2006

# Comparison of Power Output Between Rotor and Normal Cranks During a 16.1 KM Time Trial

Walter Hailes
*The University of Montana*

# COMPARISON OF POWER OUTPUT BETWEEN ROTOR AND NORMAL CRANKS DURING A 16.1 KM TIME TRIAL.

by

Walter Hailes

B.S. University of Kentucky, Lexington 2001

Thesis

presented in partial fulfillment of the requirements
for the degree of

Master of Science
Exercise Science

The University of Montana
Missoula, MT

Fall 2006

Approved by:

Dr. David A. Strobel, Dean
Graduate School

Brent C. Ruby, Chair
Health and Human Performance

Steven E. Gaskill
Health and Human Performance

James Laskin
Physical Therapy

Hailes, Walter, M.S., Fall 2006 Health and Human Performance

Comparison of power output between Rotor and normal cranks during a 16.1km time trial.

Chairperson: Brent C Ruby

Previous research has evaluated the Rotor crank system on indices of endurance performance (e.g. peak power output, $VO_2$max, lactate threshold, onset of blood lactate accumulation, economy, delta, and gross efficiency) under laboratory conditions. However, previous research has not attempted to determine whether the use of the Rotor cranks can improve sustainable power output during a time trial. The purpose of this study was to investigate the effect of the Rotor crank system on 16.1km time trial performance in the field. Eleven recreationally trained cyclists (7 male, 4 female; age 21±2 yrs) volunteered to participate in the study. On two separate days, each subject performed two 16.1 km time trials (i.e. one Rotor crank (RC) and one normal crank (NC)) each day. Crank arm length was 175mm for both systems. Each time trial was preceded by a 15-minute familiarization period. The trial order was randomly selected and a crossover design was used. Thirty minutes separated each trial, which included a five minute active cool-down, ten minutes of bicycle preparation and fifteen minutes of cycling to familiarize the subjects with the new crank system. Mean power (watt), heart rate (HR), cadence, and time to completion (minutes) were recorded using the Cyclops PowerTap Pro (Madison, WI, USA). The data was averaged for each subject's two RC and NC trials. A two-tailed dependent t-test was used to analyze differences between the RC and NC systems for the measured variables. There were no significant differences ($p<0.05$) between the two crank systems. Finish times were 30.04 ± 1.5 and 29.77 ± 1.7 for the RC and NC, respectively. Similarly, mean power output was 226.63 ± 39.1 and 230.21 ± 37.3 for the RC and NC, respectively. There were also no significant differences in average cadence and HR for the trials. The theoretical improvement in cycling efficiency by eliminating the dead spot of the pedal stroke did not translate into an improvement in cycling performance during 16.1km time trial cycling.

Keywords: Bicycle, rotor, outdoor, field, time trial, powermeter

# Table of Contents

# Tables

## Figures

# Appendices

# Chapter One: Statement of the Problem

**Introduction**:

Cycling has been thoroughly studied with the goal of increasing efficiency and improving performance. Physiological studies have improved nutrition and training techniques. Technological advancements have made bicycles light, stiff, and aerodynamic. Individual and team riding positions have been expertly examined to minimize wind drag, the most prominent force to overcome in racing (Atkinson et al., 2003, Bassett et al., 1999, Faria et al., 2005). And many attempts have been made to improve upon the inconstant force application during the circular pedal stroke (Coyle et al., 1991, Ratel et al., 2003).

The primary mechanism employed to improve the mechanical efficiency of the pedal revolution has been the use of non-circular chainrings. However, the research has shown that these non-circular chainrings, in all their manifestations, do not improve performance (Cullen et al., 1992, Hue et al., 2001, Hull et al., 1992, Ratel et al., 2003).

Another approach to increasing the efficiency of the pedal stroke is the Rotor Crank system, which uses circular chain rings but allows the crank arms to rotate independently of one another. (Santalla et al., 2002, first reported a detailed description of the exact functioning of the cranks in the scientific literature). This system attempts to eliminate the dead spot during the pedal stroke, where torque production is near zero, and better translate the power capacity of the cyclist (Santalla et al., 2002, Lucia et al., 2004). A previous study showed significant improvements in delta efficiency, i.e. the ratio of change in work accomplished·minute$^{-1}$ and the change in energy expended·minute$^{-1}$, among inexperienced cyclists, but a subsequent study showed no change in indicators of endurance performance (e.g. lactate threshold, $VO_{2max}$ or maximal power output) in experienced cyclists during laboratory incremental and constant-load tests, (Santalla et al., 2002, Lucia et al., 2004). However, no one has tested the effect of the Rotor cranks on outdoor time trial performance. The purpose of this study is to determine if the Rotor crank system decreases time to completion of a 16.1 km time trial compared to a conventional crank system.

**Problem:**

Elite cyclists are continually searching for ways to improve their performance in competition. Many areas of cycling have been evaluated to maximize performance and the majority of these variables appear to be approaching the limit of improvement. An exception to this is the perceived inefficiency of the circular pedal stroke, which has not been improved since the first chain driven bicycle. Recently a novel crank design, the Rotor crank, which can theoretically improve performance, was introduced to the market. However, the efficacy of this crank design has not been scientifically established in field-based research.

**Hypothesis:**

The Rotor crank system will reduce time to completion (minutes), and increase mean power output (watts) for trained cyclists, experienced in time trial cycling during a 16.1 km time trial.

**Significance and Rationale of the Study:**

This study is based on the claim that the Rotor crank system improves performance by eliminating the dead spot in the pedal stroke thus increasing pedaling efficiency (Santalla, 2002). The Rotor crank system does not maintain the 180 degree angle between pedals, but makes the angle change slightly during each pedal stroke in an attempt to improve the mechanical efficiency of the circular pedal stroke. During a normal pedal stroke there is a physiological dead space when the crank arms are within a few degrees of vertical, the time where the legs are neither pushing nor pulling the pedals in the vertical plane (Harrison, 1970, Coyle et al., 1991, Bertucci et al., 2005). Previous research is inconsistent in demonstrating a change in pedaling efficiency, lactate threshold, $VO_{2max}$, or maximal power output as a result of the Rotor crank (Santalla et al., 2002 Lucia et al. 2004). However, due to the novelty of the Rotor cranks, only two independent scientific studies have evaluated the functioning of the system. Both studies involved a similar incremental test in which the subjects cycled to volitional exhaustion (Santalla et al., 2002, Lucia et al. 2004). Lucia et al. also included a 20 minute steady state ride (2004). In addition, both previous studies were executed in a laboratory setting. The goal of the current study is to evaluate the effectiveness of the Rotor crank system during outdoor, time trial cycling conditions. The results of this study may help cyclists determine if using the Rotor crank system will improve their cycling performance.

**Delimitations, Limitations, Assumptions:**

This study was delimited to trained cyclists, between the ages of 18-30 years old.

The study results are limited by each subject's pre-trial nutrition, training schedule, and small changes in fitness between trials. The study results are also limited by possible environmental fluctuations affecting the outdoor trials.

It was assumed that each subject followed the guidelines concerning activities prior to each testing session. It was also assumed that the subject completed each time trial as quickly as possible, as instructed by the researcher. Additionally, it was assumed that similar environmental conditions existed for both time trials performed on a single trial day.

**Definition of Terms:**

Time trial: individual competition in which the participant completes a set distance (16.1 km for this study) as quickly as possible

Trained cyclist: individual who are currently training for the upcoming bicycle racing season

Bottom bracket: bicycle component composed of an axel to which the cranks are attached and two sets of bearings that allow the axle and cranks to rotate

Cranks: the component of a bicycle drivetrain that converts the reciprocating motion of the rider's legs into rotational motion used to drive the chain, which in turn drives the rear wheel. It consists of one or more chainrings, attaches to the axel of the bottombracket, and contains the mounting points for the pedals.

Drafting: a technique in cycling where competitors align in a close group in order to reduce the overall effect of wind resistance

# Chapter Two: Literature Review

"The Boneshaker," monomer of the first two-wheeled machine with pedals mounted directly on the front wheel, introduced in 1865, was the beginning. From that initial wood framed machine bicycles and their riders have come a long way. Chain drives, pneumatic rubber tires, near-frictionless bearings, carbon fiber frames and components, ten gear cassettes, aero-positioning, etc…but it remains two wheels, a frame, and a rider. Beautifully simple.

Not long after the invention of the bicycle, riders wanted to know who could ride the fastest and this desire has propelled the sport, technology, and research ever since. In the last quarter century there has been a surge in cycling research in conjunction with the ever-expanding field of exercise science. This research has included two basic ways to improve individual cycling performance beyond training adaptations, reducing resistance forces and improving efficiency.

