, therefore, power output (assuming an equivalent cadence). Increasing crank arm length during the downstroke of the crank cycle has been shown to produce the highest peak torque (15, 38). Such an effect can also be achieved with the use of noncircular chainrings.

Several studies found an increase in power output using noncircular chainrings or an eccentric crank system. Martinez found that subjects using Rotor Q-Rings produced around 3% more power compared to circular rings (27). In other studies using an eccentric crank system, an increase in both peak and mean power output improved anaerobic power output by increasing the force component (8, 18). Using a theoretical analysis of an optimal chainring shape, Rankin and Neptune found that there is an increased power of 2.9% compared to a conventional circular chainring (38).

Contrary to the previously discussed studies, there were no significant differences in power using an eccentric chainring design in several other studies (3, 15). Jobson also found no increases in power or cycling performance using an eccentric crank system after six weeks of training, but does suggest that the system could have acute ergogenic effects if used infrequently (18).

II. Physiological responses:

Valid physiological markers found to be predictive of cycling performance include: power output at the lactate threshold at during a maximal cycling test; peak power output indicating a power/weight ratio of greater than or equal to 5.5 W/kg; maximal lactate steady-state, representing the highest exercise intensity at which blood lactate concentration remains stable; efficiency/metabolic cost; heart rate at given workload; and ventilatory threshold (7, 8, 13). The following works describe the use of these markers to assess performance.

Blood Lactate Concentration

Blood lactate concentration at various cycling intensities is highly predictive of endurance performance and training thresholds (7). With the correct training, an athlete can recycle and buffer lactate at attained workloads until they reach a threshold. By reducing lactate production at a higher workload, an athlete can increase performance and delay fatigue (36).

Several studies have examined the effects of chainrings and eccentric crank systems on blood lactate, but the findings are inconsistent. Martinez found that the use of the Rotor Q-Rings led to a lower production of lactate at the same workload (27). When testing the Biopace chainring, Hansen et al. found a significance difference in lactate (on average 0.2 mmol/L lower) (10). An unpublished study by Conconi found that after 12 incremental tests, the lactate concentration was always higher with the traditional bike compared to the eccentric crank system (4). In comparison, several studies found no significant differences between circular chainrings and eccentric crank systems (3, 5).

Heart Rate

The ability of an athlete to work at a lower heart rate during a certain workload is similar to lactate in that lower values at the same workload will enable the athlete to perform at a higher level before fatigue (7). The findings with respect to heart rate were also similar to the effects of blood lactate production.

Martinez found that the use of Rotor Q-Rings led to a lower heart rate at the same workload when compared to circular rings (27). In a follow-up study, Martinez also found that during the test with the Q-rings the subjects produced almost a 2% lower heart rate (28). Also, the unpublished study by Conconi found that the relationship between heart rate and wattage was always slightly better with the eccentric crank system (4). With the eccentric system, subjects

were able to work at an intensity 7-9% higher, but at the same heart rate using the conventional system (4).

Oxygen consumption/RER

Due to the metabolic demands of exercise, there is a linear relationship between RER, VO_2, power, and heart rate (7). With an increase in intensity, oxygen consumption increases until a plateau is reached and no further increase occurs with an increase in work rate (36). Looking at the oxygen consumption and RER value at various work rates is indicative of fitness (36).

One of the main adaptations to training and competing at the professional level is an increased fat metabolism at any submaximal intensity (22). A similar adaptation with the noncircular chainrings would be crucial from a performance standpoint, especially in long mountain stages that are more than five hours (40). Therefore, it is important to look at the values of RER and oxygen consumption with the use of an altered system.

Rodriguez-Marroyo found no significant difference in the Rotor crank system and circular chainring systems in submaximal aerobic tests (40). However, in the anaerobic test, maximal and mean power outputs were greater with the crank system. Their findings also suggested that the subject must be adapted to the equipment in order to improve performance. Ratel and Martinez found no significant differences in RER, VO_2, or VE with the use of noncircular Harmonic chainrings and Rotor Q-Rings, respectively, when compared to circular chainrings (27, 39).

Several studies found that at a constant power output, oxygen consumption was lower in an eccentric crank system (15, 46). In addition, Henderson found that caloric outputs were 2.5% lower with a noncircular system at respective workloads versus a circular system (11).

Muscular and Joint Pain

In addition to the biomechanical and physiological variables previously discussed, muscular and joint pain with the use of an altered chainring or crank system has proved to be of interest. Knee pain is the most common lower extremity overuse problem in cyclists which, ironically, is caused by strong knee extensors (23). If only the knee extensors are strengthened, the patella will be overstrained since most of the energy in the power phase is transmitted through the patella (12, 44). This problem, if it occurs, may result in decreased performance, participation and enjoyment for cyclists at all levels.

The knee extensor muscle group is the prime mover during the downstroke phase of the pedal stroke and commonly cyclists overemphasize this group instead of others that surround and support the knee (23). There are claims that greater muscle strength can be generated with the Q-rings in relation to knee discomfort and the tender sensation in the patella is less pronounced (44). After the power stroke, Q-rings reduce the immediate gear ratio to pass through the dead spots, acting similarly to a smaller circular chainring with a smaller diameter, reducing stress on the knees (23). By reducing the time spent in the dead spots, Martinez states that knee pain, if it exisits, may be reduced (28).

Conclusion

Taken together, studies examining the effects of altered crank or chainring systems have been unequivocal. To date, no studies have examined the prolonged use of Q-rings that included an adaptation phase of chainrings and their effects on performance. Three studies mentioned that a limitation to their study was that subjects were only given brief familiarization with the chainrings (15, 22, 33). Therefore, further neuromuscular adaptations could not be ascertained, but can possibly occur if participants go through a longer familiarization period. Another factor that could be a limitation involves research that has looked at the effects of eccentric crank

systems. Although the studies that examined these effects have shown an increase in wattage and performance, these results cannot be applied specifically to the Rotor Q-Rings (1, 3. 5, 10-15, 18, 22, 25, 39, 40, 42, 46). Although biomechanical relationships between these systems are similar, more studies examining the Rotor Q-Rings are needed to support the efficacy of this modification to the bicycle drive train.

Chapter 3: Methods

Overview

The purpose of this study was to examine the effects of a non-circular chainring (Rotor Q-Rings) on physiological and biomechanical markers, as well as performance in a one kilometer (1 k) time trial. Cycling has seen many advances in technology and equipment design to help maximize athletic performance. This study compared a conventional circular chainring to the use of a non-circular chainring during a four week training period (plus two weeks of pre-testing and one week of post-testing, to carry the study over a seven week period). This chapter describes the participants, study design, test procedures, instruments used, statistical analysis and pilot study data.

Participants

Eight participants (six cyclists and two cyclists/triathletes) with a mean age of 22 ± 2.73 years, and height of 70 ± 3.09 inches were recruited from the California Polytechnic State University at San Luis Obispo and the surrounding area. Other subject characteristics can be seen in Table 1. Participants were recruited on a voluntary basis through e-mail and Cal Poly's Cycling and Triathlon Clubs. Participants were all aerobically trained and healthy as assessed by a health history questionnaire, Physical Activity Readiness Questionnaire (PAR-Q), and record of physical activity. Anthropometrics such as height, weight, and age were also measured prior to the start of testing. A maximal oxygen consumption test was performed to test for physical fitness. Inclusion criteria for the study was as follows: (1) VO_2 max >55 ml/kg/min, (2) engage in at least 8 hours/week of cycling exercise, (3) USA Cycling License Category 1-3 rider or Men's Collegiate A rider, and (4) 18 to 39 years old. Participants were all informed of the study requirements, benefits, and risks of the study. This study was approved by the Human Subjects

Committee at California Polytechnic State University. Each participant also gave verbal and written consent to participate in the study.

Table 1: Subject Characteristics. Values are means (± SD), n=8.

Age (yr)	22 ± 2.73
Height (cm)	177.8 ± 7.80
Weight (kg)	72.36 ± 8.30
VO_2 max (L/min)	4.53 ± 0.43
VO_2 max (ml/kg/min)	62.93 ± 4.21

Study Design

In order to determine the effects of chainring type on cycling performance and any long term adaptations, a Pre-Test, Intervention, Post-Test approach was employed. Throughout the study, subjects trained, raced, and were tested on their own bicycle. The study occurred during the middle part of the competitive racing season to avoid any potential off-season or pre-season effects that could possibly mask the effects of charinring type on the physiological measures targeted for collection. A repeated measures study design was used in which each participant served as their own control. All subjects completed an initial VO_2 max, blood lactate threshold, and 1 k time trial testing sessions with their original circular chainrings. After initial testing, participants completed submaximal testing every week for four weeks with non-circular chainrings (Rotor Q-Rings) as the intervention. Every week a 1 k time trial occurred after the submaximal lactate threshold test. Following the four weeks on Rotor Q-Rings, subjects were re-tested on circular chainrings with a maximum oxygen consumption test followed by a 1 k time trial (see Table 2 for timeline).

Food Intake and Training Records

Participants performed all of their scheduled exercise tests in the morning after an overnight fast. They were allowed to drink water the morning of the test, but no solid foods, caffeine, or other beverages were allowed. Participants were asked to consume the same meal the evening before each test, and were provided with a food journal log to record intake during that time.

Participants were also provided with a training journal to record mileage, average speed, HR/power, RPE, and muscular soreness each day on the bike. This was to be filled out every week and brought to the lab each testing day. Exercise was avoided 12 hours before the test, and no intense exercise sessions should have occurred 24 hours before the test. Participants were instructed to perform similar exercise sessions the day before each test session and follow consistent training during the week.

Instruments and Measures

The CompuTrainer (LAB version) with front fork mount extension, and RacerMate Coaching Software (Seattle, WA, USA) was used for all cycling tests. The participant's own personal bike was attached to the CompuTrainer at the rear wheel skewer. The CompuTrainer provides resistance to the rear wheel of the bicycle through an electronic load generator. CompuTrainer sets the industry standard for accuracy (± 2.5%), power (1500 watts), and quality (37). Crank RPM, speed, and power are all measured through the machine.

The dependent measures throughout the testing period included the following: VO_2 max, blood lactate concentration (mmol/L), respiratory exchange ratio (RER), heart rate (bpm), RPE, VO_2 (L/min), VCO_2 (L/min), VE (Ventilation, L/min), Power (Watts), 1 k time trial performance time (seconds), and delta and gross efficiency (percent).

Timeline of laboratory tests

All subjects performed testing during the same time period consisting of seven visits to the Biomechanics Laboratory on the Cal Poly Campus over seven weeks. All subjects were in the middle part of their competitive racing season with racing occurring on the weekends. Visits to the lab for data collection were scheduled for Tuesday, Wednesday, or Thursday. The following table describes the order of tests and the type of chainring employed during the testing session. A description of each of the testing sessions follows.

Table 2: Timeline of Laboratory Tests

Week	Chainring	Tests Performed
Initial	Round	Maximal Oxygen Consumption + Lactate + 1k practice Time Trial
0	Round	Graded Submaximal + Lactate + 1k Time Trial
1	Rotor	Graded Submaximal + Lactate + 1k Time Trial
2	Rotor	Graded Submaximal + Lactate + 1k Time Trial
3	Rotor	Graded Submaximal + Lactate + 1k Time Trial
4	Rotor	Maximal Oxygen Consumption + Lactate + 1k Time Trial
5	Round	Maximal Oxygen Consumption + Lactate + 1k Time Trial

Maximal Oxygen Consumption Test

The maximal oxygen consumption test was a preliminary measure to determine eligibility for the study, and was also repeated at the end of the four week training period. The test began with a 15 minute warm up at 150 watts on the participant's bike mounted to the CompuTrainer. After the warm up period, the trainer was calibrated according to industry standards (>2.0 lbs.), and the computer was set to start the test at 150 watts (37).

A clip was placed on the participant's nose with a breathing tube attached to a mouthpiece to ensure that the participant could only breathe through his or her mouth. Expired air was analyzed using a Parvo Medics TrueOne 2400 Metabolic Measurement System (Parvo Medics, Salt Lake City, UT). Participants were also fitted with a heart rate monitor strap (Polar Electro, Lake Success, NY). RER, HR, VE, VCO_2, and VO_2 max were all determined by the highest 30-second averaged values obtained through analysis. The last two minutes of each three minute stages were averaged to obtain values for data analysis. Metabolic cost and efficiency were also calculated from the data. Participants were instructed to maintain a pedaling cadence of 90 rpm. Power was automatically increased by 30 watts every 3 minutes through the computer until the participant reached exhaustion, voluntarily stops the test, or reduces cadence below 50 rpm. Rate of perceived exertion was also assessed every 3-minutes. The test was deemed valid if three of the following four criteria were met: 1) plateau of VO_2 max followed by a prolonged decrease in VO_2 at near maximal intensity, 2) respiratory exchange ratio > 1.15, 3) heart rate was within 10 beats of their age predicted max, and 4) RPE $\geq$18 (36).

After performing their initial maximal oxygen consumption test, participants underwent a 1 k familiarization trial. This included instructions for subsequent weeks of testing. Participants were allowed to experiment with gearing and were given a 1 k practice trial to avoid any testing effect in future weeks. Exact protocol for the 1 k time trial is discussed below.

Weekly Exercise Testing Protocol

Graded Exercise Test (Lactate Threshold Test)

A week after the initial maximal oxygen consumption test, an initial graded lactate threshold test with metabolic sampling was done and continued every week of testing. The graded exercise test protocol was similar to the maximal oxygen consumption test in that each

stage was three minutes long with 30 watt increases each stage. The same warm up occurred (15 minutes) followed by calibration of the CompuTrainer. Blood lactate, heart rate, RPE, and metabolic data were recorded for each stage. Instead of going to maximal exertion, this test ended when a RPE of 15-18 was reached and lactate concentration was >4.0mmol/L with an increase from the previous value >1.0mmol/L. The last stage was kept constant every week.

One Kilometer Time Trial

After the initial lactate threshold test, the participant was given five minutes to spin easy and recover at 150 watts before beginning an all out 1 k time trial. RacerMate's Coaching Software was used to design a flat one kilometer course for the time trial. During the test the program was set to record performance time, average power, maximum power, and heart rate. Participants were instructed to select their preferred gear (found during the familiarization trial and repeated each week). Once in the correct gear, pedaling ceased and the wheel was brought to a complete stop. After 30 seconds, when heart rate reached a steady value similar to initial testing, the participant was given a three second countdown to start the test. Each week the participant began the test at the same heart rate as initial testing so that performance would not be skewed. Participants were allowed to pedal out of the saddle for the first five seconds to accelerate, but had to remain seated for the remainder of the test. Feedback of cadence and heart rate were given on a visual display, but distance, speed, and power were hidden from view. Participants were free to choose their own cadence, however they were asked to try and stay around 90 RPM and to pedal at a similar cadence for subsequent time trials. No instruction or encouragement was given during the test with the exception of an announcement stating the test was halfway over, and that there was 0.02 km to go.

