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Comparison of Prototype Bicycle Pedal vs Traditional, Fixed Pedal and It's Effect on Efficiency and Power Output

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COMPARISON OF PROTOTYPE BICYCLE PEDAL VS TRADITIONAL, FIXED PEDAL

AND IT'S EFFECT ON EFFICIENCY AND POWER OUTPUT

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ABSTRACT

Purpose: To determine the prototype pedal's effect on efficiency and power output when compared to a traditional pedal.

Methods: Forty cyclists, aged 37.03 years, completed a 15-minute efficiency ride and 30 second Wingate power test on the prototype pedal and traditional bicycle pedal. Efficiency was calculated from a 15-minute ride at a set workload of 150W for females and 175W for males. The subjects rode at a cadence of their choice that represented their training speed. Heart rates were continually monitored during the ride and exercise post oxygen consumption (EPOC) was measured during the 10 minutes of recovery. Energy expenditure was calculated using the respiratory exchange ratio (RER) and applying set caloric values for each R-value. The Wingate power test was conducted on the Velotron bicycle using a PC with version 1.0 Wingate Software. The Velotron is a dynamometer calibrated and by design does not require recalibration. The resistance load was set at 7.5% of the subjects' mass in kilograms. The subjects were given 10 seconds to increase the pace to their maximal RPM before the resistance was applied. After 10 seconds, the specific resistance was immediately loaded onto the bicycle. Subjects worked maximally at this load for 30 seconds. Lactate levels were also measured after the ride.

Results: There were no significant efficiency differences found for the 40 cyclists. The only significant finding was for ventilation ($p= .012$) , which favored the traditional pedal. The gender breakdown showed that the females performed better on the traditional pedal for net ($p= .046$) and gross ($p= .038$) efficiency. The only significant difference for the males was ventilation rate ($p= .031$) but rate of perceived exertion was lower on the prototype ($p=.043$).

When analyzing the Wingate data for all 40 subjects, there were no significant differences found except for RPE ($p=.045$). Females were significantly better on the traditional pedal with anaerobic capacity ($p=.034$) and Mean RPM ($p=.027$).

Conclusions: No significant efficiency or power differences were found between the two pedals. 20 people performed better on the traditional and 20 performed better on the prototype.

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CHAPTER I

INTRODUCTION

Cyclists spend countless hours training for races and preparing for upcoming competitions. In order to maximize their performance, they focus on improving their time, power output and efficiency. There are a combination of factors that can help cyclists reach these goals, including the type of pedal they use and the pedal rate. Amongst the traditionally used pedals there are flat pedals, designs with and without clips and platform pedals, just to name a few. A new prototype pedal has been designed with the goal of maximizing the rider's power output and efficiency.

The pedal motion incorporates a skating movement where the legs move in a way that is similar to the motion of a skater. The movement is an inside to outside motion, much like a person who is roller-blading or ice-skating. The motion begins at the inside position at the top of the cycle, or wherever the beginning of the cycle begins, and moves outwards anywhere from a .25 inch to as far out as allowable in the circumference of the circle.

On a typical riding bike, this outward motion will move approximately 1.5 inches outward. The outer most distance away from the starting position is at the bottom of the cycle, or 180 degrees from the inner most position. As the cycle is completed back to the top or starting position, the motion returns back to its original inside position. This motion is created by the use of a cam, with a platform that can be angled anywhere from 1 degree to as far as 30 degrees from the cam, depending on its intended use. It is believed that the motion will increase muscle usage through the oblong like motion. The premise of this new pedal was that it would increase the rider's power output as well as their oxygen economy (efficiency).

Purpose of the Study

The purpose of this study was to evaluate the power output and efficiency of a standard bicycle pedal (Forte CR150 Road Pedal) and a new, prototype pedal.

Hypothesis I

It was hypothesized that the prototype pedal would allow the rider to increase their power output when compared to the traditional bicycle pedal design.

Hypothesis II

It was hypothesized that the prototype pedal would allow the rider to increase their efficiency rate when compared to the traditional bicycle pedal design.