Major factors affecting cycling resistance include rolling resistance, gravity, and air resistance. Faria qualifies the rolling resistance of a bicycle as a result of the total compression forces of the bicycle and the ground (2005). Major determinants of this resistance include tire pressure, type of tire, wheel diameter, and friction of the bicycle machinery such as the bearings in the hubs. Weight of the bicycle is also an important factor in cycle racing, especially when competing on courses with major hill climbing (Jeukendrup, 2001). Interestingly, rolling resistance and bicycle weight are primarily controlled by technological advancements within the industry and represent only a small portion of total cycling resistance. The major resistive force to overcome is air resistance Kyle, 1991, Jeukendrup, 2001, Faria, 2005).

Air resistance is the most influential factor associated with cycling performance at speeds greater than 15km/hour (Kyle, 1991). For this reason the rider's position deserves and receives great consideration. During His 1989 Tour de France win, Greg Lemond was the first rider to use clip-on aero bars in a major tour (Faria, 2005). Since then aero bars have been a necessity during any race that does not allow drafting, such as time trials and triathlons. The incorporation of the aero position into cycling competition was a major progression for the sport.

In addition to reducing resistance, improving efficiency is a very important variable influencing cycling performance. Research has shown that during the pedaling cycle there is an oscillation in force production corresponding to different phases of the pedal stroke (Harrison, 1970, Coyle, 1991, Bertucci, 2005). During the down stroke of each revolution there is a peak torque and this reduces to near-zero levels as the crank arms approach vertical, the area known as the dead spot (Harrison 1970, Coyle, 1991, Bertucci, 2005). This apparent weakness in the pedal stroke was observed quickly after researchers began to evaluate ways to improve cycling efficiency (Harrison, 1970). Once the power oscillation was observed individuals attempted to improve upon the design.

With the knowledge that the conventional crank design produced a dead spot in force production individuals attempted to increase the economy of the pedal cycle (Harrison, 1970, Patterson and Moreno, 1990). The most obvious and simplistic way to accomplish this was by altering the circular nature of the chainrings. Noncircular chainrings in many different shapes and orientations to the major and minor axes have been produced and tested, and have continually failed to demonstrate positive improvement in any type of cycling performance (Harrison, 1970, Ratel, 2003).

Harrison, using five healthy men, demonstrated no difference in peak power outputs between the conventional and elliptical chainrings (1970). Ratel et al., executed an investigation using 13 endurance-trained cyclists comparing circular to a noncircular chainring (2003). Each subject performed two incremental exercise tests to exhaustion, using the circular and noncircular chainrings in a randomized order. Gas exchange data and heart rate were continually collected and blood samples, used to measure blood lactate, were collected during the last 30 seconds of each level. No significant difference was found during any submaximal or maximal parameters measured during the testing.

More recently, a new crank/bottom bracket system has been introduced that changes the fixed crank arm design of the traditional crank system. This new design, the Rotor crank, uses a rotor system incorporated into the bottom bracket of the bicycle that allows the angle between the two crank arms to fluctuate as the pedals are moved around the central crank axis. Traditionally the crank arms moved in a circular pathway around the central crank axis in a fixed positioned separated by 180 degrees. As the crank arms of the Rotor crank move through the pedal cycle the crank that is ascending rotates more quickly than the one descending. This allows the ascending crank to move through the dead spot before the descending crank reaches the vertical position. Theoretically, this will allow the cyclists to maintain a more uniform power output and therefore improve performance (Santalla, 2002). Currently, two studies have been published in peer-reviewed publications that evaluated the Rotor crank system's ability to improve physiological indices of endurance performance (Santalla, 2002, Lucia, 2004).

Santalla et al. published the first study evaluating the Rotor system (2002). In this study, Santalla et al. used eight healthy males with an average age of 22±1 years who had not ridden a bicycle in the two months prior to the beginning of the study and were not experienced cyclists. The subjects' performed two randomly chosen exercise trails, one using the Rotor crank and the other using a conventional crank. These trials were completed on an 18-speed bicycle mounted on a wind resistance trainer and were separated by 24 hours of rest. The exercise test consisted of a warm-up period of at least 5 minutes at a power output of 50 W, to allow the subject to become "comfortable with the pedaling task." This was followed by an incrementally increasing resistance protocol starting at 75 W and increasing by 25 W every 3 minutes until volitional exhaustion. Each subject chose his own pedal cadence for the first trial but was required to repeat the same cadence for the second trial. During the exercise trials the researchers collected; continuous gas exchange information, heart rate, and capillary blood samples pre- and post-trial and at 3-minute intervals during the trial. Santalla et al. observed that the Rotor system improved only one determinate in endurance cycling performance, delta efficiency (i.e. the ratio of the change in work accomplished·$min^{-1}$ and the change in energy expended·$min^{-1}$) (2002).

Lucia et al., following the recommendations of Santalla et al., tested ten well trained male cyclists five of whom were experienced with the Rotor crank (2004). All ten subjects performed two incremental tests, starting at 112.5 W increasing 37.5 W at 3-minute intervals until exhaustion, and nine subjects completed two, 20-minute constant power trials. All subjects were required to maintain a pedal cadence of 75 rev·$min^{-1}$, and each tests was separated by a 24-hour rest period. Lucia et al. continuously measured gas exchange, heart rate, and collected capillary blood samples before and after each trial and at 3-minute intervals during the incremental protocol trials. Evaluating the same endurance cycling determinants, $VO_2$max, $W_{peak}$, lactate threshold, onset of blood lactate accumulation, economy, gross efficiency, and delta efficiency as Santalla et al. (2002), Lucia et al. found no difference between the Rotor and conventional cranks in the well trained cyclists (2004).

Following the recommendations of Lucia et al. (2004) the current research will evaluate the effectiveness of the Rotor crank in an outdoor time trial setting. The goal of the project is to evaluate the Rotor crank versus a conventional crank using simulated 16.1 time trial races. Within this research are many variables to consider such as environmental change between trials, warm-up procedures, determinates of pedal cadence, and data collection accuracy.

**Outdoor trials**

Previous field experimentation has attempted to compare the reliability of indoor tests to actual outdoor cycling or predict race performance using laboratory tests (Balmer et al., 2000, Smith et al., 2001,). During this investigation the performance between the dependent variable (i.e. crank type) is being evaluated outdoors in a simulated time trial setting. The study design is to minimize environmental influence.

**Warm-up**

Considerable research has been conducted to evaluate the possible benefits of different types of warm-up on many different athletic events.

Hajoglou et al. evaluated eight well-trained, experienced time trial cyclists performing four, 3-km time trials on a racing bicycle mounted on a wind load trainer

(2005). The first time trial, preceded with a 5-minute warm-up, was completed to ensure that the subjects were familiar with the experimental task. The following three time trials were preceded by no warm-up, an easy warm-up and a hard warm-up, in a randomized order. Hajoglou et al. found that performance during intermediate length events (4-5 minutes) is enhanced by warm-up, independent of intensity (2005).

Bishop published a very through article in 2003 reviewing the current knowledge about warming–up before competition. The article shows that active warm-up has the potential to improve short and intermediate length performance, possibly by temperature-related mechanisms and also by decreasing the oxygen deficit experienced during the initiation of exercise. Intensity and duration of the warm-up are the two major variables that influence the performance enhancement. However, previous studies have used varied intensities and durations of warm-up and thus have reported conflicting data concerning subsequent performance.

Many cyclists perform some type of active warm-up before normal competition. In an attempt to closely mimic the race environment, the subjects in this study will be allowed to select and execute a warm-up typical to what they would normally perform before a similar competition. This warm-up period will also allow the riders to become familiarized with the crank system with which they will be performing. On subsequent trials each subject will be asked to repeat the prior warm-up.

**Pedaling rate**

By evaluating professional cyclists during competition, Lucia et al. demonstrated that during both flat sections and individual time trials within the three major tours (Giro d'Italia, Tour de France, and the Vuelta a España) cyclists adopted a higher pedaling cadence (~90 rpm) than previous laboratory reports show as being the most economical (2001).

Nielsen et al. studied pedaling rate using twelve individuals chosen to represent a large variance in muscle fiber type composition (2004). This investigation included three endurance trials during which the subjects pedaled at a freely chosen pedaling rate, 25 percent higher and 25 percent lower than their freely chosen pedaling rate, until exhaustion. The researchers found that endurance time was longer at both the subjects' freely chosen pedaling rate and at 25 percent lower than the freely chosen pedaling rate, compared to a 25 percent higher pedaling rate.

The current researcher's goal is to simulate an individual time trial as accurately as possible, therefore, each cyclist will be allowed to self-select their pedaling cadence during each time trail. According to the research the subjects will most likely choose a high pedal cadence due to the high power requirement of the 16.1 km time trial.