After the initial graded exercise test and 1 k time trial, the chainrings on the participant's bicycle were changed over to Rotor Q-Rings. For the next four weeks, the participant reported to the lab for the graded exercise test with metabolic and blood sampling. Every week, the graded exercise test was followed by the 1 k time trial with the same procedures as mentioned before.

Blood Sample Analysis

Blood samples were obtained via ear lobe prick to measure blood lactate concentration using the Lactate Pro analyzer (Arkay Factory Inc., Shiga, Japan). The Lactate Pro analyzer has been fully approved by the FDA and needs as little as five microliters of blood for a measurement. The blood lactate analyzer was calibrated prior to each test session according to the manufacture's recommendations. Blood was obtained during the last 30 seconds of each stage during the graded exercise test. The sampling site was cleaned using an alcohol wipe followed by the use of gauze pad to dry. A lancet was used to prick the ear lobe, and a drop of blood was applied to the test strip inserted into the analyzer. Subsequent blood measurements were taken from the same site for the next stage if clotting did not occur. Researchers wore lab gloves at all times during blood sampling and testing. Universal precautions, as recommended by the Centers for Disease Control and Prevention, were used at all times. This included using a sharps container lined with a biohazard bag for all sharp objects involved in the blood sampling; all other materials (i.e. gloves, gauze pads, etc.) used during the sampling were be put in a separate waste disposal unit lined with a biohazard bag.

Statistical Analysis

All analyses in this study were carried out using SAS/Stat software Version [9.2] for Windows. A one-way ANOVA, blocking on subject, was used to determine the effect of chainring type on each performance measure during the 1k time trial. All data for time (s), average power (W), max power (W), average speed (kph), max speed (kph), and blood lactate

concentration (mmol/L) are presented as means ± SD. 1 k time trials were made after a submaximal testing session and also after maximal testing. For submaximal testing, post-hoc comparisons of Rotor Q-Ring means during weeks 1, 2, and 3, to circular rings in week 0 were adjusted using Dunnett-Hsu.

The effects of Rotor Q-Rings were examined by analyzing mean values across subjects during maximal and submaximal testing. The effects of Week/Chainring, Power, and the Week/Chainring by power interaction were then analyzed using repeated measures ANOVA, blocking on subject, with week 0 and week 5 testing occurring with subjects using circular rings, and week one through four using Rotor Q-Rings. Post-hoc comparisons of Week/Chainring means were carried out using a Dunnett-Hsu adjustment with week 0 on circular chainrings as the control. Post-hoc comparisons of interaction means were carried out using a Bonferroni adjustment. All data are presented as means ± SD and include the following: Blood Lactate Concentration (mmol/L), Maximum Oxygen Consumption (L/min and ml/kg/min), Submaximal Oxygen Consumption (L/min and ml/kg/min), Respiratory Exchange Ratio (RER), Heart Rate (bpm), Ratings of Perceived Exertion (RPE), Ventilation (VE in L/min), Carbon Dioxide Production (VCO_2 in L/min), Power (W), Delta and Gross Efficiency (percent). All effects were considered significant at $P < 0.05$.

Pilot Test

A pilot study was conducted before the start of actual data collection following the previously mentioned methods. All participants were familiar with physiological testing beforehand and briefed on the protocol for testing. Three intermediate level cyclists performed an initial lactate threshold test on their current circular chainrings. One of these participants then performed an all out 1 k time trial five minutes after the end of the LT test. Following initial

testing, all chainrings were switched over to Rotor's Q-Rings and participants trained with them for a week (4-10 hours). They were retested the following week at the same time of day. Their lactate threshold test ended at the same stage as the previous week. Five minutes after the end of the test all participants performed a 1 k time trial. Chainrings were switched back to the original circular chainrings, and the two participants that did not do the initial 1 k time trial returned the following week for another 1 k time trial under the same protocol from the LT test. This final test was performed to examine whether or not exposure to the test produced an effect independent of chainring type. Pilot data analysis and sample size calculation for the current study can be found in the Appendix on page 50.

Chapter 4: Results

Food Intake and Training Logs

Examination of food intake and training logs did not reveal any deviations from instructions given to subjects and did not warrant elimination of any particular data set. While variations in training volume were apparent across subjects, within subject variations on a weekly basis were consistent.

Submaximal Graded Exercise Test

Physiological data from all submaximal graded exercise tests (i.e., absolute VO_2, relative VO_2, CO_2, HR, VE, RER, RPE, GE, DE, lactate) are presented in Figures 4-5, and Tables 3-12. All tables show the power for each workstage followed by the least square means (LSM). Graded exercise tests stopped after six workstages (i.e., 150, 180, 210, 240, 270, 300 watts) and occurred during weeks 0-3. In week 4, data from the first six workstages (instead of using all stages to max) were used for submaximal comparisons. However, subjects continued to cycle beyond 300 watts to ascertain the effect of chainring type under maximal testing. This allowed for additional comparisons of physiological data from maximal testing that occurred during Pre-testing, week 4, and week 5. These findings are presented in Figure 12 and Table 15. There was no significant interaction ($p > 0.05$) between week/chainring and power for any of the response variables. Summary of statistical analysis for all dependent measures can be found in Appendix B, page 57.

Oxygen Consumption

A significant main effect for week/chainring type was observed for submaximal absolute oxygen consumption (VO_2 in L/min) ($p < 0.01$). Post hoc analysis revealed that absolute VO_2 was lower in weeks 2, 3, and 4 compared to week 0 with the circular rings ($p < 0.05$) (see Figure 4 and Table 3). There was no significant interaction found between week/chainring type and

power (p = 0.998). Although slight differences can be seen during each workstage (i.e., 150, 180, 210, 240, 270, 300 watts), these data display increases that are generally indicative of an increase in exercise workloads. Oxygen consumption was not significantly different when comparing the final week of testing (i.e., week 5 Post-test) to the initial week of testing (i.e., week 0) on circular chainrings (p = 0.11) (see Table 3).

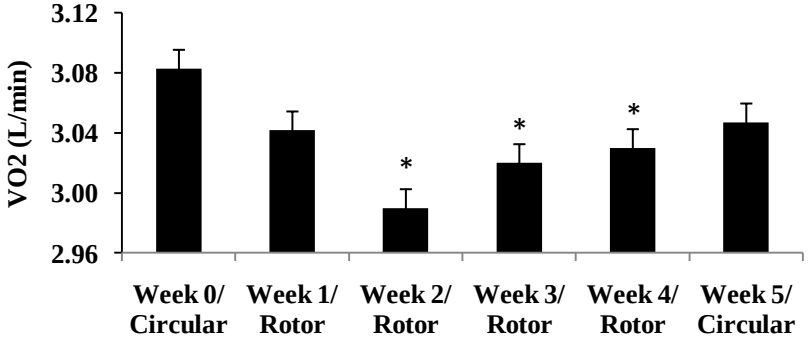
A similar main effect for week/chainring type was found for relative oxygen consumption (VO_2 in ml/kg/min) (p < 0.05). However, post hoc analysis indicated week 2 with the Rotor Q-Ring as the only significantly lower occurrence compared to week 0 with the circular ring (p < 0.05). In a similar manner as absolute VO_2, the increases in relative VO_2 correspond with increased demands of each exercise stage (see Table 4). There was no significant interaction between week/chainring type and power (p = 1.00).

Table 3: Absolute Volume of Oxygen Consumption with a Circular and Rotor Q-Ring

Week/	Power Output (Watts)						
Chainring	**150**	**180**	**210**	**240**	**270**	**300**	LSM
0/Circular	2.3 ± 0.2	2.5 ± 0.1	2.9 ± 0.1	3.2 ± 0.2	3.6 ± 0.1	4.0 ± 0.2	3.1
1/Rotor	2.2 ± 0.2	2.5 ± 0.2	2.8 ± 0.2	3.2 ± 0.2	3.6 ± 0.5	4.0 ± 0.1	3.0
2/Rotor	2.2 ± 0.2	2.4 ± 0.3	2.8 ± 0.2	3.2 ± 0.4	3.5 ± 0.4	3.9 ± 0.1	3.0 *
3/Rotor	2.2 ± 0.4	2.5 ± 0.4	2.8 ± 0.3	3.2 ± 0.3	3.5 ± 0.3	3.9 ± 0.2	3.0 *
4/Rotor	2.3 ± 0.5	2.5 ± 0.2	2.8 ± 0.2	3.2 ± 0.2	3.5 ± 0.2	3.9 ± 0.1	3.0 *
5/Circular	2.2 ± 0.1	2.5 ± 0.1	2.8 ± 0.1	3.2 ± 0.1	3.6 ± 0.1	4.0 ± 0.1	3.1

Absolute VO_2 in L/min. Values are expressed as means ± SD.*Significantly lower than circular chainrings (p<0.05).

Figure 5: Submaximal values of absolute VO_2 with a Circular and Rotor Q-Ring.



Values are expressed as means ± SE. *Significantly lower than circular chainrings (p<0.05).

Table 4: Relative Volume of Oxygen Consumption with a Circular and Rotor Q-Ring

Week/ Chainring	Power Output (Watts) 150	180	210	240	270	300	LSM
0/Circular	31.4 ± 3.4	35.4 ± 3.6	40.2 ± 4.1	44.7 ± 4.5	50.0 ± 5.1	55.1 ± 4.3	42.8
1/Rotor	30.5 ± 5.4	34.7 ± 5.9	39.4 ± 6.5	44.6 ± 6.7	49.6 ± 6.5	54.5 ± 4.9	42.2
2/Rotor	30.1 ± 6.8	33.7 ± 7.9	38.6 ± 8.1	43.8 ± 5.6	48.9 ± 5.5	53.9 ± 5.3	41.5 *
3/Rotor	31.0 ± 8.4	34.8 ± 9.5	39.4 ± 5.2	44.3 ± 5.6	49.6 ± 6.0	54.9 ± 6.7	42.3
4/Rotor	31.3 ± 10.5	34.8 ± 2.8	39.2 ± 3.4	44.1 ± 3.4	49.3 ± 4.0	54.4 ± 4.8	42.2
5/Circular	30.4 ± 3.3	34.4 ± 3.5	39.0 ± 3.4	43.9 ± 3.8	49.4 ± 4.1	55.0 ± 5.0	42.0 *

VO_2 in ml/kg/min. Values are expressed as means ± SD. *Significantly lower than circular chainrings ($p<0.05$).

Heart Rate and Rate of Perceived Exertion

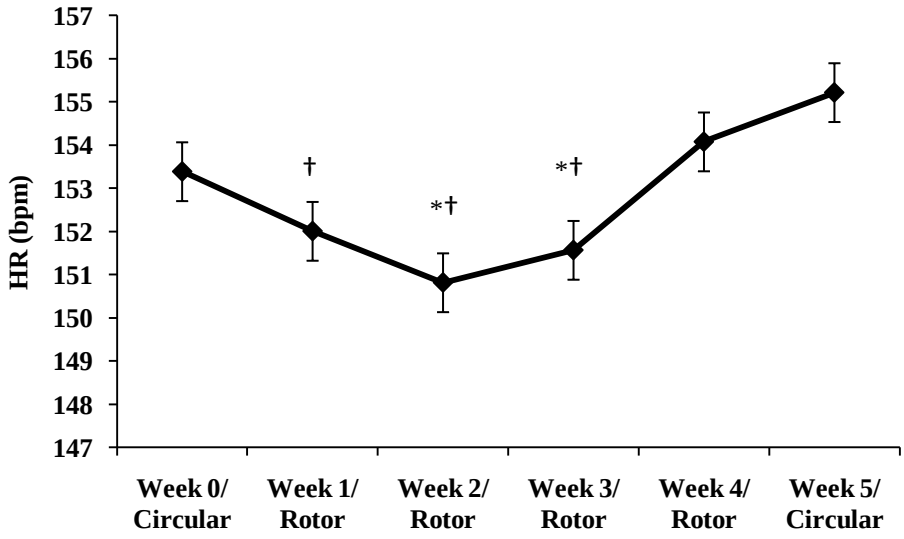
A significant main effect for week/chainring type was observed for heart rate ($p < 0.01$). Post hoc analysis revealed that heart rate was significantly lower in weeks 2 and 3 on Rotor Q-Rings compared to week 0 on circular chainrings ($p < 0.05$). Heart rate was also significantly lower during weeks 1, 2, and 3 on the Rotor Q-Rings compared to week 5 back on circular chainrings ($p < 0.05$) (see Figure 5 and Table 5). There was no significant interaction found between week/chainring and power ($p = 1.00$), although slight differences can be seen during each workstage with the Rotor Q-Rings compared back to the initial test on circular chainrings, week 0.

Table 5: Heart Rate with a Circular and Rotor Q-Ring

Week/ Chainring	Power Output (Watts) 150	180	210	240	270	300	LSM
0/Circular	129 ± 8	139 ± 8	149 ± 7	158 ± 8	168 ± 8	176 ± 7	153
1/Rotor	128 ± 11	136 ± 12	147 ± 13	158 ± 11	167 ± 16	175 ± 8	152 †
2/Rotor	126 ± 13	136 ± 14	147 ± 13	157 ± 11	166 ± 11	174 ± 8	151 *†
3/Rotor	127 ± 17	137 ± 15	148 ± 12	158 ± 11	166 ± 9	174 ± 7	152 *†
4/Rotor	130 ± 18	140 ± 10	150 ± 10	160 ± 8	168 ± 7	177 ± 7	154
5/Circular	130 ± 7	141 ± 9	151 ± 9	161 ± 7	170 ± 7	179 ± 7	155

HR in bpm. Values are expressed as means ± SD. *Significantly lower than week 0 circular chainrings ($p<0.05$). †Significantly lower than week 5 circular chainrings ($p<0.05$).

Figure 6: Main effect on HR week/chainring type during submaximal testing.



Values are expressed as means ± SE. *Significantly lower than week 0 circular chainrings ($p<0.05$). †Significantly lower than week 5 circular chainrings ($p<0.05$).

A main effect for week/chainring type reached borderline significance for the rate of perceived exertion (RPE) ($p = 0.05$). As the workstages increased during the graded exercise tests, the RPE increased in a systematic manner regardless of the type of chainring employed. There was no significant interaction found between week/chainring and power ($p = 0.99$).

Table 6: RPE with a Circular and Rotor Q-Ring

Week/ Chainring	Power Output (Watts) 150	180	210	240	270	300	LSM
0/Circular	9.3 ± 1.6	11.0 ± 1.5	12.4 ± 1.4	13.8 ± 1.3	15.3 ± 1.5	17.1 ± 1.0	13.1
1/Rotor	9.1 ± 1.9	10.9 ± 2.2	12.0 ± 2.2	13.3 ± 2.1	15.1 ± 1.7	16.8 ± 0.8	12.9
2/Rotor	8.9 ± 2.8	10.1 ± 3.2	12.0 ± 3.0	13.5 ± 1.3	14.9 ± 1.2	16.8 ± 0.8	12.7
3/Rotor	9.0 ± 2.9	10.6 ± 3.2	11.8 ± 1.6	13.4 ± 1.0	15.1 ± 0.9	17.1 ± 1.0	12.8
4/Rotor	8.8 ± 3.9	10.4 ± 1.1	11.9 ± 0.7	13.3 ± 1.1	15.1 ± 1.1	16.6 ± 1.3	12.7
5/Circular	8.5 ± 1.6	10.1 ± 1.5	11.9 ± 1.0	13.5 ± 1.1	15.0 ± 1.3	17.1 ± 1.0	12.7

Values are expressed as means ± SD.