Definition of Terms

- **Work Efficiency –** the amount of work done per unit of energy needed to perform the work. Efficiency = Output/Input x 100

- **Gross Efficiency -** Input energy requirement for efficiency contains resting energy expenditure
- **Net Efficiency –** Input energy requirement for efficiency with resting energy requirement
- **Gross Energy –** Exercise energy requirement plus resting energy requirement
- **Net Energy –** Exercise energy requirement minus resting energy
- **Exercise Post Oxygen Consumption (EPOC) –** The amount of oxygen consumed in the post-exercise recovery period to reserve the anaerobic reactions of the exercise period
- **Peak Power –** The highest mechanical power seen during Wingate test
- **Mean Power –** The average mechanical power during Wingate test
- **Anaerobic Capacity –** The mean power divided by body weight (Watts per kilogram of body weight)
- **Anaerobic Power –** Peak power divided by body weigh (Watts per kilogram of body weight)
- **Fatigue Index –** Peak watts minus Minimum Watt divided by test duration (30 seconds)
- **Total Work –** Average Watts times test duration (Joules)

CHAPTER II

LITERATURE REVIEW

In the past, there has been debate about the Wingate's accuracy in estimating anaerobic power and capacity. Minahan, Chia and Inbar (2004) concluded that power does not indicate capacity, suggesting, that when using the Wingate test, the fatigue index should be used to evaluate anaerobic capacity rather than mean power and peak power. Many believe that a 30 second Wingate test is not long enough to assess anaerobic capacity. Calbet, Chavarren, & Dorado (1997) note that a subject with high anaerobic capacity is not able to fully demonstrate this during a 30 or 45 second Wingate test.

MacIntosh, Rishaug and Svedahl also questioned whether 30 seconds is enough time to evaluate the peak power output. They then looked at whether a flying start was an appropriate protocol for the test and if the method of selecting the resistance was valid (2003). MacIntosh et al concluded that an optimal resistance level would allow for the highest peak power output based on the linear relationship between velocity and resistance.

In addition to scrutiny about the accuracy and relevance of the test, some researchers questioned whether testing the subjects in the morning, afternoon or evening had any effect on the results of the test. Souissi, Bessot, Chamari, Gauthier, Sesboue and Davenne (2007) chose several different times of day ("02:00, 06:00, 10:00, 14:00, 18:00, and 22:00 h" p. 741) for male, physical education college students to perform the Wingate test. Souissi et al used a resistance of 0.087 kilograms per kilogram of body weight and measured blood lactate levels before and after the test. It was found that peak power increased considerably from morning to mid-day during the testing procedures. However, blood lactate concentrations did not change. The authors concluded that the greater power decrease occurred in the early morning rather than in the afternoon, and that the time-of day effect on performances during the Wingate test is largely due to greater aerobic contribution in energy production during the test in the afternoon than in the morning (Souissi et al, 2007).

Kin-Isler (2006) also believed that the time of day had an effect on the test results. Circadian rhythms refer to physiological changes over a 24-hour time period. Body temperature has been stated to be the "fundamental variable" because it shows a distinct rhythm with a peak around 18:00 and a trough around 06:00h. Human performance measures Kin-Isler's (2006) study was to determine time-of-day effects in max anaerobic power and capacity and blood lactate levels after supramaximal exercise.

Fourteen male college students performed a Wingate test on three different days at different times; 9:00, 13:00 and 17:00h. Before each test, body weight, body temperature (oral) and heart rate were obtained. After the test, blood lactate levels were obtained at the 3rd, 5th and 7th minute of passive recovery. It was discovered that a significant circadian rhythm was found for body temperature, peak and mean power. It was concluded that a time-of-day effect was present in maximal anaerobic power and capacity (Kin-Isler, 2006).