**Instrumentation**

A very important part of this study is being able to collect an absolute measure of work. To measure twelve individuals, who vary in height, weight, body proportion and cycling position, in a field setting an absolute measure of work output is essential. The measure of power, watts, is a measure of torque in one second and therefore, independent of resistance forces such as wind drag. Time to completion as well as speed are influenced by the amount of power produced and the total of all resistance forces that must be overcome for motion. There are several products that attempt to accurately measure the power output of a cyclists in the field, such as SRM, Max One, Polar S170, PowerTap, and Ergomo (Bertucci, 2005). For this study the PowerTap (Cyclops, Madison, USA) will be used during all trials. The PowerTap is a powermeter that consists of eight strain gauges located in the hub of the rear wheel (Bertucci, 2005). The measurement at the rear hub is essential when comparing two different crank systems. Bertucci et al. successfully determined the PowerTap to be both a reliable and valid instrument, compared to the SRM powermeter, for measuring power output during sub-maximal road and laboratory testing (2005).

**Efficiency**

Interestingly one study by Coyle et al. minimizes the importance of economy for high caliber cyclists (1991). Coyle et al. studied 15 male competitive cyclists within the highest 2 rankings of the United States Cycling Federation. The researchers divided the subjects into two groups based on their best 40 km time trial performance. Each cyclist completed a 25-minute incremental test with increasing work every 5 minutes plus a one-hour maximum work output ride in the laboratory. From these evaluations Coyle et al. found that the faster group (group I) could produce 11% more power during the 1-hour trial than the slower group (group II), regardless of similar $VO_2$max and lean body weight (1991). This higher power was predominantly from producing higher peak torque and increased torque during the down stroke of the pedal cycle, not by increasing the effectiveness of force production during the entire pedal cycle.

This finding that increased work is a result of increased torque production during one part of the pedal cycle, rather than increased efficiency in force production during the entire pedal cycle, is a possible explanation for the overall ineffectiveness of the noncircular chainrings. The Rotor crank and the noncircular chainrings attempt to improve performance by improving the effectiveness of the pedal stroke not by increasing the torque production. However, using a crossover design it will be interesting to evaluate the Rotor crank in an environment that requires high power production. The Rotor crank might allow the cyclists to more effectively apply torque during the pedal down stroke by reducing the amount of time wasted in the dead spot.

# Chapter Three: Methodology

**Setting:**

The research was completed on a 16.1 km loop off of Highway 200 in Montana in the city of Turah.

**Subject selection**:

Eleven experienced cyclists from the University of Montana volunteered for this investigation. The chosen cyclists were endurance trained and familiar with time trial riding but none were professional time trialists, and none of the subjects had previous experience with the Rotor cranks.

Prior to the initiation of this investigation, approval from the Institutional Review Board of the University of Montana was granted. Each subject signed a statement of informed consent, which outlined the purpose of the study, risks involved with the experimental protocol, and the right to terminate testing at any time.

Descriptive data were obtained for each subject including age (yrs), height (cm), weight (kg), and $VO_2$peak ($ml \cdot min^{-1} \cdot kg^{-1}$). The subjects' peak oxygen consumption was measured during a 25 watt ramped protocol using an electronically braked cycle ergometer (Velotron, Seattle, WA) and a calibrated metabolic cart (Parvomedics, Inc., Salt Lake City, UT).

**Instrumentation**:

The subjects performed the study on two identical bicycles differing only in the type of crank system installed, conventional or Rotor. To eliminate any small differences between power meters each subject performed all trials using the same rear wheel/power meter hub and the same cycle computer. All the subjects $VO_2$peak and peak power output were determined in the Human Performance Laboratory at the University of Montana.

**Experimental Procedure**:

The subjects completed four total time trials on two days of testing separated by at least one week. On each trial day the subjects rode two 16.1 km time trials on the same course, riding the same direction and under the similar environmental conditions. During the first trial day the trial order, Rotor crank or conventional crank, was randomly assigned. This order was reversed on the second trial day to achieve the crossover design of the study. Before the first time trial on each trial day, the subjects were instructed to perform a self-selected warm-up for the event on the bicycle that they were going to be completing the first time trial. Following completion of the first time trial the experimenter retrieved the cycle computer to download information and the subjects were allowed to lightly pedal for 5 minutes. Then the experimenter spent 10 minutes preparing the bicycles for the second time trial, i.e. removing the pedals and rear wheel from one bicycle and mounting them on the other. Following this preparation the subjects were required to pedal for 15 minutes on the second bicycle to become familiar with the different crank system. The subjects began their second time trial, using the other crank system, 30 minutes after completion of the first time trial. The two trial crossover design was used to negate environmental fluctuations between trial days.

**Data collection**:

The Cyclops PowerTap continually measured power (watts), heart rate (beats·$min^{-1}$), speed (km·$min^{-1}$), cadence (revolutions·$min^{-1}$), and duration (minutes) during the time trials. Research assistants positioned on the course also collected wind speed and temperature. Subjects were blinded from performance information except distance, until the completion of the study.

**Statistics**:

Averages of time to completion, average power, and average heart rate were calculated for each subject's two Rotor crank and two conventional crank trials. The mean ±SD of each variable was compared across the two modes using a paired, 2-tailed t-test. Statistical significance was established using an alpha level of $p<0.05$. Data was analyzed using Microsoft Excel.

# References


1. Atkinson, G., R. Davison, A. Jukendrup, and L. Passfield. Science and cycling: current knowledge and future directions for research. *J. Sports Sci.* 21:767-803, 2003.

2. Balmer, J., Davidson, R.C.R., Bird, S.R. Peak power predicts performance power during an outdoor 16.1-km cycling time trial. *Med. Sci. Sports. Exerc*. 32: 1485-1490, 2000.

3. Bassett, J. R., C. R., Kyle, L. Passfield, J. P. Broker, and E. R. Burke. Comparing cycling world hour records, 1967-1996: modeling with empirical data. *Med. Sci. Sports Exerc.* 31:1665-1676, 1999.

4. Bertucci, W., Duc, S., Villerius, V., Pernin, J.N., Grappe, F. Validity and reliability of the PowerTap mobile cycling powermeter when compared with the SRM device. *Int. J. Sports Med.* 26:868-873, 2005.

5. Bertucci, W., Grappe, F., Girard, A., Betik, A., Rouillon, J.D. Effects on the crank torque profile when changing pedaling cadence in level ground and uphill road cycling. *J. Biomech*. 38: 1003-1010, 2005.

6. Bishop, D. Warm up II. Performance changes following active warm up and how to structure the warm up. *Sports med*. 33: 483-498, 2003.

7. Coyle, E. F., M. E. Feltner, S. A. Kautz, M. T. Hamilton, S. J. Montain, A. M. Baylor, L. D. Abraham, and G. W. Petrek. Physiological and biomechanical factors associated with elite endurance cycling performance. *Med. Sci. Sports. Exerc.* 23:93-107, 1991.

8. Cullen, L. K., K. Andrew, M. Lair, M. J. Widger, and B. F. Timson. Efficiency of trained cyclists using circular and noncircular chainrings. *Int. J. Sports Med.* 13:264-269, 1992.

9. Faria, E. W., D. L. Parker, I. E. Faria. The science of cycling. *Sports Med.* 35:313-337, 2005.

10. Hajoglou, A., Foster, C., DeKoning, J.J., Lucia, A., Kernozek, T.W., Porcari, J.P. Effect of warm-up on cycling time trial performance. *Med. Sci. Sports Excer*. 37: 1608-1614, 2005.

11. Harrison, J.Y. Maximizing human power output b suitable selection of motion cycle load. *Human Factors*. 12:315-329, 1970.

12. Hue, O., O. Galy, C. Hertogh, J. F. Casties, and C. Prefaut. Enhancing cycling performance using an eccentric chainring. *Med. Sci. Sports Excer.* 33:1006-1010, 2001.

13. Hull, M. L., M. Williams, K. Williams, and S. Kautz. Physiological response to cycling with both circular and noncircular chainrings. *Med. Sci. Sports Excer.* 24:1114-1122, 1992.

14. Jeukendrup, A.E., Martin, J. Improving cycling performance: how should we spend our time and money? *Sports Medicine*. 31: 559-569, 2001.

15. Kyle, C.R. The effect of crosswinds upon time trials. Cycling Sci. 3: 51-56, 1991.

16. Lucia, A., Hoyos, J., Chicharro, J.L. Preferred pedaling cadence in professional cycling. *Med. Sci. Sports Excer*. 33: 1361-1366, 2001.

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

18. Nielsen, J.S., Hansen, E.A., Sjogaard, G. Pedaling rate affects endurance performance during high-intensity cycling. *Eur. J. Appl. Physiol.* 92:114-120, 2004.

19. Patterson, R. P., and M. I. Moreno. Bicycle pedaling forces as a function of pedaling rate and power output. *Med. Sci. Sports Exerc*. 22:512-526, 1990.

20. Ratel, S., P. Duche, C. A. Hautier, C. A. Williams, and M. Bedu. Physiological responses during cycling with noncircular "Harmonic" and circular chainrings. *Eur. J. Appl. Physio.* 91:100-104, 2003.