Ventilation and Carbon Dioxide Production

No significant main effect was observed for week/chainring on VE ($p = 0.83$), and CO_2 production ($p = 0.21$). Both measures did indicate a systematic increase due to increasing workloads across all chainring conditions. There was no significant interaction found for week/chainring and power in either conditions ($p = 1.00$ for both responses).

Table 7: Ventilation with a Circular and Rotor Q-Ring

Week/ Chainring	Power Output (Watts) 150	180	210	240	270	300	LSM
0/Circular	49.0 ± 6.1	55.6 ± 4.2	64.2 ± 4.5	75.2 ± 5.9	90.1 ± 7.2	111.5 ± 10.1	74.3
1/Rotor	47.2 ± 3.7	54.7 ± 4.2	63.7 ± 7.6	76.0 ± 10.7	90.5 ± 19.2	109.3 ± 17.4	73.6
2/Rotor	46.4 ± 5.2	54.0 ± 4.3	62.8 ± 12.9	74.7 ± 13.6	90.7 ± 15.7	109.8 ± 15.2	73.1
3/Rotor	47.1 ± 11.2	54.0 ± 7.7	62.8 ± 6.5	73.0 ± 8.8	89.3 ± 12.8	111.6 ± 17.9	73.0
4/Rotor	48.6 ± 18.9	55.0 ± 5.6	63.4 ± 6.2	74.6 ± 7.5	89.4 ± 10.7	106.8 ± 14.6	73.0
5/Circular	47.4 ± 2.1	54.7 ± 2.4	62.8 ± 3.3	73.9 ± 4.8	90.4 ± 6.8	115.1 ± 11.9	74.1

VE in L/min. Values are expressed as means ± SD.

Table 8: Volume of Carbon Dioxide Production with a Circular and Rotor Q-Ring

Week/ Chainring	Power Output (Watts) 150	180	210	240	270	300	LSM
0/Circular	1.9 ± 0.2	2.2 ± 0.1	2.5 ± 0.1	2.9 ± 0.1	3.4 ± 0.1	4.0 ± 0.1	2.8
1/Rotor	1.9 ± 0.2	2.2 ± 0.2	2.5 ± 0.3	3.0 ± 0.3	3.5 ± 0.7	4.0 ± 0.2	2.8
2/Rotor	1.8 ± 0.2	2.1 ± 0.3	2.5 ± 0.4	3.0 ± 0.5	3.5 ± 0.5	4.0 ± 0.2	2.8
3/Rotor	1.9 ± 0.5	2.2 ± 0.5	2.5 ± 0.2	2.9 ± 0.2	3.4 ± 0.3	4.0 ± 0.2	2.8
4/Rotor	1.9 ± 0.7	2.2 ± 0.2	2.6 ± 0.2	3.0 ± 0.2	3.5 ± 0.2	4.0 ± 0.2	2.9
5/Circular	1.9 ± 0.2	2.2 ± 0.2	2.5 ± 0.2	3.0 ± 0.2	3.5 ± 0.2	4.1 ± 0.2	2.9

VCO_2 in L/min. Values are expressed as means ± SD.

Respiratory Exchange Ratio

A significant main effect for week/chainring type was observed for respiratory exchange ratio (RER) ($p < 0.05$). However, post hoc analysis indicated no significant differences when comparing the Rotor Q-Ring to circular chainrings ($p = 1.0$) (see Table 9). There was no significant interaction between week/chainring and power ($p = 1.00$).

Table 9: Respiratory Exchange Ratio with a Circular and Rotor Q-Ring

Week/ Chainring	Power Output (Watts) 150	180	210	240	270	300	LSM
0/Circular	0.83 ± 0.03	0.85 ± 0.03	0.87 ± 0.02	0.91 ± 0.03	0.95 ± 0.04	1.01 ± 0.04	0.90
1/Rotor	0.85 ± 0.03	0.87 ± 0.04	0.90 ± 0.05	0.93 ± 0.06	0.97 ± 0.08	1.01 ± 0.07	0.92
2/Rotor	0.85 ± 0.03	0.88 ± 0.05	0.90 ± 0.07	0.94 ± 0.06	0.98 ± 0.06	1.03 ± 0.06	0.93
3/Rotor	0.84 ± 0.06	0.87 ± 0.07	0.90 ± 0.04	0.92 ± 0.04	0.97 ± 0.05	1.02 ± 0.05	0.92
4/Rotor	0.86 ± 0.08	0.88 ± 0.03	0.91 ± 0.03	0.94 ± 0.03	0.98 ± 0.04	1.01 ± 0.05	0.93
5/Circular	0.87 ± 0.05	0.88 ± 0.05	0.90 ± 0.05	0.93 ± 0.05	0.98 ± 0.50	1.03 ± 0.06	0.93

Values are expressed as means ± SD.

Blood Lactate Concentration

No main effect was observed for week/chainring type for measured blood lactate concentration ($p = 0.86$). There was a main effect for power ($p < 0.05$), however, the increases in blood lactate correspond to the increases in workload during the graded exercise test (see Table 10). There was no significant interaction between week/chainring type and power ($p = 0.99$).

Table 10: Blood Lactate Concentration with a Circular and Rotor Q-Ring

Week/ Chainring	Power Output (Watts) 150	180	210	240	270	300	LSM
0/Circular	1.0 ± 0.2	1.1 ± 0.3	1.5 ± 0.4	2.3 ± 0.8	3.8 ± 1.5	6.3 ± 1.6	2.68
1/Rotor	1.1 ± 0.2	1.1 ± 0.6	1.6 ± 1.3	2.5 ± 2.3	3.9 ± 1.4	5.8 ± 1.8	2.63
2/Rotor	1.1 ± 0.6	1.2 ± 1.3	1.7 ± 2.5	2.5 ± 0.9	4.0 ± 1.3	5.5 ± 1.6	2.65
3/Rotor	1.1 ± 1.4	1.2 ± 2.5	1.6 ± 0.2	2.4 ± 0.6	3.7 ± 0.8	5.3 ± 1.7	2.52
4/Rotor	1.3 ± 2.0	1.4 ± 0.3	1.7 ± 0.3	2.5 ± 0.7	3.7 ± 1.2	5.4 ± 1.8	2.65
5/Circular	1.1 ± 0.3	1.3 ± 0.4	1.7 ± 0.5	2.6 ± 0.7	4.1 ± 0.9	5.7 ± 1.4	2.75

Lactate in mmol/L. Values are expressed as means ± SD.

Efficiency

A significant main effect for week/chainring type was observed for gross efficiency (GE) ($p < 0.05$), but no significant main effect was found for delta efficiency ($p = 0.53$). Delta efficiency was only calculated for 210 Watts and above (~65% of VO_2 max) based on previous research (42). Both GE and DE showed a decrease as workloads progressed during the graded exercise tests. Post hoc analysis for GE indicated that there were no significant differences between week/chainring type and power ($p = 0.99$).

Table 11: Gross Efficiency with a Circular and Rotor Q-Ring

Week/	Power Output (Watts)						
Chainring	**150**	**180**	**210**	**240**	**270**	**300**	LSM
0/Circular	19.9 ± 1.5	21.0 ± 1.1	21.4 ± 1.0	21.9 ± 1.0	21.8 ± 0.8	21.5 ± 0.8	21.3
1/Rotor	20.3 ± 1.2	21.3 ± 0.6	21.7 ± 0.9	21.8 ± 0.8	21.9 ± 0.8	21.8 ± 0.6	21.5
2/Rotor	20.6 ± 1.1	21.9 ± 1.2	22.2 ± 0.5	22.2 ± 0.5	22.1 ± 0.4	21.8 ± 0.4	21.8
3/Rotor	20.3 ± 1.8	21.5 ± 0.8	22.1 ± 1.0	22.3 ± 0.9	22.1 ± 0.7	21.8 ± 0.8	21.7
4/Rotor	19.9 ± 1.8	21.2 ± 1.1	21.9 ± 0.9	22.0 ± 0.6	22.0 ± 0.7	21.8 ± 0.6	21.5
5/Circular	20.2 ± 1.1	21.3 ± 0.9	21.8 ± 0.9	22.0 ± 1.0	21.7 ± 0.8	21.3 ± 0.7	21.4

Values are expressed as means ± SD.

Table 12: Delta Efficiency with a Circular and Rotor Q-Ring

Week/	Power Output (Watts)				
Chainring	**210**	**240**	**270**	**300**	LSM
0/Circular	24.4 ± 1.6	26.5 ± 7.1	21.5 ± 2.2	19.2 ± 2.8	25.4
1/Rotor	25.7 ± 4.5	22.3 ± 1.8	22.5 ± 2.1	20.7 ± 3.9	26.0
2/Rotor	25.2 ± 4.4	22.2 ± 3.2	21.9 ± 2.3	20.1 ± 3.3	24.6
3/Rotor	27.1 ± 5.0	24.0 ± 2.9	21.0 ± 2.0	19.6 ± 4.3	29.3
4/Rotor	27.2 ± 3.5	24.1 ± 4.2	21.7 ± 2.3	19.3 ± 2.1	27.3
5/Circular	25.6 ± 3.2	23.5 ± 2.8	20.0 ± 1.0	18.3 ± 1.6	23.6

Values are expressed as means ± SD.

Maximum Oxygen Consumption

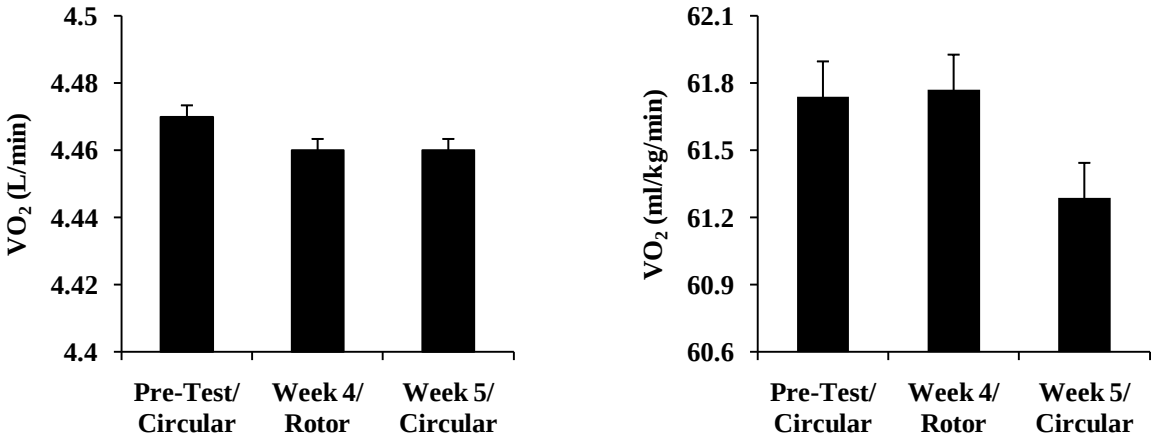
As seen in Figure 7 and Table 13, the type of chainring used during maximal testing failed to produce significant differences when comparing pre-testing to week 4 and week 5. There were no significant differences in either absolute ($p = 0.99$) or relative oxygen consumption ($p = 0.84$) between pre-testing with the circular chainrings, Rotor Q-Rings at the end of four weeks of training, and final testing with circular chainrings (i.e., week 5/Post-test).

Table 13: Absolute and relative VO_2 max values during maximal testing

Week/Chainring	VO_2 Max (L/min)	VO_2 Max (mL/kg/min)
Pre-Test/Circular	4.47 ± 0.41	61.74 ± 4.86
4/Rotor	4.46 ± 0.44	61.77 ± 4.55
5/Circular	4.46 ± 0.44	61.29 ± 4.49

Values expressed as mean ± SD.

Figure 7: Absolute and relative VO_2 max values with week/chainring type



Values expressed as mean ± SE. No significant differences were found between any of the week/chainring conditions ($p<0.05$).

1 Kilometer Time Trial Performance Results

Performance Time

Performance time in the 1km time trial was significantly lower in all trials with Rotor Q-Rings when compared to standard circular chainrings ($p<0.05$). The least square means of 1 k performance time after submaximal testing were significantly faster with the Rotor Q-Rings during week 1, week 2, and week 3 compared to the circular chainrings during week 0 ($p < 0.05$) (Table 14/Figure 8). This was the same for week 4 on Rotor Q-Rings compared to circular chainrings during week 5, with Rotor Q-Rings being significantly faster ($p < 0.05$) (Table 15/Figure 9).

Table 14: 1 k time trial performance after submaximal testing

Week/ Chainring	Time (s)	Avg Power (W)	Max Power (W)	Avg Speed (kph)	Max Speed (kph)	Lactate (mmol/L)
0/Circular	85.4 ± 3.0	421 ± 53	705 ± 89	42.3 ± 1.5	46.2 ± 2.5	9.4 ± 2.3
1/Rotor	83.9 ± 2.9 *	447 ± 54 †	732 ± 97	43.0 ± 1.5 †	47.6 ± 2.0	10.0 ± 1.9
2/Rotor	83.7 ± 3.1 *	449 ± 58 †	717 ± 115	43.1 ± 1.6 †	46.9 ± 2.4	10.4 ± 2.0
3/Rotor	83.9 ± 2.6 *	446 ± 53 †	740 ± 108	43.0 ± 1.5 †	46.9 ± 1.8	9.4 ± 2.3

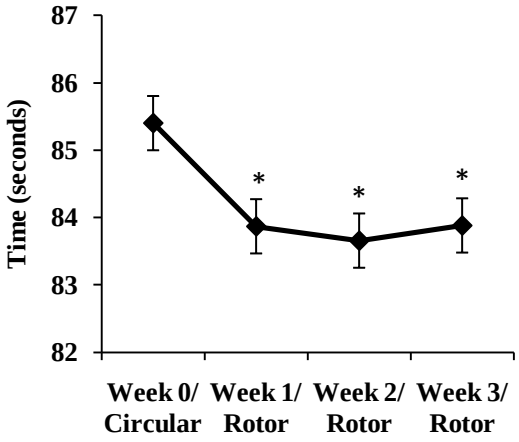
Values expressed as mean ± SD. *Significantly lower than circular chainring ($p<0.05$). † Significantly greater than circular chainring.