A number of factors affect the amount of power produced during the Wingate test. When the subject stands for the test, the pedal force is almost double that of a seated position (Reiser, Maines, Eisenmann, Wilkinson, 2002). This can be substantiated by the fact that cyclists routinely stand when pedaling uphill to complete the climb. The increase in pedal force results from the change in range of motion of the lower-extremity joints (Caldwell, Li, McCole & Hagberg 1998). Furthermore, the force on the hip joint allows work to be done in a linear motion, which increases when standing (Resier et al., 2002).

McLester, Green and Chouinard (2004) studied the results of standing and seated posture during several Wingate trials, believing that standing while riding could enhance the total muscular performance, thus increasing Wingate performance. Thirty-five healthy participants performed three consecutive Wingate anaerobic power tests in both a seated and standing position. Peak power results were compared and it was concluded that the difference was not significant; however, significant increases in mean power, minimum power, and fatigue index were found during the standing test. This suggests that standing increases performance throughout consecutive Wingate cycling.

Peak power, mean power, fatigue index and anaerobic capacity were computed. Peak power (force times total distance) is measured during the first 5-seconds of the test. The force is the load, or resistance, that is applied to the bicycle flywheel. Total distance is the distance per revolution multiplied by the number of revolutions completed and time is 5 seconds (0.0833 minutes). Peak power is measured in watts (W) (Beneke, Pollmann, Bleif, Leithauser and Hutler, 2002).

Relative Peak Power (RPP) is calculated by dividing peak power by body mass; the result is expressed as W/kg. (http://www.sport-fitness-advisor.com/wingate-test.html) Anaerobic Fatigue (AF) is determined a bit differently. One takes the largest 5-second peak power output then subtracts the lowest 5-second peak power output. The answer is then multiplied by the highest 5-second peak power output (The Health Finder Limited (2008). Lastly, the result is multiplied by 100 to obtain a percentage. Anaerobic Capacity (AC) is expressed as kilogram-Joules (1 kg-m = 9.804 J) and is calculated by summing each 5-second peak power output over the 30 seconds (Beneke et al, 2002).

When evaluating efficiency, there are several factors that contribute to optimal efficiency. Chavarren and Calbet tested seven road cyclists to determine the influence of pedaling rate on cycling efficiency (1999). They focused on oxygen cost at different rates of pedaling, gross efficiency and the change in efficiency. Their study showed that lower revolutions per minute (60rpm vs 80,100,120) allowed for the best oxygen cost when cycling. They also found that gross efficiency was enhanced when the exercise intensity increased, but it decreased as the pedaling rate increased. Mechanical efficiency has been defined as the ratio between mechanical work and the energy needed to do the work. Economy was defined as the ratio between VO2 and power output.

Busko conducted research to understand the influence of pedaling frequency on mechanical efficiency during exercise with the same intensity. He collected data on 12 students that performed four tests, each lasting three minutes on a cycle-ergometer (2004). He kept the load steady (250W) as well as the mechanical work that was performed (45kJ). The pedaling rate was set at four different RPM's

(40,60,80,100) and the tests were conducted with a seven day rest period between each collection time. Busko used the same ratio to find gross efficiency as was used in previous studies and also calculated net efficiency as the "mechanical work and total net energy ratio (p51, 2004). Oxygen consumption was measured by a gas analyzer and software program and values were averaged every 20 seconds. The data showed that gross efficiency and net efficiency were highest at 80rpm and findings were consistent with previous studies. Despite this data, it has been noted that cyclists favor a higher rate upwards of 100rpm because it allows for "optimal application of force to pedals" (p 56., 2004).

Cyclists haven't always used the most efficient pedal rate when competing and their energy cost has suffered. Although cyclists favor a pedaling rate of at least 90rpm, the lowest oxygen consumption occurs between 42-60rpm (Kohler, Boutellier, 2005). Riders are usually focused on the power output and winning a race largely depends on maximizing their power output over a specific distance. Pedaling rate has a lot of influence on oxygen consumption and a lot of literature that discussed the preferred rate by cyclists vs. the rate that is more efficient. The discrepancy caused many to investigate this disparity between them. Marsh and Martin discovered that oxygen consumption is diminished when the pedal rate is between 40-65rpm at a power output below 200 watts (1993). At an increased power output, a pedal rate of 70-80 rpm minimized oxygen consumption, however, cyclists continue to select a pedal rate between 85-100rpm. One reason why a cyclist might choose a higher frequency is because a lower pedal force is required and it delays the occurrence of fatigue (Takaishi and Moritani, 1994).