21. Santalla, A., J. M. Manzano, M. Perez, and A. A. Lucia. A new pedaling system: the Rotor-effects on cycling performance. *Med. Sci. Sports Exerc.* 34:1854-1858, 2002.

22. Smith, M.F., Davidson, R.C.R., Balmer, J., Bird, S.R. Reliability of mean power recorded during indoor and outdoor self-paced 40 km Cycling time-trials. *Int. J. Sports Med*. 22: 270-274, 2001.

# Cycling time trial performance is not improved with the use of Rotor crank

Walter Hailes[1], Ruby, B.C.[1], Gaskill, S.E.[1]

[1]Human Performance Laboratory, The University of Montana. Missoula, MT

Addresses for correspondence:

Brent C. Ruby, Ph.D

Director, Human Performance laboratory

Department of Health and Human Performance

The University of Montana

Tel: 406-243-2117

Fax: 406-243-6252

e-mail: brent.ruby@mso.umt.edu

## ABSTRACT

**Purpose:** The purpose of this study was to investigate the effect of the Rotor crank system on 16.1 km time trial performance in the field. **Methods:** Eleven recreationally trained cyclists (7 male, 4 female; age 21±2 yrs) volunteered to participate in the study. On two separate days, each subject performed two 16.1 km time trials (i.e. one Rotor crank (RC) and one normal crank (NC)) each day. Crank arm length was 175mm for both systems. Each time trial was preceded by a 15-minute familiarization period. The trial order was randomly selected and a crossover design was used. Thirty minutes separated each trial, which included a five-minute active cool-down, ten minutes of bicycle preparation and fifteen minutes of cycling to familiarize the subjects with the new crank system. Mean power (watt), heart rate (HR), cadence, and time to completion (minutes) were recorded using the Cyclops PowerTap Pro (Madison, WI, USA). The data was averaged for each subject's two RC and NC trials. A two-tailed dependent t-test was used to analyze differences between the RC and NC systems for the measured variables. **Results:** There were no significant differences ($p<0.05$) between the two crank systems. Finish times were 30.02 ± 1.4 and 29.80 ± 1.6 for the RC and NC, respectively. Similarly, mean power output was 222.93 ± 38.3 and 226.37 ± 38.4 for the RC and NC, respectively. There were also no significant differences in average cadence or HR for the trials. **Conclusion:** The theoretical improvement in cycling efficiency by eliminating the dead spot of the pedal stroke did not translate into an improvement in cycling performance during 16.1km time trial cycling.

## INTRODUCTION

The role of science in the sport of cycling has been to increase efficiency and improve performance. Additionally, physiological studies have demonstrated the effectiveness of supplemental feeding strategies, which have been shown to improve 40km time trial performance (Jeukendrup et. al. 2001). Technological advancements and the development of composite materials have also been incorporated resulting in lighter, stiffer frame construction. Moreover, individual and team riding positions have been expertly examined to minimize wind drag, the most prominent force to overcome in racing (Atkinson et. al., 2003, Bassett et. al., 1999, Faria et. al., 2005). Furthermore, many attempts have been made to improve upon the inconstant force application during the circular pedal stroke (Coyle et al., 1991, Ratel et al., 2003).

The primary mechanism employed to improve the mechanical efficiency of the pedal revolution has been the use of non-circular chainrings, included on production bicycles during the 1980's. However, past research has concluded that the non-circular chainrings do not improve mechanical efficiency or performance (Cullen et al., 1992, Hue et al., 2001, Hull et al., 1992, Ratel et al., 2003).

The normal crank creates a dead spot in the circular pedal stroke where the cyclists is neither pushing down nor pulling up on the pedals, but is required to move the pedal laterally. A more recent design that attempts to increase the efficiency of the pedal stroke is the Rotor Crank (RC), which uses circular chainrings but allows the crank arms to rotate independently of one another. Briefly, this system attempts to eliminate the dead spot during the pedal stroke, where torque production is near zero, and better translate the power capacity of the cyclist into power output (Santalla et al., 2002, Lucia et al., 2004). The function of the RC system has been previously described in an article by Santalla et al. (2002). The RC system has been shown to significantly improve delta efficiency (i.e. the ratio of change in work accomplished$\cdot$minute$^{-1}$ and the change in energy expended$\cdot$minute$^{-1}$) among inexperienced cyclists (Santalla et. al., 2002). However, a subsequent study demonstrated no change in several physiological indicators of endurance performance (lactate threshold, $VO_{2max}$ or maximal power output) when experienced cyclists were evaluated using incremental and constant-load tests, (Lucia et al., 2004). Although physiological markers have been addressed, the effectiveness of the RC on time trial performance has not been evaluated. The purpose of this study was to determine the effects of the RC system on average power output (watts) and time to completion (minutes) of a 16.1 km time trial compared to a normal crank (NC) system.

We hypothesized that the RC system would increase mean power output (watts) during a 16.1 km time trial while decreasing the time to completion.

## METHODS

**Subject selection**:

Eleven experienced cyclists (4 females and 7 males) served as subjects for this study.

**Table 1.** Mean (±SD) age, height, mass and $VO_2$peak for four female and seven male subjects.

| | Age (yrs) | Height (cm) | Mass (kg) | $VO_2$peak ($ml \cdot kg^{-1} \cdot min^{-1}$) |
|---|---|---|---|---|
| Females | 21±2 | 174.6±10.0 | 62.6±3.9 | 56.2±8.4 |
| Males | 23±4 | 177.3±6.6 | 67.3±6.2 | 67.9±5.5 |

The subjects were endurance trained and familiar with time trial riding but none were professional time trialists, and none of the subjects had previous experience with the RC.

Prior to the initiation of this investigation, approval from the University Institutional Review Board was obtained. Each subject signed an IRB approved informed consent prior to the collection of all data.

**Instrumentation**:

$VO_2$peak was measured on an electronically braked cycle ergometer (Velotron, Seattle, WA) using a calibrated metabolic cart (Parvomedics, Inc., Salt Lake City, UT). Expired gases were continuously analyzed during a ramp protocol (25 watt·min$^{-1}$) until the subject reached volitional exhaustion or until a pedal cadence of 50 rev·min$^{-1}$ could not be maintained. Peak $VO_2$ was selected as the average of the highest 30-second value recorded by the metabolic system.

The time trials were performed on two identical road bicycles differing only in the type of crank system installed, NC or RC. Data during the time trials were monitored using a rear wheel/power meter hub system and the cycle computer (Cycle Ops, Madison, WI). To eliminate any differences between equipment the subjects performed all trials using the same Cycle Ops wheel and computer.

**Experimental Procedure**:

The subjects completed four total time trials on two days of testing. On each testing day, subjects completed two 16.1 km time trials on the same course, riding the same direction with similar environmental conditions (wind speed and ambient temperature, table 3). During the first days' trial, the trial order, RC or NC, was randomly assigned. To obtain the crossover design this order was reversed for the second testing day. Prior to the initial time trial on each test day, subjects were provided with a 15-minute warm-up period completed at a self-selected pace on the first test bicycle. Subjects' were instructed to complete each 16.1 km time trial as quickly as possible. Following the completion of the first time trial the cycle computer was retrieved and the data was downloaded to a laptop computer while the subjects lightly pedal for 5 minutes. The second bicycle was then prepared for the second time trial (i.e. transferring the pedals and rear wheel). Following this preparation, subjects were provided with 15 minutes on the second bicycle. Saddle position was kept constant for both trials. The subjects began their second time trial, using the other crank system, 30 minutes after completion of the first time trial. The two trial crossover design was used to negate environmental fluctuations between trial days. Values for average power output (watts) and heart rate (HR) along with finish times (minutes) for the two trials with each crank system were averaged for later comparison.

**Data collection**:

Power output (watts) was continuously measured using a system built into the rear hub of the bicycle (Cyclops PowerTap, Madison, WI). The PowerTap system, validated by Bertucci et. al. (2005) has been demonstrated as an accurate and consistent tool for measurement of power output. In addition to power output, heart rate ($beats \cdot min^{-1}$), speed ($km \cdot min^{-1}$) and cadence ($rev \cdot min^{-1}$) were continually measured during each of the time trials. Research assistants positioned on the course also collected wind speed and temperature data. With the exception of distance, subjects were blinded to all performance/physiological information (watts, speed, HR) for all time trials.

**Statistics**:

The subjects' average finish time, power output, and heart rate were calculated for each of the two RC and two NC trials. Each dependent variable, temperature (°C) and wind speed ($m \cdot s^{-1}$) was compared between trials (NC and RC) using a paired, 2-tailed t-test. Statistical significance was established using an alpha level of $p<0.05$. Data was analyzed using Microsoft Excel.

## RESULTS

Subjects completed two trials for each crank system in a randomized, crossover design. Values from the two trials were averaged and mean values for finish time (min), power output (watts) cadence (rpm) and heart rate (HR) were compared across trials. There were no significant differences for average measures of time to completion, power output, cadence, or heart rate between the RC and NC during the 16.1 km time trials (Table 2). There were no significant differences in mean temperature (°C) or wind speed ($m \cdot s^{-1}$) between each RC and NC trial (Table 3).