Table 15: 1 k time trial performance after maximal testing

Week/ Chainring	Time (s)	Avg Power (W)	Max Power (W)	Avg Speed (kph)	Max Speed (kph)	Lactate (mmol/L)
4/Rotor	84.2 ± 1.8 *	440 ± 32 †	739 ± 110	42.8 ± 0.9 †	46.9 ± 1.6	11.7 ± 2.3
5/Circular	85.5 ± 2.4	422 ± 39	733 ± 118	42.2 ± 1.1	46.2 ± 1.2	11.6 ± 2.0

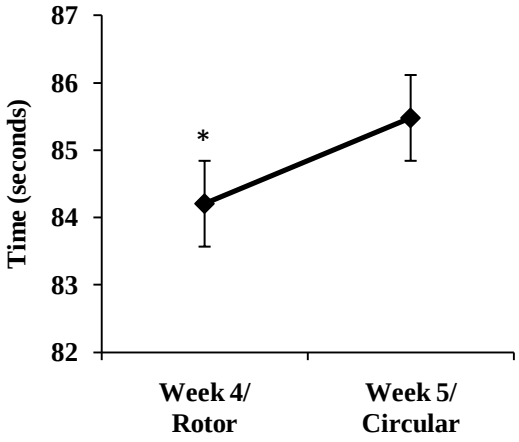
Values expressed as mean ± SD. *Significantly lower than circular chainring ($p<0.05$). † Significantly greater than circular chainring.

Figure 8: Average 1k time after submaximal testing



Values expressed as means ± SE. *Significantly lower than Circular Chainring ($p<0.05$).

Figure 9: Average 1k time after maximal testing



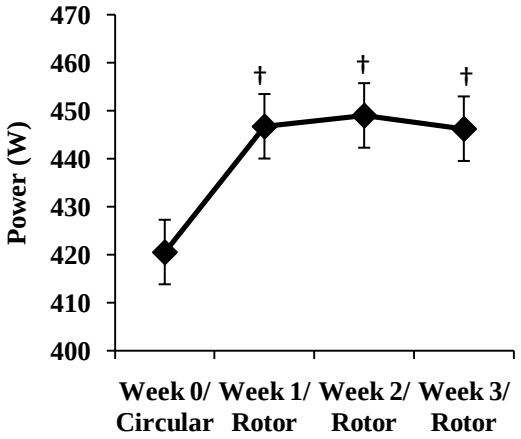
Values expressed as means ± SE. *Significantly lower than Circular Chainring ($p<0.05$).

Power and Speed

Average power (Watts) and average speed (kph) were significantly higher in all trials with the Rotor Q-Ring compared to circular chainring ($p < 0.05$). These results occurred in both conditions in which a 1km time trial was performed after the submaximal testing (Table 14; Figure 10 and 12) and after maximal testing (Table 15; Figure 11 and 13).

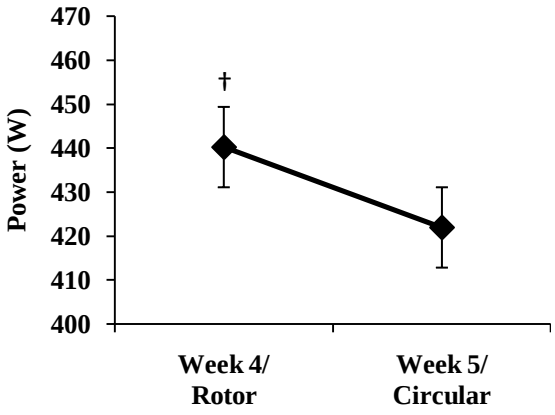
No main effect was observed for week/chainring type for maximum power after submaximal testing ($p = 0.37$) or after maximal testing ($p = 0.81$). There was also no main effect observed for week/chainring type for maximum speed after submaximal testing ($p = 0.07$) or after maximal testing ($p = 0.32$).

Figure 10: Average power after submaximal testing



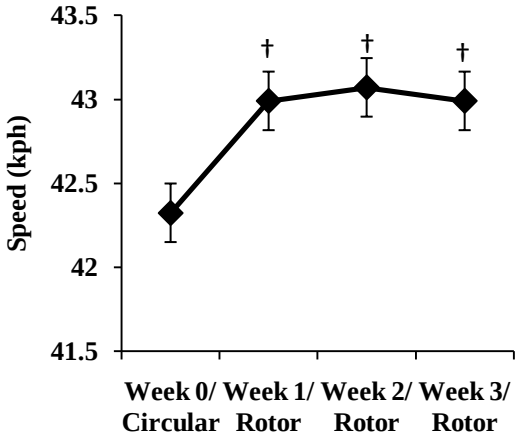
Values expressed as means ± SE. †Significantly greater than Circular Chainring ($p<0.05$).

Figure 11: Average power after maximal testing



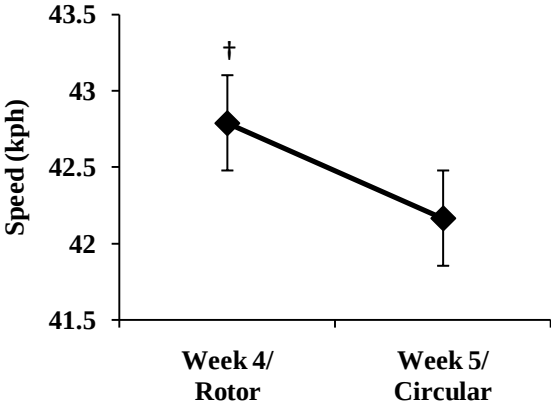
Values expressed as means ± SE. †Significantly greater than Circular Chainring ($p<0.05$).

Figure 12: Average speed after submaximal testing



Values expressed as means ± SE. †Significantly greater than Circular Chainring ($p<0.05$).

Figure 13: Average speed after maximal testing



Values expressed as means ± SE. †Significantly greater than Circular Chainring ($p<0.05$).

Blood Lactate Concentration

No main effect was observed for chainring type for blood lactate concentration after submaximal testing ($p = 0.10$) or after maximal testing ($p = 0.83$) measured three minutes after the 1k time trial.

Chapter 5: Discussion

Summary

The purpose of this study was to examine physiological and biomechanical effects of chainring type (circular vs. non-circular Rotor Q-Ring) on elite cyclists during submaximal graded exercise testing and performance in a 1 k time trial. Performance measures during the time trial (i.e., speed; power) were used to assess the efficacy of the Rotor Q-Rings compared to circular chainrings. In order to examine possible adaptation effects, physiological measures (i.e., oxygen consumption, heart rate, blood lactate, efficiency) collected during maximal and submaximal testing were also examined over the entire time span of the study. The main findings were: 1) Participants were on average 1.6 seconds faster in the 1 k time trial with Rotor Q-Rings compared to a circular chainrings. 2) There was a significant increase in average power (26.7 watts) and average speed (0.7 kph) during the 1 k time trial with Rotor Q-Rings. 3) Oxygen consumption (during weeks 2-4) and heart rate (weeks 1-3) were significantly lower with Rotor Q-Rings during submaximal testing when compared to circular chainrings. However, in contrast to our hypotheses no benefits were observed for other submaximal dependent measures (i.e., CO_2, VE, RER, RPE, GE, DE, and lactate). Making direct comparisons between these results on the Rotor Q-Rings with previous research is difficult, as the majority of previous research was performed with different shape chainrings or crank systems. However, the results of this current study are in line with similar systems as discussed in the physiological measures and performance results below.

Physiological measures

During week 0 through week 5, metabolic measures were recorded during graded submaximal test sessions and also during maximal test sessions for the Pre-test, week 4, and week 5 (Post-test). While all of the response variables displayed trends typically observed due to

increases in workload, there were two notable effects (oxygen consumption and heart rate) due to cycling with the Rotor Q-Ring.

Oxygen consumption and Heart Rate

First, as seen in Figure 4, during all submaximal testing, cycling with the Rotor Q-Ring resulted in lower absolute oxygen consumption for weeks 2, 3, and 4. Our results also indicated that oxygen consumption was not significantly different between the Pre-test and final testing on week 5 (Post-test), both occurring while cycling with circular chainrings. This Pre-test, Post-test comparison is notable since it demonstrated that subjects in this study were not realizing improvements simply through repeated exercise bouts over the course of five weeks, but instead clearly show that the Rotor Q-Ring was directly responsible for the observed changes.

These results are similar to those of Henderson et al. who found a significant decrease (2.4%) in VO_2 using elliptical chainrings at 900 kpm/min (11). Although not significant, this author also noted that VO_2 tended to be lower at all power outputs. In a similar fashion, Cullen et al. found that VO_2 was lower at 70 rpm with a Biopace chainring, but did not reach significance (5). Hue and his co-workers mentioned in one of their unpublished studies (15) that at a constant power output, oxygen consumption was lower in an eccentric crank system and Zamparo and his co-workers (46) found similar effects in their study. In contrast, other studies found no differences in oxygen consumption when comparing circular versus non-circular chainrings (5, 22, 27, 39). Rodriguez-Marroyo et al. (40) also found no significant difference in oxygen consumption with the Rotor crank system and circular chainring systems in submaximal aerobic tests. However, when comparing findings from the anaerobic test, mean power output increased with the altered crank system used in their study. Rodriguez-Marroyo and his co-workers also suggested that the subject must be adapted to the equipment in order to improve performance.

Our findings would partially support that ideal in that significantly lower absolute oxygen consumption was not evident until the second week of testing with the Rotor Q-Ring (i.e., week 2). Subjects in their study were tested only once in each condition and long term exposure to the non-circular chainring was not examined.

Secondly, in the current study, we observed a significantly lower heart rate during submaximal testing with the Rotor Q-Ring during weeks 1, 2, and 3 across all workstages (for comparison, approximately 2% lower). Martinez and his co-workers (26, 27) found that the use of Rotor Q-Rings led to a lower heart rate when compared to circular rings at the same workload (also about 2% lower). In an unpublished study, Conconi (3) found a similar relationship between heart rate and wattage with subjects able to produce greater work (approximately 7-9%) with an eccentric crank system, but at the same heart rate using a conventional crank system. However, in the study by Cullen et al. (4), there were no significant differences in heart rate, and similar results were also reported by Lucia et al. (21) in that the type of chainring had no influence on heart rate. The ability of an athlete to work at a lower heart rate at the same workload will enable the athlete to perform at a higher level before fatigue (6). The lower heart rate found in this study combined with lower oxygen consumption could potentially have a significant impact on cycling performance.

Ventilation, Carbon dioxide production, and Respiratory Exchange Ratio

There was no measureable significance found for ventilation, however on average VE was lower across workloads with Rotor Q-Rings as shown in Table 5. CO_2 production and RER also had no significant differences between Rotor Q-Rings and circular chainrings. This result is in line with Rodriguez-Marroyo who found no significant difference in the Rotor crank system and circular chainring systems in submaximal aerobic tests (40). Ratel and Martinez also found

no significant differences in RER or VE with the use of noncircular Harmonic chainrings and Rotor Q-Rings, respectively, when compared to circular chainrings (27, 39).

Blood Lactate Concentration and Rate of Perceived Exertion

Several studies have examined the effects of chainrings and eccentric crank systems on blood lactate, but the findings are inconsistent. Martinez et al. (27) found that cycling with Rotor Q-Rings led to a lower production of lactate at the same workload compared to circular chainrings, and when testing the Biopace chainring, Hansen et al. (10) found a significance difference in lactate (on average 0.2 mmol/L lower). In the previously mentioned study by Conconi (3), he found that after 12 incremental tests, the lactate concentration was always higher with a traditional crank system compared to the eccentric crank system. In comparison, Belen et al. (2), and Cullen et al. (4), found no significant differences in blood lactate between circular chainrings and eccentric crank systems. In the current study, we did not observe a significant main effect of week/chainring type on blood lactate. While a closer inspection of Table 8 indicated that blood lactate decreased while cycling with the Rotor Q-Ring at 270 and 300 watts, without a significant interaction, we urge caution when reading the findings even though the differences in lactate production appear to be ecologically meaningful.

Rate of perceived exertion (RPE) can have a large impact on an athlete's performance (6), and the use of a noncircular chainring such as a Rotor Q-Ring can in theory lower RPE (5). However, in our current study RPE only reached borderline significance during the graded exercise tests. Therefore, there seems to be no measureable impact on perceived exertion with our sample. RPE increased as expected due to increased workload.

Efficiency

Gross mechanical efficiency has been defined as ratio of work done to the total metabolic cost (5). This variable can provide insight into the effects due to different equipment used, in our case, between different types of chainrings. Delta efficiency can be defined as the change in power over the change in metabolic rate with increasing work rate (5). Examining delta efficiency can also be used to analyze changes as workloads increase, such as in this study. An increase in efficiency would lower the rate of oxygen uptake at any given power output or speed, and be advantageous for longer duration exercise/performance (10).

Since a decrease in VO_2 was found with Rotor Q-Rings in the current study, this improvement in theory should have contributed to an increase in efficiency. However, there are several factors that impact efficiency during cycling (i.e., duration, workload, pedaling rate), and the theoretical improved efficiency of the Rotor Q-Rings was most likely too small to reach a measureable significance to demonstrate improved efficiency with our lower oxygen consumption values.

Slight increases in cycling efficiency, up to 3%, were found when the Rotor crank system was compared to a traditional crank system (41, 45). Henderson et al. (11) also found that caloric outputs were 2.5% lower with a noncircular system at respective workloads versus a circular system. However, Jobson et al. (17) found no changes in gross efficiency after six weeks of training with a Rotor crank system, and neither did Lucia and his co-workers (21). In the current study, we did not observe a significant difference in gross efficiency or delta efficiency due to chainring type. While the various methods used to calculate efficiency from the observed metabolic and workload data are valid, they are not universally standard. Since we did not observe significant differences in ventilation, respiratory exchange ratio, and carbon dioxide

production, the failure to find any significance difference in efficiency is not surprising. While there were significant effects due to chainring type on oxygen consumption and heart rate in the current study, the testing protocol employed in the current study (i.e., graded submaximal exercise test) may not have been the most robust for revealing changes in efficiency. A thorough examination of these measures is beyond the scope of the current study, however, for an in depth discussion of efficiency measures during cycling, see Sidossis et al. (43).

1 k Time Trial

Results from the 1 k time trial indicated that cycling with the Rotor Q-Ring led to increased average speed (by 1.7 kph) and increased average power (by 26.7 watts) compared to cycling with circular chainrings, thereby improving performance time on average of 1.6 seconds. This is in line with studies by Hue et al. (14) that employed a 1 k all out performance test in a laboratory setting using an "eccentric" chainring. However, when performing the 1 k time trial on a 333m outdoor track, Hue and his co-workers found no differences in performance (12). Our findings are also in line with those of Martinez et al. in that a variable crank system (27) and Rotor Q-Ring (28) allowed cyclists to produce greater power. Rodriguez-Marroyo et al. found that use of the Rotor crank system with elite cyclists leads to increased power in maximal 30-s anaerobic sprints (38). Previous works that examined performance over longer distances failed to show significant improvements in performance while employing an elliptical chainring during a 10 k time trial (35), or an eccentric crank system in a 40.23 k time trial (17). It appears that shorter duration events that afford a higher effort can more readily take advantage of the mechanical alteration provided by the non-circular design of the chainring. That is, if the cyclist is able to exert greater amounts of force during cycling, there are greater benefits in performance that are not elicited in longer duration events in which the cyclist typically lowers the application

of force in order to complete the distance. Small power increases at submaximal workloads may actually become significant at higher workloads which may be a reason only small differences in VO_2 and HR were found in our results. Therefore, during a 1 k time trial or other event where power output is near maximal, the mechanical advantage provided by the Rotor Q-Rings provides significant performance benefits as shown in our results.