Cannon, Kolkhurst and Cipriani also understood that pedaling technique and its effect on muscle activity contributes to the efficiency of cyclists. Their focus was on the relationship between the talocrural joint position and gross efficiency while riding. They believed that by manipulating the joint angles into a "dorsi and plantar-flexed position" then riders might be able to enhance their capacity for continuous cycling (p. 659, 2007). They tested this theory by conducting three tests on eleven trained cyclists using three different techniques – self selected pedaling, dorsi-flexed and plantarflexed. The cyclists rode for 6 minutes at 80% of their maximal aerobic capability. EMG allowed for muscle activity to be monitored while oxygen consumption was measured breath by breath using a metabolic measurement system (Cannon et al, 2007). The EMG activity revealed that the dorsiflexion position allowed for increased muscle activity but lessened the gross efficiency when compared to the riders' self-selected pedal stroke.

Coyle, Sidossis, Horowitz and Beltz were curious whether technique had a role in predicting cycling efficiency or if it was more influenced by muscular factors. To test this hypothesis, they estimated efficiency by measuring RER and whole body VO2 while cycling at specific work rates (1992). Nineteen competititve, male cyclists consented to muscle biopsies prior to testing and then participated in tests that evaluated their efficiency at a steady-work rate below the lactate threshold. Their findings showed a significant correlation between the percentage of Type 1 muscle fibers and gross efficiency.

Horowitz, Sidossis and Coyle conducted a study on Type 1 muscle fibers and how the percentage of fiber composition can affect cycling performance. Previous to this particular study they proved that cyclists with a higher percentage of type I fibers exemplify a higher efficiency when riding (Coyle, Sidossis, Horwitz, Beltz, 1992). Horowitz et al. conducted biopsies of the muscle fibers in the vastus lateralis prior to the one hour test where VO2 max, blood lactate and average VO2 were measured. If the subjects had a composition of Type I fibers that was greater than 56% they were put in the High % Group and the rest were put in the Normal % Group. When comparing the results between both groups, it was found that the High % Group sustained a power output that was 9% greater than the Normal % Group as well as a significantly higher gross efficiency rate (1994).

In 1996 Barstow, Jones, Nguyen and Casaburi hypothesized that there was a correlation between type II (slow twitch) fibers and slow component oxygen uptake during intense exercise. Skeletal muscle is comprised of two primary fiber types, each providing benefits for certain types of exercise. Coyle, Sidossis, Horowitz and Beltz found that cyclists with a larger percentage of type I fibers could produce a higher power output at the same VO2 than those with a smaller percentage of type I fibers (1992). Since type II are not as efficient, those with type I have a better advantage when cycling. Barstow et al. tested this theory in a series of four trials on 10 subjects while pedaling at 45, 60, 75 and 90rpm. They took biopsies of the muscle fibers to analyze their composition. When analyzing the data, a faster pedal rate revealed an association with a decrease in relative stress but didn't have any impact on the association between fiber type percentage and VO2 factors (1996). After further investigation, Barstow et al. concluded that the distribution of fiber type had a noteworthy affect on both the slow and fast components of VO2 during intense exercise.

When looking at cycling efficiency is it important to understand definitions and applications of the word. Gross efficiency, as defined by Moseley and Jeukendrup, is the "ratio of work done during the specific activity to the total energy expended and expressed as a percentage" (p 621, 2000). Next, the reliability of calculating efficiency must be tested. There has been some discussion that the gross efficiency ratio and its linearity makes one thing that efficiency increases with work rate by distorting the relationship between work rate and energy expenditure (Moseley et al, 2000). What some fail to look at is the energy required to maintain homeostasis and how that plays into calculating efficiency while cycling or just exercising in general. Since efficiency is influenced by many different factors, the reliability of measuring it has been questioned. The researchers' goal was to measure the reproducibility of efficiency while using a cycle ergometer. They had 17 male subjects pedal at a constant rate of 80rpm and measured oxygen uptake as well as VCO2. The work-load began at 60W and increased by 35W every three minutes, all while maintaining a steady pedal cadence. Moseley et al had the subjects pedaled until exhaustion and tested them three different times, making sure the same seat height and angle were steady throughout the testing since these factors due affect efficiency (2000). It was concluded that this type of testing allowed for reproducible measurements of efficiency.