**Table 2.** Mean data for each subject's first and second RC trial and the mean (±SD) of all RC trials. Mean data for each subject's first and second NC trial and the mean (±SD) of all NC trials.

| Crank type | Finish Time (min) | Power Output (watts) | Cadence (rpm) | HR |
|---|---|---|---|---|
| RC1 | 30.1 | 222.2 | 87.7 | 161.9 |
| RC2 | 29.9 | 223.7 | 87.7 | 162.4 |
| **RC Average** | **30.0 ± 1.4** | **222.9 ± 38.3** | **88.0 ± 7.1** | **162.3 ± 4.0** |
| NC1 | 29.9 | 223.0 | 87.0 | 162.3 |
| NC2 | 29.7 | 229.7 | 86.7 | 161.8 |
| **NC Average** | **29.8 ± 1.6** | **226.4 ± 38.4** | **86.9 ± 7.2** | **162.6 ± 5.3** |

**Table 3.** Mean (±SD) temperature and wind speed data for each trial day.

| Crank Type | Temperature (°C) | Wind (m/s) |
|---|---|---|
| RC 1 | 7.8 ± 4.2 | 2.0 ± 1.6 |
| RC 2 | 9.5 ± 4.9 | 3.8 ± 3.3 |
| NC 1 | 7.6 ± 4.0 | 1.7 ±1.4 |
| NC 2 | 8.6 ± 4.1 | 3.3 ± 2.1 |

Figures 1 and 2 show the mean power output and heart rate for each kilometer during the time trials. Power output and heart rate are very consistent across all trials during similar but variable weather conditions.

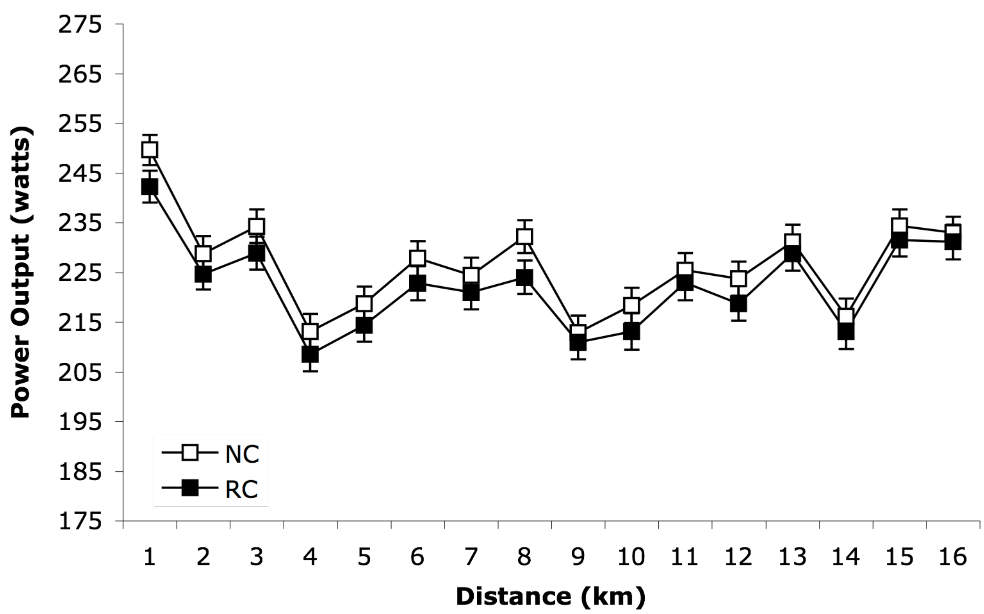


**Figure 1.** Mean power output (±se) for the RC and NC trials during the 16.1 km time trials.

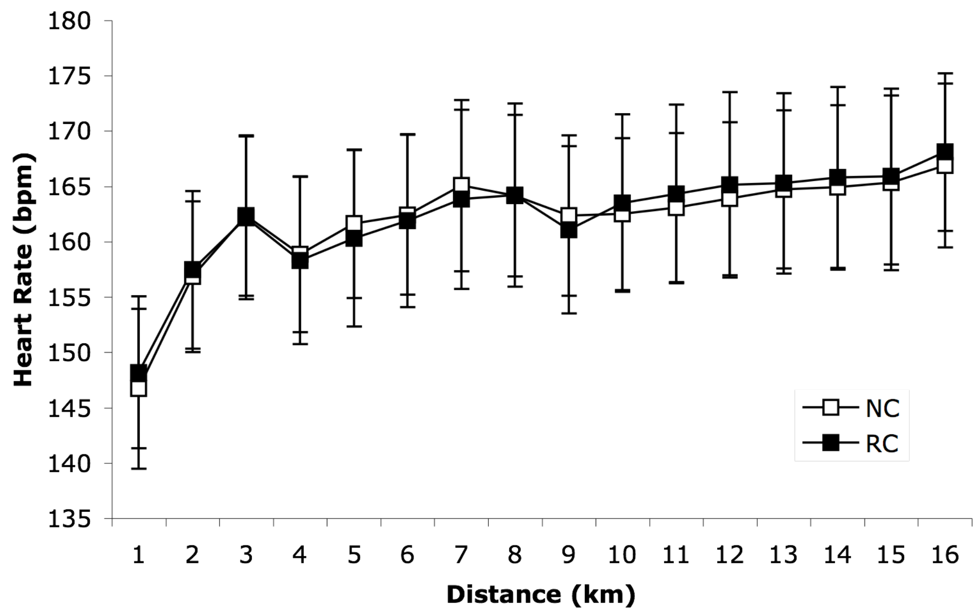


**Figure 2.** Mean heart rate (±se) for the RC and NC trials during the 16.1 km time trials.

## DISCUSSION

The main finding from this study was that the RC system did not improve cycling time trial performance. Self-selected power output and cadence were similar during the trials, which related to similar heart rate and time to completion for all trials. Values for heart rate and power output were similar between the RC and NC trials. However, the consistency of the data demonstrates the practical usefulness of bicycle-integrated power meters for field trial evaluation.

The premise of the RC design is that these cranks allow the rising pedal to rotate through the vertical position, the dead spot, prior to the opposite pedal reaching the lowest point in the pedal rotation. This allows the cyclist to constantly be in the power phase of the pedal stroke. Eliminating this dead spot would theoretically improve the mechanical efficiency of the pedal stroke. This was supported by a study that demonstrated improvements in delta efficiency for inexperienced cyclists; however, experienced cyclists exhibited no efficiency improvements (Lucia et. al., 2004, Santalla et. al., 2001).

One potential limitation of the present investigation was the short amount of time each rider had to assimilate to the RC. All subjects were experienced cyclists but none had experience using the RC prior to participation in this study. However, it is unclear whether additional experience with the RC would alter pedal mechanics sufficiently to improve efficiency and/or performance. Each subject was given fifteen minutes with each crank system prior to the time trial. Although many subjects noted that the RC initially felt different the feeling dissipated during the fifteen-minute warm-up period. However, this fifteen minute warm-up does not guarantee that each subject was habituated to the RC and therefore might not have been as efficient using the RC as they were using the NC (their normal mode of training). Even though, Lucia et. al. (2004) studied individuals who were experienced with the RC, there were no apparent physiological benefits associated with the RC compared to the NC. Therefore, it is not likely that familiarization alone contributed to the lack of difference in the physiological variables between the two crank types.

Another potential explanation for the lack of performance improvement is that the RC is not effectively eliminating the dead spot. The RC was installed by a professional bicycle mechanic to the specifications provided by the company for this study. However, it is possible that the recommended crank arm offset is too slight to elicit the desired mechanical improvement. It would be interesting if future research could determine if installation of the RC with a greater variation from the NC would result in a performance difference.

Conducting this research project in the field complicated data collection process. The field collection required performing a time trial using each crank system on the same day to provide the crossover data needed. Randomizing the trial selection and reversing the order of the second day mitigated potential environmental fluctuations in air temperature and wind speed. We felt it was important to collect data in the field, rather than in a laboratory setting in order to provide a more accurate representation of cycling conditions and a true measure of performance.

In conclusion, it appears that the RC does not enhance performance of an outdoor 16.1 km time trial. Moreover, self-selected power output and cadence were not different between crank systems. Additionally, it should be determined whether performance is negatively affected by the reduction in power during the dead spot, or do cyclists obtain maximum efficiency using normal crank systems?

**Acknowledgements**

Special thanks to the Bicycle Hangar for providing bicycles for this study.

## WORKS CITED

1. Atkinson, G., R. Davison, A. Jukendrup, and L. Passfield. Science and cycling: current knowledge and future directions for research. *J. Sports Sci.* 21:767-803, 2003.