Conclusion

In this study, we employed a Pre-test, Intervention, Post-test approach to examine the efficacy of cycling with Rotor Q-Rings compared to traditional circular chainrings. Most of the previous works examining the effects of using an eccentric chainring (or eccentric crank system) on cycling performance did so with minimal exposure to the modified system (4, 10, 11, 12, 13, 14, 16, 21, 27, 38, 39, 41, 35, 45) with Jobson et al. (17) as the exception. In the current study, we were interested in uncovering any signs indicating that adaptations were necessary to exploit the claimed benefits of the Rotor Q-Ring and we specifically targeted the testing period to occur during the middle part of the competitive racing season to avoid any confounding effects of increased cardiovascular efficiency that would most likely be evident during pre-season training. Rotor Q-Rings are designed to provide a mechanical advantage and it is possible that without sufficient habituation cyclists are unable to benefit as they are forced to carry out a movement pattern that would necessarily recruit the active musculature in an unfamiliar way (33). For this reason, participants taking part in this study trained solely with the Rotor Q-Rings for four weeks during the testing period.

Evidence from this study indicated that for these well trained cyclists and triathletes, performance improved after just one week employing the Rotor Q-Rings. The maximal oxygen consumption results from the Pre-test, week 4, and week 5 Post-test further demonstrate that positive performance effects were only evident with the Rotor Q-Rings and did not transfer to

circular rings after four weeks of exposure. While it appears from this study that there may also be positive long term effects as noted by the significant reduction in submaximal oxygen consumption and heart rate during the intervention period (i.e., cycling with Rotor Q-Rings), the majority of the physiological measures we examined do not equivocally support the notion that an adaptation period is necessary for this increased 1 k time trial performance.

In the current study, we also compared the effects cycling with Rotor Q-Rings on 1 k time trial performance over four weeks and found that the effect was essentially the same over four weeks in which the Rotor Q-Ring was employed. Consequently, when subjects discontinued using the Rotor Q-Rings and were tested on circular rings at the conclusion of the study (i.e., week 5) performance measures returned to week 0 values with circular rings.

The 1 k performance tests and metabolic data collected during the submaximal and maximal testing also suggest that the central nervous system was not confronted with a task that is markedly different than pedaling with circular chainrings. That is, the Rotor Q-Rings did not cause an initial increase in oxygen consumption or heart rate indicating a disruption to the coordinative structure used to apply force to the pedals. Conversely, it appears that the well established coordination pattern used in conventional cycling is well suited to take advantage of this alteration to the bicycle drive train.

We did not collect respiratory gases during the 1 k time trial and therefore, cannot thoroughly evaluate the metabolic consequences during this maximal effort test. However, Hue et al. (14) did analyze respiratory gases during the same test employed in the current study (i.e., 1 k time trial in a laboratory setting) and found no significant differences in metabolic measurements. As seen in Table 14 and 15 in the current study, there was an increase in blood lactate concentration after completion of the time trial during with the Rotor Q-Ring, however

significance was not reached. Our subjects also repeated this test after maximal testing on weeks 4 and 5. As expected, blood lactate concentrations in this condition were greater compared to samples taken after submaximal testing, but the type of chainring failed to produce a significant difference (see Table 14 and 15).

The most important findings from our current study show that there is a significant improvement in 1 k performance time (average of 1.6 seconds faster) as well as an increase in average power (26.7 watts) and average speed (0.7 kph) with the Rotor Q-Rings when compared with the circular chainrings. The significance of these findings can be emphasized when observing performance times from the 2011 UCI Track World Cycling Championships in which the difference between first and second in the Men's 1 k time trial was only a slender 0.386 seconds (6). This shows that very small gains in time, speed and power through the use of a Rotor Q-Ring can mean the difference between a silver and gold medal. Oxygen consumption (during weeks 2-4) and heart rate (weeks 1-3) were significantly lower with Rotor Q-Rings during submaximal testing when compared to circular chainrings.

In conclusion, our findings indicate that Rotor Q-Rings provide an ergogenic effect that is apparent after only one week of exposure. Our performance test was limited to a 1 k time trial, but the Rotor Q-Ring could also prove beneficial in criterium style racing events and at the end of a long road race in which bicycle racers often perform at similar intensities for a similar amount of time. Furthermore, when considering the reduction in oxygen consumption and heart rate observed during submaximal testing, it also seems tenable that a greater energy savings could be realized for endurance type cycling.

Recommendations

Rotor Q-Rings are a variable gear chainring that has five different orientation settings. Our current study used setting three, which is the recommended starting position, for all the

participants. Future research should look at the optimal chainring position for each participant and its potential benefits. As previously noted, due to activation-deactivation dynamics, there is a trade-off between maximizing the time in the power phase (downstroke) and minimizing the negative work that results while the muscles are deactivating during the upstroke (33). Neptune has stated that the optimal chainring shape for an individual cyclist most likely varies depending on a rider's fiber type distribution (i.e., activation-deactivation dynamics). For example, an endurance cyclist may have predominately slow-twitch fibers with slower deactivation dynamics and a decreased average power output. This would result in increased negative work with a more eccentric noncircular chainring shape. Conversely, a cyclist with predominantly fast-twitch fibers (fast deactivation dynamics) would benefit from the more noncircular chainring shape without increased negative work and an increase in average power due to the reduction of negative work. This theory of increasing power output by prolonging the positive work phase is consistent with work-loop studies using animal models showing considerable increases in power output during cyclical tasks by extending the positive work phase (1). Therefore, further research with different orientation settings on the Rotor Q-Rings could show even greater performance depending on the athlete's fiber type.

In addition to different fiber type, rider experience could also play a factor in the performance benefit to Rotor Q-Rings. Further research should look at non-cyclists or beginner athletes to see if there may be a measurable difference in efficiency. Perhaps the differences were too small in this study with competitive cyclists to reach significance. It is also of interest to see if beginner athletes take longer to adapt to an eccentric chainring design with similar performance benefits. In a similar manner, looking at highly elite or professional cyclists may present different results. Our participants were both competitive cyclists and triathletes that

individually kept their workouts similar throughout the testing period, however their training distances within the eight subjects varied. Having highly trained participants that are riding longer distances everyday may have led to a better sample size with different results.

Finally, some studies have suggested that performing testing in the laboratory compared to in the field (i.e., 1 k on the velodrome or open road) could potentially affect results because of the different setting (13). Outdoor testing with skilled track cyclists could possibly elucidate this discrepancy in performance results, however indoor testing in a controlled setting in still highly preferable in cycling research since multiple confounding factors can be controlled (e.g., temperature, humidity, wind) especially across multiple testing dates spanning seven weeks during our testing. Future research in outdoor settings with various distances (i.e., time trials) would be the next step in determining the ecological validity of this modification to the bicycle drivetrain.

References

1. Askew GN, Marsh RL. Optimal relative shortening velocity (V/Vmax) of skeletal muscle during cyclical contractions: length-force effects and velocity dependent activation and deactivation. *Journal of Experimental Biology* 201: 1527-1540, 1998.

2. Barani D, Commandre F, Digoin A. The "Harmonic" chainring: presentation and biomechanical characteristics. *Med Sport* 68: 77–81, 1994.

3. Belen L, Habrard M, Micallef JP, Perrey S, Gallais D. Cycling performance and mechanical variables using a new prototype chainring. *Eur J Appl Physiol* 101: 721-726, 2007.

4. Conconi IE. Unpublished study. University of Ferrara.1998.

5. Cullen LK, Andrew K, Lair M, Widger MJ, Timson BF. Efficiency of trained cyclists using circular and noncircular chainrings. *Int J Sports Med* 13: 264–269, 1992.

6. Ettema G, Loras HW. Efficiency in cycling: a review. *Eur J Appl Physiol* 106: 1-14, 2009.

7. Faria EW, Parker DL, Faria IE. The science of cycling: physiology and training-part 1. *Sports Medicine* 35: 285–312, 2005.

8. Faria EW, Parker DL, Faria IE. The science of cycling: factors affecting performance-part 2. *Sports Medicine* 35: 313–337, 2005.

9. Hailes W. Effects of the rotor crank on a 16.1 kilometer time trial performance. Unpublished, 2005.

10. Hansen EA, Jensen K, Hallén J, Rasmussen J, Pedersen PK. Effect of chain wheel shape on crank torque, freely chosen pedal rate, and physiological responses during submaximal cycling. *Journal of physiological anthropology* 28: 261–267, 2009.

11. Henderson SC, Ellis RW, Klimovitch G, Brooks GA. The effects of circular and elliptical chainwheels on steady-rate cycle ergometer work efficiency. *Med Sci Sports Exerc* 9: 202–207, 1977.

12. Horvais N, Samozino P, Zameziati K, Hautier C, Hintzy F. Effects of a non circular chainring on muscular, mechanical and physiological parameters during cycle ergometer tests. *Isokinetics and Exercise Science* 15: 271–279, 2007.

13. Hue O, Chamari K, Damiani M, Blonc S, Hertogh C. The use of an eccentric chainring during an outdoor 1 km all-out cycling test. *Journal of Science and Medicine in Sport* 10: 180-186, 2007.

14. Hue O, Racinais S, Chamari K, Damiani M, Herogh C, Blonc S. Does an eccentric chainring improve conventional parameters of neuromuscular power? *Journal of Science and Medicine in Sport* 11: 264-270, 2008.

15. Hue O, Galy O, Hertogh C, Casties J, Prefaut C. Enhancing cycling performance using an eccentric chainring. *Medicine & Science in Sports & Exercise* 33: 1006-1010, 2001.

16. Hug F, Bendahan D, Le Fur Y, Cozzone PJ, Grelot L. Heterogeneity of muscle recruitment pattern during pedaling in professional road cyclists: a magnetic resonance imaging and electromyography study. *Eur. J. Appl. Physiol*. 92: 334-342, 2004.

17. Hull ML, Williams M, Williams K, Kautz S. Physiological response to cycling with both circular and noncircular chainrings. *Med Sci Sports Exerc* 24: 1114–1122, 1992.

18. Jobson SA, Hopker J, Galbraith A, Coleman DA, Nevill AM. Effect of the Rotor crank system on cycling performance. *Journal of Sports Science and Medicine* 8: 463–467, 2009.

19. Jones AD. Physiological response to incremental stationary cycling using conventional, circular and variable-geared, elliptical Q-chain rings. Unpublished, 2008.

20. Josephson RK. Dissecting muscle power output. *Journal of Experimental Biology* 202, 3369–3375, 1999.

21. Kautz SA, Hull ML. Dynamic optimization analysis for equipment setup problems in endurance cycling. *Journal of biomechanics* 28: 1391–1401, 1995.

22. Lucia A, Balmer J, Davison RCR, Perez M, Santalla A, Smith PM. Effects of the rotor pedalling system on the performance of trained cyclists during incremental and constant-load cycle-ergometer tests. *Int J Sports Med* 25: 479-485, 2004.

23. Malfait L, Storme G, Derdeyn M. Comparative biomechanical study of circular and non-circular chainrings for endurance cycling at constant speed. Release 2: 2006.

24. Martin JC. Muscle power: the interaction of cycle frequency and shortening velocity. *Exercise and sport sciences reviews* 35: 74-81, 2007.

25. Martin JC, Spirduso WW. Determinants of maximal cycling power: crank length, pedaling rate and pedal speed. *European Journal of Applied Physiology* 84: 413-418, 2001.

26. Martin JC, Lamb SM, Brown NAT. Pedal trajectory alters maximal single-leg cycling power. *Med Sci Sports Exerc* 34(8): 1332-1343, 2002.

27. Martínez AC. Study about the metabolic efficiency of the rotor system compared with a conventional bicycle. University of Vallodolid, Spain, Unpublished, 2006.

28. Martinez D, Vicente D, Calvo D, Zudaire I. Preliminary report on q-rings. University of Vallodolid, Spain, Unpublished, 2006.

29. Martinez D, Vicente D, Calvo D, Zudaire I. Summary report on q-rings. Vallodolid, Spain, Unpublished, 2006.

30. Moffit JK, Castro M. The effect of q-rings on cycling economy. *Medicine & Science in Sports & Exercise* 40(8): 215-225, 2008.

31. McDaniel J, Durstine JL, Hand GA, Martin JC. Determinants of metabolic cost during submaximal cycling. *Journal of Applied Physiology* 93: 823-828, 2002.

32. Neptune RR, Herzog W. Adaptation of muscle coordination to altered task mechanics during steady-state cycling. *Journal of biomechanics* 33: 165–172, 2000.

33. Neptune RR, Kautz SA. Muscle activation and deactivation dynamics: the governing properties in fast cyclical human movement performance. *Exercise and Sport Sciences Reviews* 29: 76-81, 2001.

34. Neptune RR, McGowan CP, Fiandt JM. The influence of muscle physiology and advanced technology on sports performance. *Annu. Rev. Biomed. Eng* 11: 81-107, 2009.

35. Peiffer JJ, Abbiss CR. The influence of elliptical chainrings on 10 km cycling time trial performance. *Int Journal of Sports Physiology and Performance*, 5: 459-468, 2010.

36. Powers S, Howley E. Exercise Physiology: Theory and application to fitness and performance (7th Edition), 2008.

37. RacerMate, Inc. Bicycling training technology for world class performance. Computrainer Stand Alone User Guide. 2009.

38. Rankin JW, Neptune RR. A theoretical analysis of an optimal chainring shape to maximize crank power during isokinetic pedaling. *Journal of biomechanics* 41: 1494–1502, 2008.

39. Ratel S, Duche P, Hautier CA, Williams CA, Bedu M. Physiological responses during cycling with noncircular "Harmonic" and circular chainrings. *European Journal of Applied Physiology* 91: 100-104, 2004.

40. Rodriguez-Marroyo JA. The rotor pedaling system improves anaerobic but not aerobic cycling performance in professional cyclists. *Eur J Appl Physiol* 106:87–94, 2009.

41. ROTOR Bicycle Components USA. www.rotorbikeusa.com. 2010.

42. Santalla A, Manzano JM, Perez M, Lucia A. A new pedaling design: the Rotor-effects on cycling performance. *Medicine & Science in Sports & Exercise* 34: 1854, 2002.

43. Sidossis LS, Horowitz JF, Coyle EF. Load and Velocity of Contraction Influence Gross and Delta Mechanical Efficiency. *Int J Sports Med*, 13: 407-411, 1992.

44. Tricás-Moreno JM, Cozar-Bartos JM. Rotor, generator of health: analysis of the effects of the rotor propulsion system upon the knee joint. University of Zaragoza, N.D.