Several studies have focused on bike pedal positioning, cadence, crank length, seat height and angular positioning. Zamparo, Menetti and Prampero believe that modifying the gear to each rider will allow for optimal power transfer (2002). Zamparo et al. hypothesized that greater efficiency can be achieved by a pedal-crank prototype whose length changed as a function of the crank angle being "maximal during the pushing phase and minimal during the recovery one" (p.1387). The researchers saw no significant difference at low intensities between the two pedals but there was a lower oxygen uptake and a 2% larger efficiency rate at a higher intensity of 250-300W (2002).

Herzog and Yoshihuku (1990) believe that the current apparatus of pedaling with fixed crank length and crank angular velocity values do not permit maximal power to be achieved. If these two constraints can be adjusted, there would be an improvement in overall power. In regards to the crank length, previous studies have agreed that optimal crank length has a direct relationship to the subject's height (Abbott and Wilson, 1995).

The push and pull motions during cycling are integral in maintaining efficiency while riding. Gruben, Ortiz and Schmidt researched the control of foot force during the pushing efforts while cycling. They designed a study to further understand the motor system and isolated the muscles used during the foot force while pedaling (2003). The subjects rode a cycle ergometer at a rate of 60rpm while trying to match specific foot force (force path) targets. An electric motor kept the velocity of the crank angle at a constant rate. By keeping the intertia and posture components at a steady rate, the changes in foot force could easily be accredited to the variance of muscle force production. The researchers compiled data on the crank angle, pedal angle and foot force that allowed them to create a graph display for each of the different angles during the pushing phase of the pedaling cycle. Most of the force paths were a straight line while some were a simple curve.

Different muscle fibers, slow twitch (ST) and fast twitch (FT), also contribute to efficiency rates. Hansen and Sjogaard conducted a study with the hypothesis that muscular efficiency is related to the percentage of ST muscle fibers and that the relationship is even more apparent at lower pedal rates than higher ones (2007). The two concluded that muscular efficiency had a positive correlation with %ST fibers when pedaling at 115rpm but not at 61 or 88rpm. There have been some discrepancies between studies about efficiency rate increasing or decreasing based on pedal rate. A few studies showed that muscular efficiency increased when the pedal rate increased (Asmussen, 1952; Boning et al., 1984, Sidossis et al., 1992; Chavarren & Calbet, 1999; Martin et al., 2002). Gaessar & Brooks, however, found that the efficiency decreased with an increase in pedal rate (1975).

Children and adults were tested by a group of researchers in order to see the effect of age and pedaling rate on cycling efficiency. Martin, Hautier and Bedu conducted a series of tests at two different pedal rates (60 rpm, 90rpm) in which external mechanical power and metabolic power were measured. Metabolic power was calculated by using a Douglas bag and then VO2 was converted using an energy equivalent of 20.6kJ. The study showed a correlation between gross efficiency and efficiency of muscle contraction and metabolic internal power (2001). Martin et al. demonstrated that the increase in efficiency and metabolic internal power was influenced by an increase in pedal rate. They did, however, find that metabolic power was higher in children at 90rpm than adults at the same pedaling rate (2001).