2. Bassett, J. R., C. R., Kyle, L. Passfield, J. P. Broker, and E. R. Burke. Comparing cycling world hour records, 1967-1996: modeling with empirical data. *Med. Sci. Sports Exerc.* 31:1665-1676, 1999.

3. Bertucci, W., Duc, S., Villerius, V., Pernin, J.N., Grappe, F. Validity and reliability of the PowerTap mobile cycling powermeter when compared with the SRM device. *Int. J. Sports Med.* 26:868-873, 2005.

4. Coyle, E. F., M. E. Feltner, S. A. Kautz, M. T. Hamilton, S. J. Montain, A. M. Baylor, L. D. Abraham, and G. W. Petrek. Physiological and biomechanical factors associated with elite endurance cycling performance. *Med. Sci. Sports. Exerc.* 23:93-107, 1991.

5. Cullen, L. K., K. Andrew, M. Lair, M. J. Widger, and B. F. Timson. Efficiency of trained cyclists using circular and noncircular chainrings. *Int. J. Sports Med.* 13:264-269, 1992.

6. Faria, E. W., D. L. Parker, I. E. Faria. The science of cycling. *Sports Med.* 35:313-337, 2005.

7. Hue, O., O. Galy, C. Hertogh, J. F. Casties, and C. Prefaut. Enhancing cycling performance using an eccentric chainring. *Med. Sci. Sports Excer.* 33:1006-1010, 2001.

8. Hull, M. L., M. Williams, K. Williams, and S. Kautz. Physiological response to cycling with both circular and noncircular chainrings. *Med. Sci. Sports Excer.* 24:1114-1122, 1992.

9. Jeukendrup, A.E., Martin, J. Improving cycling performance: how should we spend our time and money? *Sports Medicine*. 31: 559-569, 2001.

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

11. Ratel, S., P. Duche, C. A. Hautier, C. A. Williams, and M. Bedu. Physiological responses during cycling with noncircular "Harmonic" and circular chainrings. *Eur. J. Appl. Physio.* 91:100-104, 2003.

12. Santalla, A., J. M. Manzano, M. Perez, and A. A. Lucia. A new pedaling system: the Rotor-effects on cycling performance. *Med. Sci. Sports Exerc.* 34:1854-1858, 2002.

# Appendix A 11 Point Institutional Review Board Summary

Title: ***Effects of the Rotor crank on 16.1 kilometer time trial performance.***

Walter Hailes, Masters Student, Health and Human Performance-McGill Hall, Phone: 546-1120, email: walter.hailes@umontana.edu

Brent Ruby, Ph.D., Professor, Health and Human Performance-
McGill Hall 111, Phone: 243-2117 email: brent.ruby@mso.umt.edu

**1) PURPOSE**

OBJECTIVES:

To examine the differences between two different crank systems during time trial cycling.

SIGNIFICANCE:

This study will compare the effectiveness of a new crank/bottom bracket system to the traditional bicycling pedaling system. The new, Rotor crank, system does not maintain the 180 degree angle between pedals, but makes the angle change slightly in an attempt to improve mechanical efficiency. During a normal pedal stroke there is a physiological dead space when the crank arms are within a few degrees of perpendicular to the ground, the time where the legs are neither pushing the pedals down or pulling the pedals up. The Rotor crank system allows one pedal to move past this dead space before the other pedal enters the dead space, therefore, theoretically eliminating the dead space. The goal of this project is to determine whether the Rotor crank system allows the subjects' to complete a 16.1 km time trial faster as compared to the traditional crank system.

**2) INDICATE *WHOM THE SUBJECTS ARE AND NOTE EXPLICITLY WHETHER THEY INCLUDE MINORS (UNDER AGE 18, PER MONTANA LAW) AND/OR MEMBERS OF PHYSICALLY, PSYCHOLOGICALLY OR SOCIALLY VULNERABLE POPULATIONS.***

Subjects will include 8-12 well-trained cyclists living in the city of Missoula. Subjects will be between ages 18 and 40**.** Subjects will have a minimal maximal oxygen capacity ($VO_{2peak}$) of 50 $ml \cdot kg^{-1} \cdot min^{-1}$ and be free from the use of medication. Individuals with injury, illness or any risk factors for coronary heart disease (CHD) will be excluded from this study. Each subject will be screened for known risk factors of CHD using the physical activity readiness questionnaire (PAR-Q).

**3) INCLUDE *THE PROCEDURE(S) FOR RECRUITING OR SELECTION OF SUBJECTS.***

Participants will be recruited from within the city by word of mouth; that is to say, individuals helping with data collection will discuss and invite individuals interested in the study to contact the study coordinators (Walter Hailes or Brent Ruby). There are no cash payments or other inducements. Potential subjects will be informed, in advance all procedures that will occur during all phases of testing and that they will be given an accurate appraisal of their aerobic capacity based on standard tests and age-group. The procedures used in this research are standard exercise testing methods which require sub maximal intensities of exercise thus only recreationally active subjects with no risk factors for CHD will be included.

**4) *EXPLAIN WHERE THE STUDY WILL TAKE PLACE. IF ANY PERMISSION WILL BE REQUIRED TO USE ANY FACILITIES, INDICATE THOSE ARRANGEMENTS.***

This research will be coordinated at the University of Montana, Human Performance Laboratory in McGill Hall. No special arrangements are necessary. All materials, time and space are available for this research. **The research time trials will be conducted outdoors on road ride routes that Missoula cyclists commonly ride during normal training.**

**5) *INDICATE PRECISELY AND EXPLICITILY THE ACTIVITIES THE SUBJECTS WILL PERFORM AND HOW THE EXPERIMENTAL SUBJECTS WILL BE USED. DESCRIBE THE INSTRUMENTATION AND PROCEDURES TO BE USED AND KINDS OF DATA OR INFORMATION TO BE GATHERED. PROVIDE ENOUGH DETAIL SO THE IRB WILL BE ABLE TO EVALUATE THE INSTRUCTION FROM THE SUBJECT'S PERSPECTIVE.***

METHODS:

Eight to twelve recreationally active students, as discussed previously, will be recruited. Subjects will be required to visit the Human Performance Laboratory on three separate occasions. The first visit will take approximately 1 hour, while the second and third visits will take approximately 3 hours. The test and measurements for each visit will include:

ANTICIPATED SCHEDULE OF EVENTS IS AS FOLLOWS:

Prior to visiting the lab, subjects will be given a brief summary of research methodology.

**VISIT ONE will take approximately 1 hr:**

- Be seated in a comfortable seat and asked to relax while they read through the Informed Consent explaining the research. They will then be given an opportunity to have questions answered before choosing to participate. Prior to signing the informed consent, subjects will complete the ParQ (physical activity readiness Questionnaire) that serves as the screening tool to qualify subjects for participation. After this, the IRB approved consent form will be read and signed by the subject.
- Fill out a subject information form including name, address and telephone.

- Height and weight will be measured.
- $VO_2$peak will be measured using an electronically braked cycle ergometer. Ventilatory Threshold (VT) will be calculated using the data collected during the $VO_2$peak measurement for exercise intensity. VT is defined as the point at which pulmonary ventilation ($CO_2$ production) increases disproportionately with oxygen uptake during graded exercise.

**VISIT TWO and THREE will take approximately 3 hours**

- Visits two and three will include two 16.1 km time trial rides each. One trial will be completed on a bicycle outfitted with the Rotor crank system and the other bicycle will be outfitted with a conventional crank system.
- The trial order will be chosen randomly for visit two, and then the reverse order will be used for trial three.
- Subjects will complete two time trials on each visit.
- Subjects will be instructed to complete each trial as quickly as possible.
- A fifteen-minute warm up will be included, before each trial, to allow the cyclists to better prepare for the trial.
- Data to be measured during the four trials includes: duration (minutes), speed ($km*min^{-1}$), power (watts), heart rate ($beats*min^{-1}$).
- Heart rate will be measured using a chest strap, against the skin that transmits the heart rate data to a computer mounted on the bicycle.
- Power, time, and speed will be measured using a Cyclops PowerTap rear hub that transmits a radio signal to a cycle computer mounted on the bicycle.
- Subjects will be allowed an active recovery period of approximately 30-45 minutes between the first and second time trials
- During the ride, subjects will be followed by a chase vehicle that will bring additional water and provide mechanical assistance if you have a flat tire.

**6)** ***DISCUSS THE BENEFITS OF THE RESEARCH, IF ANY, TO THE HUMAN SUBJECTS AND TO SCIENTIFIC KNOWLEDGE.***

Benefits to the subjects will be minimal.

- o Subjects will be given the results of all testing.
- o Subjects who wish to know their results from the maximal cycle ergometer test will have those data explained to them compared to normative data.

This research should result in a meaningful and unbiased evaluation of the effectiveness of the Rotor crank pedaling system on cycling performance.