45. Vergara PC. United States Patent. http://www.patentgenius.com/patent/7749117.html, 2010.

46. Zamparo P, Minetti AE, di Prampero PE. Mechanical efficiency of cycling with a new developed pedal-crank. *Journal of biomechanics* 35: 1387–1398, 2002.

Appendices

APPENDIX A.

Pilot Data Statistical Analysis

Minitab 16 statistical software (Minitab Inc., State College, PA) was used for statistical analysis of the pilot data and to calculate sample size. 1 k performance time and blood lactate concentration were the two dependent measures chosen for analysis based on their importance. A General Linear Model ANOVA was used to determine time versus participant and chainring, as well as blood lactate versus participant, chainring, and power and their interactions. Due to the nature of the design, each participant underwent each condition of different chainrings with both tests allowing comparisons to be done 'within subject'. Because each participant performed the lactate threshold test and 1 k time trial with each chainring, the effect of the chainring interaction was evaluated 'within subject' and a Tukey's post hoc analysis was administered with 95% confidence.

Sample Size Calculation

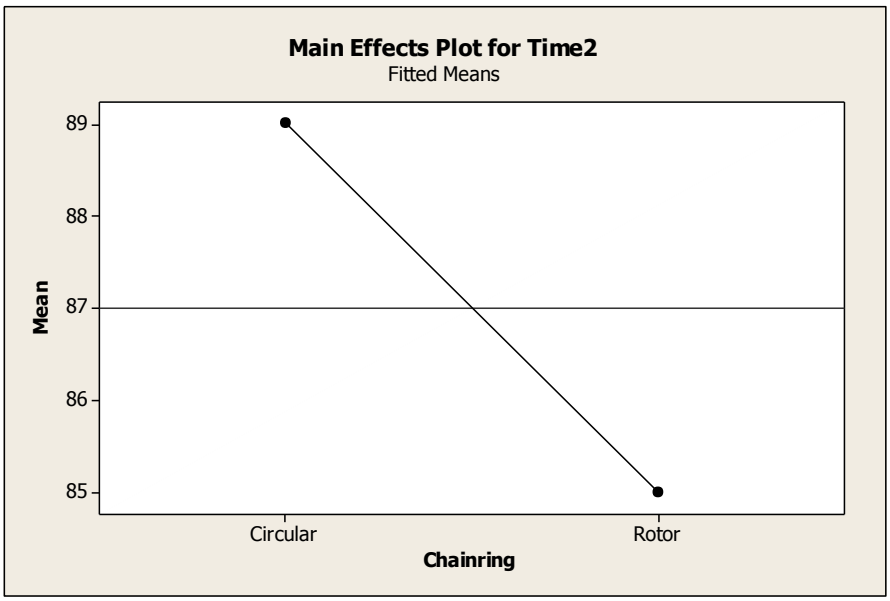
One kilometer performance time and blood lactate concentration from the pilot data was used to calculate the sample size for this study. Using a general linear model, a mean difference of four seconds was found during pilot testing in the 1 k time trial with a standard deviation of 0.71 seconds and power of .99. Using eight participants, performance time computations were carried out using a standard deviation of 0.71 seconds to detect a difference of .95 seconds with $\alpha = 0.05$ with power of 0.9 (refer to data set 1). Blood lactate computations were carried out using a standard deviation of 0.61 mmol/L to detect a difference of .82 mmol/L with $\alpha = 0.05$ with power of 0.9, using a sample size of eight participants (refer to data set 2). Therefore, using 8 participants was deemed to be significant for data collection.

Data Set 1:

General Linear Model: Time versus Subject, Chainring

```
Factor     Type    Levels  Values
Subject    random       3  1, 2, 3
Chainring  fixed        2  Circular, Rotor

Analysis of Variance for Time, using Adjusted SS for Tests

Source     DF   Seq SS   Adj SS  Adj MS       F      P
Subject     2  109.000  109.000  54.500  109.00  0.009
Chainring   1   24.000   24.000  24.000   48.00  0.020
Error       2    1.000    1.000   0.500
Total       5  134.000

S = 0.707107   R-Sq = 99.25%   R-Sq(adj) = 98.13%

Expected Mean Squares, using Adjusted SS

              Expected Mean Square
   Source     for Each Term
1  Subject    (3) + 2.0000 (1)
2  Chainring  (3) + Q[2]
3  Error      (3)

Error Terms for Tests, using Adjusted SS
                                 Synthesis
   Source     Error DF  Error MS  of Error MS
1  Subject        2.00     0.500  (3)
2  Chainring      2.00     0.500  (3)


Variance Components, using Adjusted SS
         Estimated
Source       Value
Subject    27.0000
Error       0.5000


Least Squares Means for Time
Chainring   Mean
Circular   89.00
Rotor      85.00


Grouping Information Using Tukey Method and 95.0% Confidence
Chainring  N  Mean  Grouping
Circular   3  89.0  A
Rotor      3  85.0    B

Means that do not share a letter are significantly different.
```

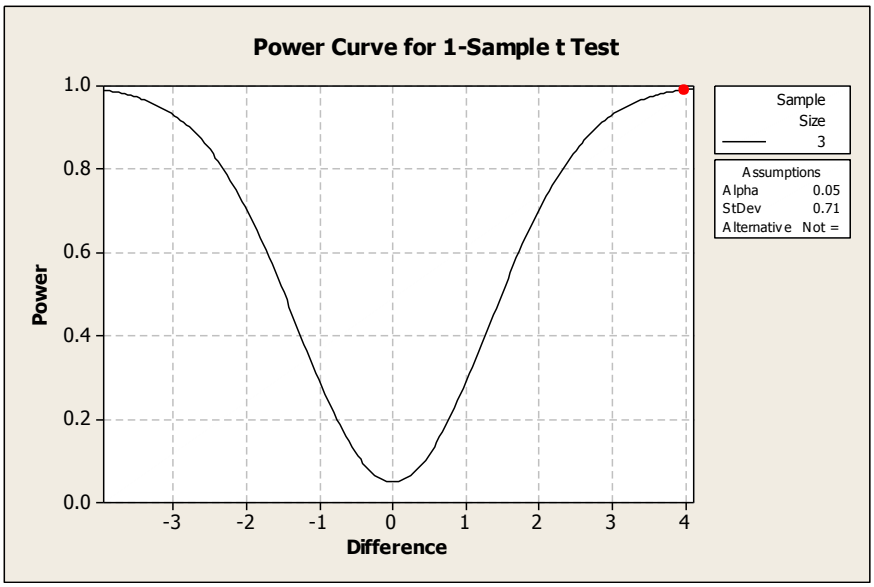
Main Effects Plot for Time



Power and Sample Size

```
1-Sample t Test

Testing mean = null (versus not = null)
Calculating power for mean = null + difference
Alpha = 0.05  Assumed standard deviation = 0.71


            Sample  Target
Difference    Size   Power  Actual Power
```

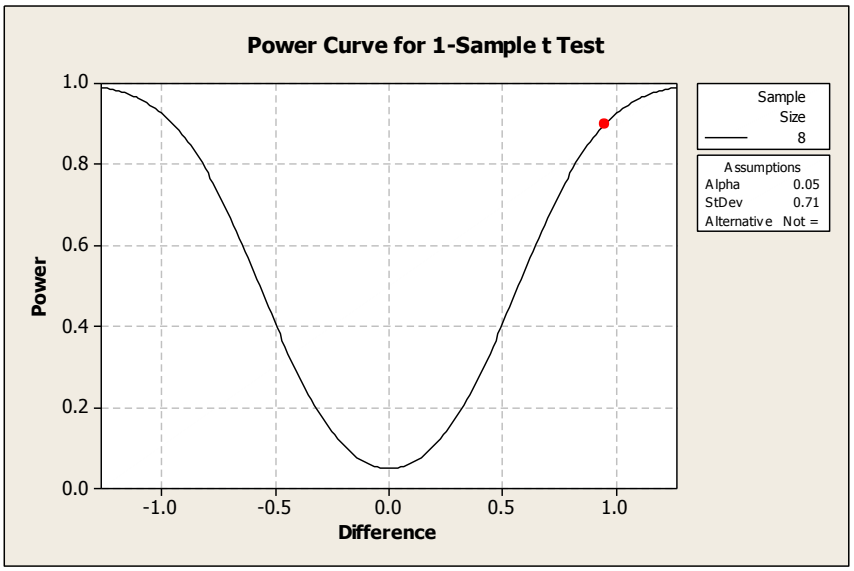
Power Curve for 1-Sample t Test



Power and Sample Size

```
1-Sample t Test

Testing mean = null (versus not = null)
Calculating power for mean = null + difference
Alpha = 0.05  Assumed standard deviation = 0.71

Sample
  Size  Power  Difference
     8    0.9    0.952680
```

Power Curve for 1-Sample t Test



Data Set 2:
General Linear Model: Lactate versus Subject, Chainring, Power

```
Factor     Type    Levels  Values
Subject    random       3  1, 2, 3
Chainring  fixed        2  circular, noncircular
Power      fixed        5  150, 180, 210, 240, 270

Analysis of Variance for Lactate, using Adjusted SS for Tests
Source              DF   Seq SS   Adj SS  Adj MS      F      P
Subject              2   5.7307   5.7307  2.8653   7.76  0.114
Chainring            1   1.5413   1.5413  1.5413   4.17  0.178
Subject*Chainring    2   0.7387   0.7387  0.3693   1.28  0.306
Power                4  21.7687  21.7687  5.4422  18.83  0.000
Chainring*Power      4   0.3153   0.3153  0.0788   0.27  0.891
Error               16   4.6240   4.6240  0.2890
Total               29  34.7187


S = 0.537587   R-Sq = 86.68%   R-Sq(adj) = 75.86%
```

Unusual Observations for Lactate

Obs	Lactate	Fit	SE Fit	Residual	St Resid
5	4.90000	4.04667	0.36724	0.85333	2.17 R
25	2.40000	3.22667	0.36724	-0.82667	-2.11 R

R denotes an observation with a large standardized residual.

Expected Mean Squares, using Adjusted SS

	Source	Expected Mean Square for Each Term
1	Subject	(6) + 5.0000 (3) + 10.0000 (1)
2	Chainring	(6) + 5.0000 (3) + Q[2, 5]
3	Subject*Chainring	(6) + 5.0000 (3)
4	Power	(6) + Q[4, 5]
5	Chainring*Power	(6) + Q[5]
6	Error	(6)

Error Terms for Tests, using Adjusted SS

	Source	Error DF	Error MS	Synthesis of Error MS
1	Subject	2.00	0.3693	(3)
2	Chainring	2.00	0.3693	(3)
3	Subject*Chainring	16.00	0.2890	(6)
4	Power	16.00	0.2890	(6)
5	Chainring*Power	16.00	0.2890	(6)

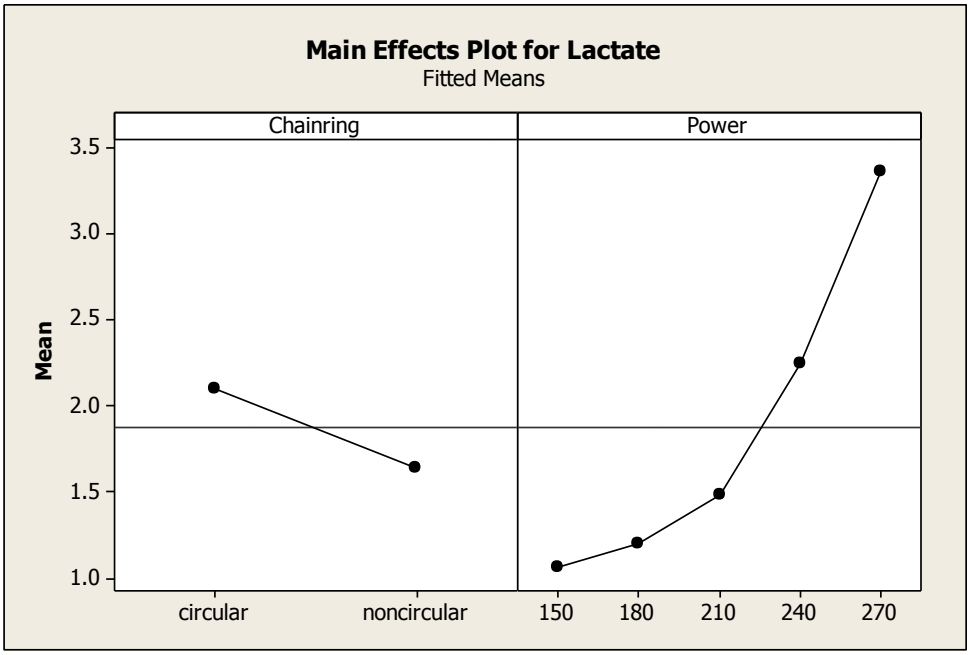
Variance Components, using Adjusted SS

Source	Estimated Value
Subject	0.24960
Subject*Chainring	0.01607
Error	0.28900

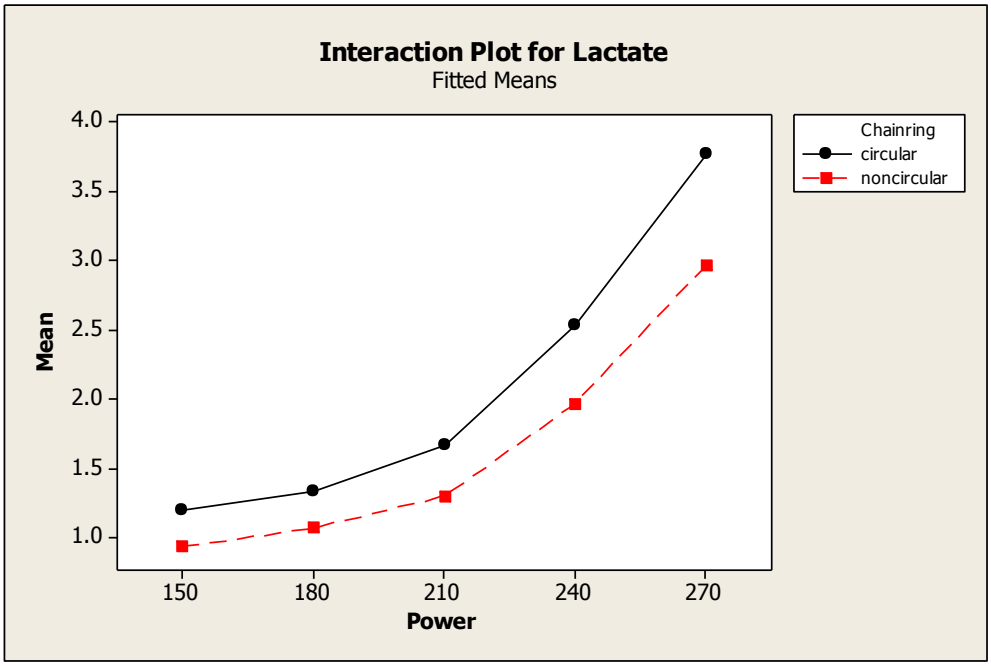
Least Squares Means for Lactate

Chainring		Mean
circular		2.1000
noncircular		1.6467
Power		
150		1.0667
180		1.2000
210		1.4833
240		2.2500
270		3.3667
Chainring*Power		
circular	150	1.2000
circular	180	1.3333
circular	210	1.6667
circular	240	2.5333
circular	270	3.7667
noncircular	150	0.9333
noncircular	180	1.0667
noncircular	210	1.3000
noncircular	240	1.9667
noncircular	270	2.9667