Maximal oxygen consumption was obtained for 10 women bicycling on rollers at 3 saddle heights (SH), 95, 100 and 105% trochanteric height. Kinematic patterns described by the hip, knee, ankle and foot were discerned from one pedal cycle at each of the 3 SH. Subjects cycled on a Fuji Dynamic 10 10-speed bicycle, at 60 rpm, (a work load of 799 kpm/min was applied by a tensioning belt from a bicycle ergometer) until they reached steady state. Expired air was then collected and cine films were taken during gas collection. The 100% SH was most efficient, mean values for 95, 100 and 105% SH were 1.69, 1.61 and 1.74 lit/min, respectively. Kinematic patterns showed no variation in the range of motion (ROM) at the hip, values at the dead centers (DC) did change. The ROM at the knee varied from 69 to 82.9 degrees, 95 to 105% SH, values at the DC varied also. Plantar flexion (PF) at bottom dead center increased by 10% from 95 to 105% SH. Foot angle showed no significant variation with increasing SH. The major adaptations to increases in SH are found at the knee and in ankle PF. (Armon, Cooper, Flores, Zanconato, Barstow 1991).

Another study focused on a new way of scaling, allometric, rather than the traditional way of ratio scaling, which fails to make proper modifications for body mass (BM). Ratio scaling assumes that BM was appropriately controlled for but the results are not conclusive because there are positive and negative correlations depending on the size of the subjects. (Winter 1992). Allometric scaling differs from ratio scaling because it is not influenced by BM. This method is an efficient way of measuring anaerobic power because it efficiently controls for BM (Hetzler, Stickley, Kirmura, 2009). The application of this type of scaling has been used of late to analyze Wingate data but there is some concern about its validity. Hetzler et al. wanted to design a study that showed the benefits of allometric scaling and establish percentile ranks for female subjects. One hundred women performed a 30 second Wingate test and Hetzler et al developed a set of percentile ranks and exponents to analyze peak power and mean power. The researchers applied these to the data to determine the validity. Through a series of calculations and logrhythmic models they were able to determine its level of effectively removing the effect of MB for peak power and mean power.

A study in 2008 focused on the upstroke phase and whether the shoe-pedal interface had an effect on the pulling-up action. The subjects completed a series of three tests at 60% of their maximal aerobic power and at a pace of 90RPM. The subjects included seven non-cyclists as well as eight elite cyclists. The cyclists performed the test with clipless pedals, a single pedal and with pedal force feedback (Mornieux, Stepelfeldt, Golhofer, Belli, 2008). The results of all 3 tests showed no significant difference between the single pedals and clipless pedals in terms of muscular activity, net mechanical efficiency or effectiveness. There was a significant difference, favoring the pedal force feedback, in effectiveness and muscle activity on the upstroke between the clipless pedals and the pedal force feedback.

The previous studies focused on several key aspects of cycling and testing. The research showed that pedal cadence, time of day, muscle fiber composition, pedal force, riding position and testing protocols all contribute to the accuracy of the test, the performance of the subjects and the validity of the data. Specific cadences are more advantageous for efficiency while others are more beneficial for power output. A time-of-day effect should be considered when testing subjects because a larger power decrease occurred during the early morning rather than the afternoon. Those with Type I muscle fibers consistently performed better during efficiency testing than those with Type II fibers. When a subject stood for the Wingate test, the pedal force was significantly increased as well as mean power and minimum power. All of these factors should be taken into consideration when conducting research and testing subjects.

CHAPTER III

METHODS

This was an experimental study to examine the differences in efficiency, power output and energy consumption between two different kinds of bicycle pedals (Prototype vs. traditional). The prototype pedal uses a skating movement where the legs move in a way that is similar to the motion of a skater. As the rider pushes the pedal down, it traverses outward and upon the completion of the upward motion the pedal traverses back to the original starting position.

All of the subjects were tested and randomly assigned to the prototype or standard pedal to avoid any order effect.

Subjects

Forty healthy, male and female, volunteers were recruited from local cyclist groups in the Cleveland, Ohio area. The subjects all train and regularly participate in bicycle road races throughout the year. Prior to participation, all participants signed a written, informed consent approved by the Institutional Review Board at Cleveland State

University as well as a non-disclosure agreement. Each subject was screened for any health risk using the AHA/ACSM Pre-participation Screening Questionnaire and anyone that answers “yes” on any item that indicates a history of respiratory, metabolic, or cardiovascular disease were excluded. Also, any subject taking prescription medication that could possibly effect the results of the study or have prior instances of chest pain, dizziness or fainting was excluded. Only low risk subjects were considered for this study.