**7)** ***OUTLINE THE RISKS AND DISCOMFORTS, IF ANY, TO WHICH THE SUBJECTS WILL BE EXPOSED. SUCH DELETERIOUS EFFECTS MAY BE PHYSICAL, PSYCHOLOGICAL, OR SOCIAL. SOME RESEARCH INVOLVES VIOLATIONS OF NORMAL EXPECTATIONS, RATHER THAN RISKS OR DISCOMFORTS; SUCH VIOLATIONS, IF ANY, SHOULD BE SPECIFIED.***

**RISK/DISCOMFORTS**

1. Mild discomfort may result during and after the exercise. These discomforts include shortness of breath, tired or sore legs, nausea and possibility of vomiting.
2. Muscle soreness after the tests may occur as a result of the exercise, but should not persist.
3. Certain changes in body function take place when any person exercises. Some of these changes are normal and others are abnormal. Abnormal changes may occur in blood pressures, heart rate, heart rhythm or extreme shortness of breath. Vary rare instances of heart attack have occurred, as with other moderately strenuous exercise activities. Every effort will be made to minimize possible problems by the preliminary evaluation and constant surveillance during testing. Equipment and trained personnel are available to deal with unusual situations should they arise. A trained CPR technician will be on hand at all times and the laboratory has standard emergency procedures should any potential need arise.
4. Mild symptoms of dehydration such as headache and general fatigue may result during and after the exercise. Immediately after the exercise sessions, water will be provided to you.
5. You will be informed of any new findings that may affect your decision to remain in the study.
6. During any of the exercise tests should symptoms, such as chest discomfort, unusual shortness of breath or other abnormal findings develop, the exercise physiologist conducting the research will terminate the test. Guidelines by the American College of Sports Medicine will be followed to determine when a test should be stopped.
7. Due to the trials taking place in the field, it is possible that injury could occur due to environmental conditions including but not limited to, adverse road conditions, interactions with vehicular traffic, and inclimate weather.

**8)** ***DESCRIBE THE MEANS TO BE TAKEN TO MINIMIZE EACH SUCH DELETERIOUS EFFECT OR VIOLATION.***

Only well trained cyclists who are used to long maximal exercise bouts will be included in the research.

During any of the exercise tests should symptoms, such as chest discomfort, unusual shortness of breath or other abnormal findings develop, the exercise physiologist conducting the research will terminate the test. Guidelines by the American College of Sports of Medicine will be followed to determine when a test should be stopped. Subjects will be informed that they have the right to request that a test be stopped at any time.

The Laboratory of Health and Human Performance has in effect emergency procedures conforming to guidelines set by the American College of Sports Medicine. Someone currently certified in CPR will be present during each test.

The information that is obtained from the exercise test will be treated as a confidential medical record and will be seen only by the study investigators.

Each subject will be followed and monitored by a research assistant in a chase vehicle, during all road cycling. Only roadways typically traveled by cyclists and in safe riding condition will be used during this study.

**9)** ***INDICATE THE MEANS BY WHICH THE SUBJECT'S PERSONAL PRIVACY IS TO BE PROTECTED, AND THE CONFIDENTIALITY OF INFORMATION MAINTAINED.***

Names, phone numbers and addresses will be requested in the event that we need to later contact a subject or if the subject wishes to have the test results mailed. Each subject will be assigned a personal identification code (PID) for the research. This code will be kept with the subject's personal information, separate from all research data. Subjects will be identified in in-house research results only by their PID code. In addition, no names or individual data will be reported or used in any written reports or papers about this research. Individual data will be available only to the researchers at the University of Montana or released to the individual subject upon the subject's request. All research data will be kept in the Laboratory of Health and Human Performance, while the personal information files will be kept in the office of the lead investigator. Once the research is finished, all subject identification will be removed from the data, including ID #'s. The original data and subject files will be kept in separate locked offices for two years before being destroyed.

**10)** ***INCLUDE A COPY OF ANY WRITTEN CONSENT FORM TO BE SIGNED BY THE SUBJECTS, IF USED.***

Form attached.

**11)** ***IF A WAIVER OF WRITTEN INFORMED CONSENT IS DESIRED, INCLUDE JUSTIFICATION FOR THE WAIVER.***

Though the risk of injury or heart attack during exercise is considered to be minimal, there are slight risks. Subjects need to be aware of the nature of the testing and the potential risks of exercise in a field setting.

## Appendix B Institutional Review Board Checklist

For Internal
Use Only

**PROPOSAL #____**
Form RA-108
(Rev. 11/03)

The University of Montana
INSTITUTIONAL REVIEW BOARD (IRB)
**CHECKLIST**

Submit one completed copy of this Checklist, including any required attachments, for each project involving human subjects. The IRB meets monthly to evaluate proposals, and approval is usually granted for one year. See *IRB Guidelines and Procedures* for details.

Project Director: **Brent C. Ruby** Dept.: **HHP** Phone: x **2117**

E-mail: **brent.ruby@mso.umt.edu**

Signature:______________________________________Date: ____________________

Co-Director(s): **Walter Hailes** Dept.: HHP Phone: 546**-1120**

E-mail: **walter.hailes@umontana.edu**

Project Title: **Effects of the Rotor crank on 16.1 kilometer time trial performance**

Project Description: (in non-technical language)
**The purpose of this proposed study will be to evaluate the effect of the Rotor crank on the time to completion of 16.1 km individual time trials. It is possible that by improving the efficiency of the circular pedal stroke, by using the Rotor crank, individuals could increase their total power output without altering their effort.**

All investigators, including faculty supervisors, on this project must complete the self-study course on protection of human research subjects, available at the UM IRB website: http://www.umt.edu/research/irb.htm. Certification: I/We have completed the course - (Use additional page if necessary)

| Signature | Date | Signature | Date |
|---|---|---|---|
| | | | |
| | | | |
| | | | |

**Students Only:**
Faculty Supervisor: **Brent Ruby** Dept.: **HHP** Phone: **x2117**
Signature:____________________________________________________
(My signature confirms that I have read the IRB Checklist and attachments and agree that it accurately represents the planned research and that I will supervise this research project.)

For IRB Use Only

## IRB Determination:

____ Approved Exemption from Review — Exemption #______________

____ Approved by Expedited/Administrative Review

____ Full IRB Determination:
____ Approved
____ Conditional Approval (see attached memo)
____ Resubmit Proposal (see attached memo)
____ Disapproved (see attached memo)

Signature IRB Chair:_____________________________________Date:______________

## Project Information

1. Human Subjects. *Describe briefly (include age/gender)*: **Subjects will include trained male cyclists between the ages of 18-40 years with a minimal peak maximal oxygen consumption of 50 ml/kg/min and a recent road riding schedule of 100-400 miles/week.**

Are any of the following included? *Check all that apply.* **NA**
___ Minors (under age 18) If YES, specify age range(s):______________________________

___ Members of physically, psychologically or socially vulnerable population? Explain why:____
______________________________________________________________________________

2. How are subjects selected/recruited? *Explain briefly:* **Subjects will be recruited by word of mouth through the local cycling/triathlon community of Missoula, MT**

3. How many subjects will be included in the study? **At this time, we plan to include between 8-12 subjects**

4. Identification of subjects
__**x**__ Anonymous, no identification ____ Identified by name and/or address or other ____ Confidentiality Plan

5. Subject matter or kind(s) of information to be compiled from/about subjects.
*Describe briefly:*
**Subjects will complete two initial laboratory tests (body composition and maximal aerobic capacity) in addition to two field exercise trials (road cycling). Each of the two road cycling trials are comprised of two time trials on the same 16.1 km course, separated by a 30 minute rest period. Data collected during the road cycling include time to completion of the 16.1 km course, speed, power, and heart rate.**

Is information on any of the following included? *Check all that apply.* **NA**

____ Sexual behavior ____ Illegal conduct
____ Alcohol use/abuse ____ Drug use/abuse
____ Information about the subject that, if it became known outside the research, could reasonably place the subject at risk of criminal or civil liability or be damaging to the subject's financial standing or employability.