Main Effects Plot for Lactate



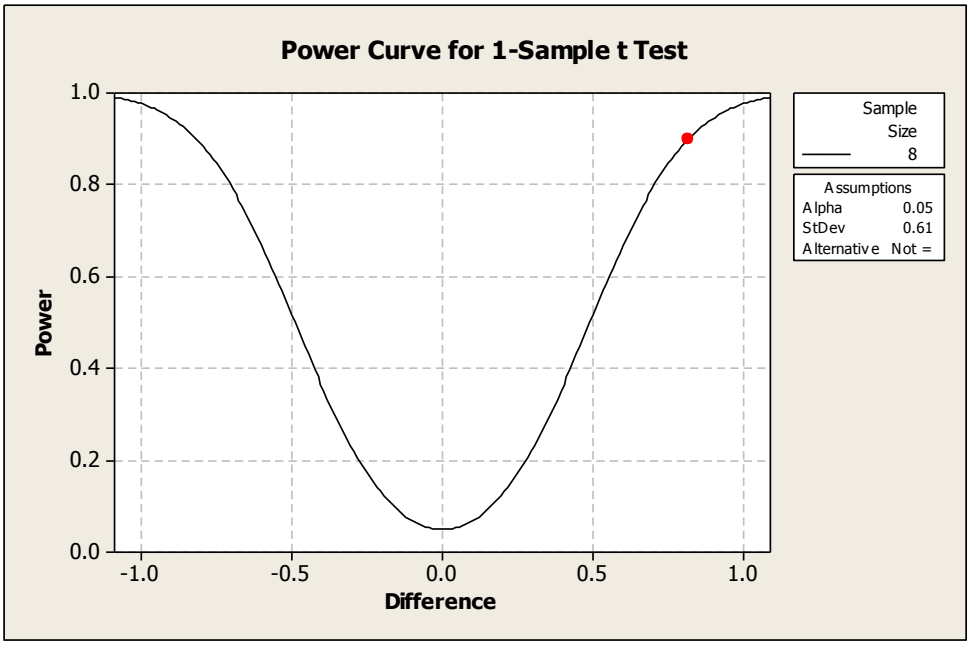
Interaction Plot for Lactate



Power and Sample Size

```
1-Sample t Test

Testing mean = null (versus not = null)
Calculating power for mean = null + difference
Alpha = 0.05  Assumed standard deviation = 0.61


Sample
  Size  Power  Difference
     8    0.9    0.818499
```

Power Curve for 1-Sample t Test



APPENDIX B. Complete Statistical Analysis

Submaximal Graded Exercise Testing Comparisons

Absolute Volume of Oxygen Consumption

VO2 L/min Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	239	5.41	<.0001
Power	5	239	2229.19	<.0001
Chainring*Power	25	239	0.34	0.9989

VO2 L/min Least Squares Means					
Effect	**Chainring**	**Estimate**	**DF**	**t Value**	**Pr > |t|**
Chainring	Week0Circular	3.0829	9.4	91.34	<.0001
Chainring	Week1ROTOR	3.0418	9.4	90.12	<.0001
Chainring	Week2ROTOR	2.9884	9.4	88.54	<.0001
Chainring	Week3ROTOR	3.0153	9.4	89.34	<.0001
Chainring	Week4ROTOR	3.0319	9.4	89.83	<.0001
Chainring	Week5Circular	3.0471	9.4	90.28	<.0001

VO2 L/min Differences of Least Squares Means								
Effect	**Chainring**	**Chainring**	**Estimate**	**DF**	**t Value**	**Pr > t**	**Adjustment**	**Adj P**
Chainring	Week0Circular	Week1ROTOR	0.04106	239	2.13	0.0173	Dunnett-Hsu	0.0655
Chainring	Week0Circular	Week2ROTOR	0.09444	239	4.89	<.0001	Dunnett-Hsu	<.0001
Chainring	Week0Circular	Week3ROTOR	0.06754	239	3.50	0.0003	Dunnett-Hsu	0.0013
Chainring	Week0Circular	Week4ROTOR	0.05095	239	2.64	0.0044	Dunnett-Hsu	0.0187
Chainring	Week0Circular	Week5Circular	0.03582	239	1.86	0.0324	Dunnett-Hsu	0.1145

Relative Volume of Oxygen Consumption

VO2 ml/kg/min Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	239	3.22	0.0078
Power	5	239	1427.26	<.0001
Chainring*Power	25	239	0.16	1.0000

VO2 ml/kg/min Least Squares Means						
Effect	**Chainring**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Chainring	Week0Circular	42.7807	1.6902	7.23	25.31	<.0001
Chainring	Week1ROTOR	42.2205	1.6902	7.23	24.98	<.0001
Chainring	Week2ROTOR	41.4929	1.6902	7.23	24.55	<.0001
Chainring	Week3ROTOR	42.3337	1.6902	7.23	25.05	<.0001
Chainring	Week4ROTOR	42.1728	1.6902	7.23	24.95	<.0001
Chainring	Week5Circular	42.0069	1.6902	7.23	24.85	<.0001

VO2 ml/kg/min Differences of Least Squares Means								
Effect	**Chainring**	**Chainring**	**Estimate**	**DF**	**t Value**	**Pr > t**	**Adjustment**	**Adj P**
Chainring	Week0Circular	Week1ROTOR	0.5602	239	1.69	0.0464	Dunnett-Hsu	0.1558
Chainring	Week0Circular	Week2ROTOR	1.2878	239	3.88	<.0001	Dunnett-Hsu	0.0003
Chainring	Week0Circular	Week3ROTOR	0.4470	239	1.35	0.0897	Dunnett-Hsu	0.2679
Chainring	Week0Circular	Week4ROTOR	0.6080	239	1.83	0.0342	Dunnett-Hsu	0.1198
Chainring	Week0Circular	Week5Circular	0.7738	239	2.33	0.0103	Dunnett-Hsu	0.0410

Heart Rate

HR Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	239	8.67	<.0001
Power	5	239	988.78	<.0001
Chainring*Power	25	239	0.14	1.0000

HR Least Squares Means					
Effect	**Chainring**	**Estimate**	**DF**	**t Value**	**Pr > |t|**
Chainring	Week0Circular	153.39	7.55	56.95	<.0001
Chainring	Week1ROTOR	152.01	7.55	56.43	<.0001
Chainring	Week2ROTOR	150.82	7.55	55.99	<.0001
Chainring	Week3ROTOR	151.57	7.55	56.27	<.0001
Chainring	Week4ROTOR	154.08	7.55	57.20	<.0001
Chainring	Week5Circular	155.22	7.55	57.62	<.0001

HR Differences of Least Squares Means								
Effect	**Chainring**	**Chainring**	**Estimate**	**DF**	**t Value**	**Pr > t**	**Adjustment**	**Adj P**
Chainring	Week0Circular	Week1ROTOR	1.3822	239	1.73	0.0428	Dunnett-Hsu	0.1454
Chainring	Week0Circular	Week2ROTOR	2.5685	239	3.21	0.0008	Dunnett-Hsu	0.0035
Chainring	Week0Circular	Week3ROTOR	1.8190	239	2.27	0.0120	Dunnett-Hsu	0.0471
Chainring	Week0Circular	Week4ROTOR	-0.6917	239	-0.86	0.8058	Dunnett-Hsu	0.9774
Chainring	Week0Circular	Week5Circular	-1.8308	239	-2.29	0.9885	Dunnett-Hsu	0.9999

Volume of Carbon Dioxide Production

VCO2 Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	239	1.45	0.2059
Power	5	239	1666.93	<.0001
Chainring*Power	25	239	0.34	0.9989

Ventilation

VE Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	239	0.42	0.8327
Power	5	239	668.65	<.0001
Chainring*Power	25	239	0.35	0.9986

Respiratory Exchange Ratio

RER Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	239	5.16	0.0002
Power	5	239	183.52	<.0001
Chainring*Power	25	239	0.19	1.0000

Gross Efficiency

GE Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	239	3.66	0.0033
Power	5	239	43.80	<.0001
Chainring*Power	25	239	0.32	0.9994

Delta Efficiency

DE Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	197	0.83	0.5325
Power	4	198	15.30	<.0001
Chainring*Power	20	197	0.63	0.8911

Blood Lactate Concentration

Lactate Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	233	0.39	0.8587
Power	5	233	190.35	<.0001
Chainring*Power	25	233	0.36	0.9982

Rate of Perceived Exertion

RPE Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	5	239	2.21	0.0540
Power	5	239	628.20	<.0001
Chainring*Power	25	239	0.43	0.9929

1 k Time Trial Comparisons

Performance Time after submaximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	3	21	6.47	0.0028

Performance Time Least Squares Means						
Effect	**Chainring**	**Estimate**	**Standard Error**	**DF**	**t Value**	**Pr > |t|**
Chainring	CIRCULAR	85.3987	1.0199	8.12	83.73	<.0001
Chainring	ROTORweek1	83.8675	1.0199	8.12	82.23	<.0001
Chainring	ROTORweek2	83.6550	1.0199	8.12	82.02	<.0001
Chainring	ROTORweek3	83.8800	1.0199	8.12	82.24	<.0001

Performance Time Differences of Least Squares Means								
Effect	**Chainring**	**Chainring**	**Estimate**	**DF**	**t Value**	**Pr > t**	**Adjustment**	**Adj P**
Chainring	CIRCULAR	ROTORweek1	1.5312	21	3.42	0.0013	Dunnett-Hsu	0.0035
Chainring	CIRCULAR	ROTORweek2	1.7438	21	3.89	0.0004	Dunnett-Hsu	0.0012
Chainring	CIRCULAR	ROTORweek3	1.5188	21	3.39	0.0014	Dunnett-Hsu	0.0038

Obs	**Effect**	**Chainring**	**_Chainring**	**Estimate**	**DF**	**tValue**	**Probt**
1	Chainring	CIRCULAR	ROTORweek1	1.5312	21	3.42	0.0026
2	Chainring	CIRCULAR	ROTORweek2	1.7438	21	3.89	0.0008
3	Chainring	CIRCULAR	ROTORweek3	1.5188	21	3.39	0.0028
4	Chainring	ROTORweek1	ROTORweek2	0.2125	21	0.47	0.6401
5	Chainring	ROTORweek1	ROTORweek3	-0.01250	21	-0.03	0.9780
6	Chainring	ROTORweek2	ROTORweek3	-0.2250	21	-0.50	0.6206

Performance Time after maximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	1	7	5.64	0.0493

Least Squares Means					
Effect	**Chainring**	**Estimate**	**DF**	**t Value**	**Pr > |t|**
Chainring	CircularWeek5	85.4763	9.07	115.37	<.0001
Chainring	ROTORweek4	84.2025	9.07	113.65	<.0001

Obs	**Effect**	**Chainring**	**_Chainring**	**Estimate**	**DF**	**tValue**	**Probt**
1	Chainring	CircularWeek5	ROTORweek4	1.2737	7	2.37	0.0493

Average Power after submaximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	3	21	7.06	0.0018

Obs	Effect	Chainring	_Chainring	Estimate	DF	tValue	Probt
1	Chainring	CIRCULAR	ROTORweek1	-26.1875	21	-3.66	0.0015
2	Chainring	CIRCULAR	ROTORweek2	-28.4500	21	-3.98	0.0007
3	Chainring	CIRCULAR	ROTORweek3	-25.6875	21	-3.59	0.0017
4	Chainring	ROTORweek1	ROTORweek2	-2.2625	21	-0.32	0.7549
5	Chainring	ROTORweek1	ROTORweek3	0.5000	21	0.07	0.9449
6	Chainring	ROTORweek2	ROTORweek3	2.7625	21	0.39	0.7032

Average Power after maximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	1	7	7.76	0.0271

Least Squares Means					
Effect	**Chainring**	**Estimate**	**DF**	**t Value**	**Pr > |t|**
Chainring	CircularWeek5	421.91	8.01	33.50	<.0001
Chainring	ROTORweek4	440.19	8.01	34.95	<.0001

Obs	Effect	Chainring	_Chainring	Estimate	DF	tValue	Probt
1	Chainring	CircularWeek5	ROTORweek4	-18.2750	7	-2.79	0.0271

Maximum Power after submaximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	3	21	1.10	0.3712

Maximum Power after maximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	1	7	0.06	0.8101

Average Speed after submaximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	3	21	4.21	0.0176

Least Squares Means					
Effect	**Chainring**	**Estimate**	**DF**	**t Value**	**Pr > |t|**
Chainring	CIRCULAR	26.2987	8.16	78.73	<.0001
Chainring	ROTORweek1	26.7125	8.16	79.97	<.0001
Chainring	ROTORweek2	26.7625	8.16	80.11	<.0001
Chainring	ROTORweek3	26.7125	8.16	79.97	<.0001

Obs	Effect	Chainring	_Chainring	Estimate	DF	tValue	Probt
1	Chainring	CIRCULAR	ROTORweek1	-0.4137	21	-2.77	0.0114
2	Chainring	CIRCULAR	ROTORweek2	-0.4637	21	-3.11	0.0053
3	Chainring	CIRCULAR	ROTORweek3	-0.4137	21	-2.77	0.0114
4	Chainring	ROTORweek1	ROTORweek2	-0.05000	21	-0.34	0.7408
5	Chainring	ROTORweek1	ROTORweek3	5.83E-15	21	0.00	1.0000
6	Chainring	ROTORweek2	ROTORweek3	0.05000	21	0.34	0.7408

Average Speed after maximal testing condition

Type 3 Tests of Fixed Effects				
Effect	Num DF	Den DF	F Value	Pr > F
Chainring	1	7	6.43	0.0390

Least Squares Means						
Effect	Chainring	Estimate	Standard Error	DF	t Value	Pr > |t|
Chainring	CircularWeek5	26.2000	0.2230	8.83	117.50	<.0001
Chainring	ROTORweek4	26.5875	0.2230	8.83	119.24	<.0001

Obs	Effect	Chainring	_Chainring	Estimate	StdErr	DF	tValue	Probt
1	Chainring	CircularWeek5	ROTORweek4	-0.3875	0.1529	7	-2.53	0.0390

Maximum Speed after submaximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	3	21	2.70	0.0718

Maximum Speed after maximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	1	14	1.05	0.3226

Blood Lactate Concentration after 1 k after submaximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	3	21	2.39	0.0974

Blood Lactate Concentration after 1 k after maximal testing condition

Type 3 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F Value**	**Pr > F**
Chainring	1	7	0.05	0.8344

APPENDIX C. Participant Forms

Informed Consent
Form for Cal Poly Research

INFORMED CONSENT TO PARTICIPATE IN RESEARCH STUDYING THE PHYSIOLOGICAL AND BIOMECHANICAL EFFECTS OF NON-CIRCULAR CHAINRINGS ON ELITE LEVEL CYCLISTS AND PERFORMANCE

NATURE AND PURPOSE OF STUDY

A research project on the effects of ROTOR Bicycle Component's Q-Rings is being conducted by Christie O'Hara, student researcher in the Department of Kinesiology at Cal Poly, San Luis Obispo under the supervision of faculty advisor, Dr. Clark. The purpose of the study is to examine the physiological and biomechanical effects of Rotor's Q-Rings (oval shaped chainrings). Participants will perform initial testing with their conventional chainrings, followed by 4 weeks (1 laboratory test each week) of training and testing on non-circular chainrings, and post-testing on the original chainrings (for a total of 6 weeks for completion of the study). The testing each week will consist of a graded exercise test on the participant's bicycle followed by a 1 k time trial every week. Physiological measures such as heart rate, VO_2 (oxygen consumption), RER (indication of carbohydrates versus fat burned), and blood lactate concentration will be measured as well as biomechanical markers involving spin scan analysis, efficiency, and power output.