Procedures

Efficiency Testing

This testing took place in the Human Performance Laboratory at Cleveland State University. The subject was weighed to the nearest ¼ lb and height was measured to the nearest ¼ inch using a stadiometer and medically balanced scale. The saddle height and handle bar distance were adjusted according to the subject’s height and arm length in order to accommodate different size riders. Each subject was tested on the Velotron Dynafit Pro, an electronic bicycle that connected to a PC using Velotron CS software. The subject sat quietly for five minutes before data collection for resting values. Resting and exercise heart rates along with continuous measurement of oxygen consumption were recorded throughout the test. Heart rates were obtained using a Polar heart rate monitor and chest strap. Oxygen consumption was measured using the Cosmed K4 b2 portable oxygen and carbon dioxide analyzer.

After the initial resting data was collected they began the ride at the specific workload. Efficiency was calculated from a 15-minute ride at a set workload of 150W for females and 175W for males. The subjects rode at a cadence of their choice that represented their training speed. During the ride, heart rates were continually monitored by a Polar heart rate monitor and exercise post oxygen consumption (EPOC) was measured during the 10 minutes of recovery after the 15 minute ride was completed. A minute by minute average of each measurement was analyzed for an overall efficiency rate. Energy expenditure was calculated using the respiratory exchange ratio (RER) and applying set caloric values for each R-value. In addition, the subject reported their rate of perceived exertion (RPE) using the Borg scale at the end of the test.

Power Output Testing

The Wingate power test was conducted using a PC with version 1.0 Wingate Software. The Velotron is a dynamometer calibrated and by design does not require recalibration. The Wingate Software allows for 3 different torque functions, an unlimited number of protocol settings and consecutive results to be automatically stored. The results are plotted on a graph at the end of each testing session and all of the subjects' results can easily be exported as a comma separated value file.

The 15-minute efficiency ride served as a warm up for the Wingate power test. Each subject completed a 30 second Wingate test which measured Peak Power, Mean Power, Anaerobic power, Anaerobic capacity, total work, fatigue index and Peak RPM. Fatigue index is also referred to as anaerobic fatigue and is the percentage decline in power output during the test. It is determined by calculating the difference between the peak watts minus the minimum watts, then divided the time of the test (30 seconds). Power was analyzed and expressed in watts, while the work completed was measured in Joules.

The resistance load was set at 7.5% of the subjects' mass in kilograms. To begin the test, subjects were instructed to pedal at a comfortable pace for 1-2 minutes prior to the start. The protocol for the Wingate test required the subjects to remain seated. They were given 10 seconds to increase the pace to their maximal RPM before the resistance was applied. After 10 seconds, the specific resistance was immediately loaded onto the bicycle. Subjects worked maximally at this load for 30 seconds. When the test was completed, the resistance was removed and the subject continued to pedal at a relaxed pace for a few minutes.

Blood Lactate Analysis

Blood lactate is a product of anaerobic metabolism. It reflects the amount of anaerobic work that the muscles perform. Post-test lactate was assessed two minutes after the test was completed using a micro technique that requires a finger prick with a blood lancet to acquire a small drop of blood. The finger was cleaned with alcohol prior to testing and dried with gauze. The Microtouch lancet was then used to make a small stick to obtain a drop of blood. The drop of blood was placed in the Lactate plus analyzer for analysis and a band-aid is placed over the prick site.

SPSS

Data was analyzed for the total group and gender differences by using inferential statistics, paired T tests, were used to assess treatment differences due to the independent variable (pedal type) on the dependent variables (power output and efficiency).