6. Means of obtaining the information. *Check all that apply.*

| | |
|---|---|
| _x_ Field/Laboratory observation | ___ Mail survey (Attach questionnaire/instrument) |
| ___ Tissue/Blood sampling | ___ On-site survey (Attach questionnaire/instrument) |
| _x_ Measurement of motions/actions | ___ Examine public documents, records, data, etc. |
| ___ In-person interviews/survey (Attach questionnaire/instrument) | ___ Examine private documents, records, data, etc. |
| ___ Telephone interviews/survey (Attach questionnaire/instrument) | ___ Use of standard educational tests, etc. |

___ Other means (specify):______________________________________________________________

Will subjects be videotaped, audio-taped or photographed? **Photographs may be taken upon consent. This has been included in the consent form.**

7. Is a written consent form being used? _**x**_ Yes *(attach copy)* ___ No

8. Will subject(s) receive an explanation of the research before and/or after the project?
___ Yes *(attach copy)* __**x**_ No
**(the IRB approved consent form will serve as the written explanation of the study).**

9. Is this part of your thesis or dissertation? __**x**__ Yes __ No
If YES, date you successfully presented your proposal to your committee: **November 2005**

10. Are you applying for funding for this project? ____ Yes ___**x**__ No __ Continuing Funding

# Appendix C  Subject Information and Consent Form

HUMAN PERFORMANCE LABORATORY
Dept of Health and Human Performance
UNIVERSITY OF MONTANA
Missoula, Montana

SUBJECT INFORMATION AND CONSENT FORM

Participant:________________________________ID#___________Today's Date___/___/___

Address:______________________________________________________________________

*Effect of the Rotor crank on 16.1 kilometer time trial performance*

**STUDY DIRECTOR(S)**: Walter Hailes 406-243-4780 University of Montana
Brent Ruby, Ph.D. 406-243-2117 University of Montana

This consent form may contain words that are new to you. If you read words that are not clear, please ask the person who gave you this form to explain their meaning.

**PURPOSE OF THE RESEARCH**
You may be eligible to take part in a research study to evaluate the effect of the Rotor crank on the time to completion of 16.1 km individual time trials. It is possible that by improving the efficiency of the circular pedal stroke, by using the Rotor crank, individuals could increase their total power output without altering their fitness.

**OVERALL PROCEDURES**
This research will require 3 visits to the Human Performance Lab in McGill Hall, University of Montana. You may be eligible to participate in this study if you are a trained male cyclist between the ages of 18-40, have a peak $VO_2$ of at least 50ml/kg/min and have a history of road riding between 100-400 miles/week.

The different tests that will be done as part of this study include:

1. A measure of underwater weight to establish body composition.

2. A graded exercise test on a road bicycle (mounted to a stationary trainer) to measure the maximal rate of oxygen your body can consume during intense exercise. This test will also allow us to estimate your ventilatory threshold (anaerobic threshold).

3. Four 16.1 km time trail rides on two separate days separated by at least one week. On each day of time trials you will receive a 30 minute rest between the first and second trial. The order of trials will be randomized and you will be blinded from performance information until completion of the study.

The following testing sessions will be completed for this study:

- Session 1: Body Fat Measurement-Underwater Weighing
This test will require that you do not eat for a minimum of 4 hours prior to testing. Prior to the test, your body weight will be recorded in your bathing suit. You will then be asked to complete 3-6 underwater weighing procedures. The underwater weighing requires that you are submerged in our weighting tank and that you perform a maximal exhalation while submerged. Your underwater weight will be recorded within 4 seconds and you will be signaled to surface. This procedure will be repeated until 3 measurements have been obtained that are within 100 grams of each other. A nose clip will be provided upon request. This test will take approximately 30 minutes.

- Session 2: Maximal Exercise Test-Cycle Ergometer:
This test will consists of riding a road bicycle provided by the laboratory mounted on a stationary trainer to a maximal effort. You will be asked to increase the resistance of the bicycle each minute by changing your cadence and/or your gears. This will progress to fatigue. You will be encouraged to continue to ride until exhaustion. During the entire testing session on the cycle, you will wear a nose clip and headgear that will support a mouthpiece. This will allow us to measure the amount of oxygen your body uses during exercise. Your heart rate will be measured using an elastic chest strap that is worn against the skin around your chest. This test will take approximately 1 hour. You should not eat for a period of approximately 3 hours prior to the completion of this test.

- Session 3, 4: Two 16.1 km time trial rides:
The order of these sessions will be randomized and the performance results will be blinded to you as a study participant, until completion of the study. These trials will be separated by no less than 7 days to allow full recovery between trial days. You will be required to arrive at the laboratory at your scheduled time having not eaten for approximately 3 hours. After arrival the following procedures will be completed in order.
1) After calibration of all instrumentation you will be required to ride the first bicycle, provided by the laboratory, to the start of the 16.1 km course, approximately 15 minutes. During this time you may perform a self-selected warm-up in preparation for the time trial.
2) When ready you will begin the first 16.1 km time trial of the day, followed by a chase car for protection and in case of an unforeseen emergency.
3) After completion of the first time trial you will be given 15 minutes of passive rest, while you are transported back to the beginning of the time trial course, followed by 15 minutes of active rest on the second bicycle.
4) After completion of the rest period, you will begin the second time trial of the day.
5) Upon completion of the second time trial you will be given the choice to ride back to the laboratory or be transported back by a research assistant. The total time commitment for each of these exercise session days will be approximately 3 hours (including exercise, rest and return).

**LOCATION AND STUDY LENGTH**
The majority of the study will be conducted outdoors on road ride routes that you commonly ridden during your normal training. The time commitments for each of the testing sessions have been indicated above. Your total time commitment for participation in this study is expected to be approximately 7.5 hours.

**RISK/DISCOMFORTS**

8. Mild discomfort may result during and after the exercise. These discomforts include shortness of breath, tired or sore legs, nausea and possibility of vomiting.
9. Muscle soreness after the tests may occur as a result of the exercise, but should not persist.

10. Certain changes in body function take place when any person exercises. Some of these changes are normal and others are abnormal. Abnormal changes may occur in blood pressures, heart rate, heart rhythm or extreme shortness of breath. Vary rare instances of heart attack have occurred, as with other moderately strenuous exercise activities. Every effort will be made to minimize possible problems by the preliminary evaluation and constant surveillance during testing. Equipment and trained personnel are available to deal with unusual situations should they arise. A trained CPR technician will be on hand at all times and the laboratory has standard emergency procedures should any potential need arise.
11. Mild symptoms of dehydration such as headache and general fatigue may result during and after the exercise. Immediately after the exercise sessions, water will be provided to you.
12. You will be informed of any new findings that may affect your decision to remain in the study.
13. During any of the exercise tests should symptoms, such as chest discomfort, unusual shortness of breath or other abnormal findings develop, the exercise physiologist conducting the research will terminate the test. Guidelines by the American College of Sports Medicine will be followed to determine when a test should be stopped.
14. Due to the trials taking place in the field, it is possible that injury could occur due to environmental conditions including but not limited to, adverse road conditions, interactions with vehicular traffic, and inclimate weather.
15. Irritation of the mouth might occur during $VO_2$peak testing as a result of using the mouthpiece required for collection of expired gas.

**BENEFITS OF PARTICIPATION IN THIS STUDY**

1. There is no promise that you will receive any benefit as a result of taking part in this study.
2. The information from these tests will provide you with an accurate assessment of your aerobic fitness and body composition that can be compared with norms for your age and sport, but may be of little benefit to your understanding of your personal fitness. There are no other direct benefits to the participants in the study.

**CONFIDENTIALITY**

1. Your records will be kept private and will not be released without your consent except as required by law.
2. Only the researchers will have access to the files.
3. Your identity will be kept confidential.
4. If the results of this study are written in a scientific journal or presented at a scientific meeting, your name will not be used.
5. All data, identified only by an anonymous ID#, will be stored in our laboratory.
6. Your signed consent form and information sheet will be stored in a locked office separate from the data.

**COMPENSATION FOR INJURY**

Although we believe that the risk of taking part in this study is minimal, the following liability statement is required in all University of Montana consent forms. "*In the event that you are injured as a result of this research you should individually seek appropriate medical treatment. If the injury is caused by negligence of the University or any of its employees, you may be entitled to reimbursement pursuant to the Comprehensive State Insurance Plan established by the Department of Administration under the authority of M.C.A Title 2, Chapter 9. In the event of a claim for such injury, further information may be obtained from the University's Claim representative or University Legal Counsel.*"

**VOLUNTARY PARTICIPATION/WITHDRAWAL**

1. You have the right to request that a test be stopped at any time.
2. Your decision to take part in this research study is entirely voluntary.
3. You may refuse to take part in or you may withdraw from the study at any time without penalty or loss of benefits to which you are normally entitled.
4. You may leave the study for any reason.

**You may be asked to leave the study for any of the following reasons:**

1. Failure to follow the study investigator's instructions.
2. A serious adverse reaction, which may require evaluation.
3. The study director/investigator thinks it is in the best interest of your health and welfare.
4. The study is terminated.

**QUESTIONS**

You may wish to discuss this with others before you agree to take part in this study.
If you have any questions about the research now or during the study contact: Walter Hailes at the Human performance laboratory 243-4780, Dr. Brent Ruby 406-243-2117(office), or the IRB chair 243-6670.

**SUBJECT'S STATEMENT OF CONSENT**

I have read the above description of this research study. I have been informed of the risks and benefits involved, and all my questions have been answered to my satisfaction. Furthermore, I have been assured that a member of the research team will also answer any future questions I may have. I voluntarily agree to take part. I understand I will receive a copy of this consent form.

___________________________________

Printed (Typed) Name of Subject

___________________________________ ____________

Subject's Signature Date

___________________________________ ____________

Witness Signature Date