You (the subject) are being asked to take part in this study because you are 18 to 39 years old, are in good health, and are a USA Cycling Category 1-3 rider or Men's Collegiate A rider with a VO_2 max >55mL/kg/min. Approximately 8 participants will be included in this study. If you decide to participate, it will require a time commitment of approximately 1 hour per week for 6 weeks for completion of the study (see below for more details). For the first and last test week you will be riding on your own chainrings, and the remaining 4 weeks will require you to ride, race and test with Rotor's Q-Rings. The testing will take place at Cal Poly in the Kinesiology Department Building (43-A, first floor lab). Scheduling times will be randomized based on your availability, and each test will be no less than 6 days apart. Please be aware that you are not required to participate in this research and you may discontinue your participation at any time without penalty.

PROCEDURES

If you decide to participate in this study, you will have an initial interview meeting. During this time, you will be asked to complete a health history questionnaire and physical activity readiness questionnaire (PAR-Q) to screen for any potential complications that may arise as a result of the exercise tests during the duration of this study. Height, weight, and blood pressure will also be recorded during this time. If you have no health risks or medical conditions, you will be asked to schedule a maximal oxygen consumption test to determine inclusion into the study (>55ml/kg/min). If you qualify for the study, you will then be asked to complete the conditions below:

Maximal Oxygen Consumption Test

Your initial physical fitness will be assessed during a maximal oxygen consumption test on your own bike mounted to a Computrainer (stationary electronic ergometer). You will be required to breathe into a mouthpiece with your nose clipped to collect expired air. You will also be wearing a heart rate monitor during the entire duration of the test. After a 15 minute warm up (at 125 watts), and calibration on the Computrainer, the test will begin. The first stage will start at 150 watts and increase 30 watts every 3 minutes. Each stage will become increasingly more difficult. You will be asked your rate of perceived exertion (RPE) on a scale of 6-20 toward the end of each stage, and then asked if you are ok to advance to the next stage. The test will end when you no longer wish to continue, the test administrator does not see any increase in VO_2 or heart rate, or the test administrator notices adverse symptoms from the subject. Blood pressure will also be assessed every stage to insure safety of the subject. This test is physically demanding and you may feel fatigued afterward. After termination of the test, you will be encouraged to spin easy at a decreased power output for 5 minutes to allow your body's physiological markers to return to near normal values. You will complete a final maximal oxygen consumption test your final week of testing. This test will follow the same procedures as the initial test.

Weekly Exercise Testing Protocol

Graded Exercise Test (Lactate Threshold Test) and 1 k Time Trial

A week after your initial maximal oxygen consumption test, you will complete an initial graded lactate threshold test followed by a 1 kilometer time trial with metabolic sampling. The graded exercise test will be similar to the maximal oxygen consumption test in that you will complete 3 minute stages followed by a 30 watt increase for each stage. The same warm up applies (15 minutes) followed by calibration of the Computrainer. The difference is that this test does not go to maximal exertion (so that the rest of your training day isn't ruined). This test ends when a RPE of 15-18 is reached and lactate concentration is >4.0mmol/L with an increase from the previous value >1.0mmol/L. After the initial lactate threshold test, the participant will have 5 minutes to recover at 150 watts before beginning the 1k time trial test. This is an all out test to measure max power and time.

After the initial graded exercise test and 1k time trial, the chainrings on the subject's bicycle will be changed over to the non-circular rings. Every week for 4 weeks, the participant will come in for the graded exercise test with metabolic sampling. Every other week, there will be blood sampling during the graded exercise test followed by the 1k time trial with the same procedures as mentioned before.

Blood Sampling

An ear lobe blood sample will be used to determine blood lactate levels during the last 30 seconds of each 3 minute stage in the submaximal graded exercise test. Each measurement only requires a small drop of blood. The total amount of blood collected from each subject will be less than 50 microliters for each test session. A lancet will be used to prick the ear lobe, and a drop of blood will be applied to the test strip. Blood sampling for the next stage will be taken from the same site during the next stage if clotting does not occur. The ear lobe is used for sampling since it is not as painful as finger sticks, and produces similar results to the finger. Researchers will use alcohol swabs and wear latex lab gloves at all times during blood sampling and testing. Universal precautions, as recommended by the Centers for Disease Control and Prevention, will be used at all times. This includes using a sharps container lined with a biohazard bag for all sharp objects involved in the blood sampling; all other materials (i.e. gloves, gauze pads, etc.) used during the sampling will be put in a separate waste disposal unit lined with a biohazard bag.

Food Consumption and Training Records

Your scheduled exercise test will occur in the morning after an overnight fast. You are allowed to drink water the morning of the test, but no breakfast or other beverages. You will be asked to consume the same meal the evening before each test, and will be provided a food journal to record what you ate during that time.

You will be provided with a training journal to record your mileage, average speed, heart rate, power output, and muscular soreness each day on the bike. You will fill this out every week and bring it with you on your testing day. Exercise should be avoided 12 hours before the test, and no intense exercise sessions should occur 24 hours before the test. Similar exercise sessions should occur the day before each test session in the lab.

RISKS AND DISCOMFORTS

According to the American College of Sports Medicine's Guidelines for Exercise Testing and Prescription, the risk associated with maximal testing for individuals categorized as "low risk" is very minimal, and physician supervision is not necessary. The amount and intensity of physical exertion in this study is comparable to what subjects would experience in a cycling competition. The conditions under which the exercise bouts are to take place (controlled laboratory setting with trained researchers) are likely safer than the typical training and competition environments of the subjects. Any subjects who are not accustomed to heavy cycling training, or who are deemed to be at risk for cardiovascular or metabolic diseases (as outlined by the ACSM) will not be allowed to participate in the study. In the unlikely event of cardiac or other complications during exercise, an emergency plan is in place. This includes immediate access to a phone to call emergency personnel.

All possible attempts will be made to minimize the risks involved with research. Trained graduate students will conduct all laboratory procedures with your well-being as their first priority. All procedures will be explained and demonstrated until you are comfortable with your participation in the study. The possible risks associated with participation in this study include the following:

Exercise Tests

During any type of exercise, especially strenuous exercise, there are slight health risks, along with the possibility of fatigue and muscle soreness. Possible side effects of maximal exertion include brief feelings of nausea, lightheadedness, muscle cramps, or dizziness after completion of exercise. However, any health risks are small in subjects who have no prior history of cardiovascular, respiratory or musculoskeletal disease or injury. Any ordinary fatigue or muscle soreness is temporary and usually lasts 24-96 hours.

Blood pressure and heart rate will be monitored during both the exercise tests. The exercise test will be stopped if any of the following conditions happen: onset of chest pain; signs of poor circulation, including pallor (changes in skin color), cyanosis (blue skin), or cold and clammy skin; severe shortness of breath; vertigo or confusion; leg cramps, or intermittent claudication (blood clotting that can cause intense leg pain). First aid and an automated external defibrillator (AED) will be on hand to treat any problems that may arise. To minimize risk, all maximal testing will be conducted indoors on an electronically-braked cycling ergometer on the 1st floor of the Kinesiology Building.

Blood Sampling

The total amount of blood taken during the entire study is extremely small. A small drop (approx. 5 microliters) is required for each blood measurement. Although the amounts are small, there are some minor risks involved. To minimize these risks, only trained research assistants using sterile techniques at all times will take the blood sample. There may be some slight pain associated with the prick on the earlobe. Although rare, there can be local infection if the site is not kept clean following the procedure. There is the possibility of bruising of the skin in the area around the site that poses no health risk and should subside within a few days.

Injuries

If you should experience any injuries or emotional distress and you are a Cal Poly student, please be aware you may contact the campus Health Center at (805) 756-1211 and/or Cal Poly Counseling Services at (805) 756-2511. If you are not a Cal Poly student, please consult your personal doctor for treatment. You will be responsible for the costs of any treatment due to injuries sustained during this research.

CONFIDENTIALITY

Your confidentiality will be protected during the entire research period, and records will be destroyed 6 months after the completion of the study. All paperwork and assessment data from this study will be treated as confidential. Your name and the fact that you are in the study will be kept confidential. Information stored on a computer database will be password protected and only the primary investigator will have access to it. Information on questionnaires will be identified by participant ID and decoded using a separate protected list that only the primary investigator will have access to. All paperwork will be stored in a locked cabinet.

BENEFITS OF PARTICIPATION

Although your participation is strictly voluntary, a subject that completes the entire study will receive two free VO_2 max assessments, and four lactate threshold tests in the Kinesiology Laboratory, along with copies of individual results at the end of the completed study. You will also get images of your spin scan analysis. A final meeting will occur in which you will receive copies of these results along with explanations. By taking part in this study, we hope that you will learn valuable biomechanical and physiological information that will continue to benefit you with your racing and training.

WITHDRAWAL

Your participation in this study is strictly voluntary. You have the right to choose not to participate or to withdraw your participation at any point in this study without consequence.

QUESTIONS

If you have questions regarding this study or would like to be informed of the results when the study is completed, please feel free to contact Christie O'Hara (primary researcher) by phone at (201) 803-9724 and/or e-mail crohara@calpoly.edu, or Dr. Clark (faculty advisor) of Cal Poly's Kinesiology Department at (805) 756-0285 and/or rdclark@calpoly.edu. If you have questions or concerns regarding the manner in which the study is conducted, you may contact Dr. Steve Davis, Chair of the Cal Poly Human Subjects Committee, at 756-2754, sdavis@calpoly.edu, or Dr. Susan Opava, Dean of Research and Graduate Programs, at 756-1508, sopava@calpoly.edu.

If you agree to voluntarily participate in this research project as described, please indicate your agreement by completing and returning the attached questionnaires and signing below. Please keep one copy of this form for your reference. Thank you for your participation in this research.

I have read this consent form. I agree to take part in the research. I have had an opportunity to ask questions and all of my questions have been answered to my satisfaction. By signing this consent form, I willingly agree to participate in this study.

_____ _____

Signature of Volunteer Date

_____

Printed name of Volunteer

I have explained the research to the subject and answered all of his/her questions. I believe that he/she understands the information described in this consent form and freely consents to participate. I have fully explained to the above volunteer the nature and purpose, procedures, and possible risks of the research study.

_____ _____

Signature of Researcher Date

California Polytechnic State University
Kinesiology Department

Health Status Questionnaire

Instructions: Complete each question accurately. All information provided is **confidential.**

Part I: Demographic Information

1. _____ _____
Legal Name Date

2. _____
Nickname

3. _____ _____
Local Phone Email

4. Date of Birth _____ _____
Month/ Day/ Year Age

5. Height: ____'____" Weight: _____ lbs Blood Pressure: _____

Part II: Medical History

6. Circle any that died of heart attack before age 50: Father Mother Brother Sister Grandparent

7. Date of last medical exam: _____Last physical fitness test: _____

8. Circle operations you have had: Back Heart Kidney Eyes Joint Neck Ears Hernia
Lung Other _____

9. Please circle any of the following for which you have been diagnosed of treated by a physician or health professional:

Alcoholism	Diabetes	Kidney Problems
Anemia (sickle cell)	Emphysema	Mental Illness
Anemia (other)	Epilepsy	Muscular Injury
Asthma	Eye Problems	Neck Strain
Back Strain	Gout	Obesity
Bleeding trait	Hearing Loss	Orthopedic Injuries
Bronchitis, chronic	Heart Problem	Phlebitis
Cancer	High Blood Pressure	Rheumatoid arthritis
Cirrhosis, liver	Hypoglycemia	Stroke
Concussion	Hyperglycemia	Thyroid problem
Congenital defect	Infectious Mononucleosis	Ulcer

Other _____

10. Circle all medications taken in the last six months:

Blood thinner	Epilepsy medication	Nitroglycerin
Diabetic pill	Heart-rhythm medication	Other _____
Digitalis	High-blood pressure medication	
Diuretic	Insulin	

11. Any of these health symptoms that occur frequently is the basis for medical attention. Circle the number indicating how often you have each of the following:

5 = Very often 4 = Fairly often 3 = Sometimes 2 = Infrequently 1= Practically never

a. cough up blood
1 2 3 4 5

b. abdominal pain
1 2 3 4 5

c. low back pain
1 2 3 4 5

d. leg pain
1 2 3 4 5

e. arm or shoulder pain
1 2 3 4 5

f. chest pain
1 2 3 4 5

g. swollen joints
1 2 3 4 5

h. feel faint
1 2 3 4 5

i. dizziness
1 2 3 4 5

j. breathless on slight exertion
1 2 3 4 5

Part III: Health Related Behavior

12. Do you smoke? Yes No

13. How many times in a week do you spend at least 30 minutes in moderate to strenuous/vigorous exercise?

1 2 3 4 5 6 7 days per week

14. Can you walk 4 miles briskly without fatigue? Yes No

15. Can you jog 3 miles continuously at a moderate pace without discomfort? Yes No

16. Weight now: _____ lb. One year ago: _____ lb

17. USA Cycling Category: _____

18. Collegiate Category (if applicable): _____

19. Years competing in one of the above: _____

20. Do you have any chronic injuries that could prevent you from riding?

(circle one) No Yes (If so please explain):

Physical Activity Readiness Questionnaire (PAR-Q)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly:

YES	NO		
☐	☐	1.	Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
☐	☐	2.	Do you feel pain in your chest when you do physical activity?
☐	☐	3.	In the past month, have you had chest pain when you were not doing physical activity?
☐	☐	4.	Do you lose your balance because of dizziness or do you ever lose consciousness?
☐	☐	5.	Do you have a bone or joint problem that could be made worse by a change in your physical activity?
☐	☐	6.	Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
☐	☐	7.	Do you know of any other reason why you should not do physical activity?

If you answered:

YES to one or more questions

Talk to your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want – as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- Start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- Take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively.

Delay becoming much more active:

- If you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- If you are or may be pregnant – talk to your doctor before you start becoming more active.

Please note: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction.

Name _____

Signature _____ Date _____