CHAPTER IV

RESULTS & DISCUSSION

Subjects

Forty cyclists participated in a study to evaluate the efficiency (economy of oxygen) and power output of a standard bicycle pedal (Forte CR 150 Road Pedal) and a new, prototype pedal. The 40 cyclists (average age was 37.03 years old, 174.57 cm, and 76.36 kg) were comprised of 17 females (36.18 years old, 166.85 cm, and 62.27 kg) and 23 males (37.65 years old, 180.47 cm, and 86.72kg).

Efficiency

Net efficiency, gross efficiency, net energy, gross energy, ventilation, EPOC, heart rate and RPE were measured using each set of pedals (Table 1). The only significant finding was for ventilation, which favored the traditional pedal. Since they were allowed to self-select their cadence, an analysis was done for the men and women. Each pedaled at a similar cadence for each pedal. There were no significant differences for this category in either gender. The men had a mean RPM of 84.25 on the prototype pedal and a mean RPM of 83.42 on the traditional pedal. The women had a mean RPM of 85.76 on the prototype pedal and a mean RPM of 82.76 on the traditional pedal.

Table 1. Efficiency results from the prototype and traditional pedals

N=40		**Mean**	**Std. Deviation**	**Sig. (2 tailed)**
Pair 1	ProEFfNet	25.75	3.99	0.127
	TraEffNet	26.72	3.86	
Pair 2	ProEffGross	20.31	2.83	0.121
	TraEffGross	20.97	2.73	
Pair 3	ProNetEnergy	140.1	24.63	0.124
	TraNetEnergy	134.92	23.95	
Pair 4	ProGrossEnergy	177.46	30.92	0.074
	TraGrossEnergy	171	28.42	
Pair 5	ProVent	62.2	8.45	0.012*
	TraVent	59.14	7.21	
Pair 6	ProEPOC	1.78	0.78	0.261
	TraEPOC	1.63	0.8	
Pair 7	ProHR	145.67	18.1	0.278
	TraHR	144.26	16.61	
Pair 8	ProRPE	12.48	1.62	0.073
	TraRPE	12.76	1.74	

*significance $p \leq .05$. **Gross Efficiency -** Input energy requirement for efficiency contains resting energy expenditure. **Net Efficiency** – Input energy requirement for efficiency with resting energy requirement. **Gross Energy** – Exercise energy requirement plus resting energy requirement. **Net Energy** – Exercise energy requirement minus resting energy. **Exercise Post Oxygen Consumption (EPOC)** – The amount of oxygen consumed in the post-exercise recovery period to reserve the anaerobic reactions of the exercise period.

Gender Differences

To determine if there was a difference between genders using the two types of pedals, 17 females and 23 males were analyzed for net and gross efficiency, energy cost, ventilation, EPOC, HR and RPE (Tables 2 &3).

Table 2. Female efficiency data with significant differences

N=17		Mean	Std. Deviation	Sig. (2 tailed)
Pair 1	ProEFfNet	25.97	4.19	0.046*
	TraEffNet	28.23	4.58	
Pair 2	ProEffGross	20.86	2.76	0.038*
	TraEffGross	22.43	3.17	
Pair 3	ProNetEnergy	126.86	19.94	0.076
	TraNetEnergy	117.12	20.91	
Pair 4	ProGrossEnergy	156.87	21.05	0.065
	TraGrossEnergy	146.41	22.46	
Pair 5	ProVent	61.1	5.9	0.114
	TraVent	59.29	7.7	
Pair 6	ProEPOC	1.63	0.57	0.248
	TraEPOC	1.43	0.51	
Pair 7	ProHR	152.62	11.72	0.295
	TraHR	150.94	9.91	
Pair 8	ProRPE	13.35	1.41	0.503
	TraRPE	13.56	1.62	

* significance $p \leq .05$. The females were significantly more efficient using the traditional pedal when compared to the prototype pedal.

Table 3. Significant differences in male efficiency data

N=23		Mean	Std. Deviation	Sig. (2 tailed)
Pair 1	ProEFfNet	25.58	3.95	0.973
	TraEffNet	25.61	2.84	
Pair 2	ProEffGross	19.92	3.86	0.976
	TraEffGross	19.89	1.75	
Pair 3	ProNetEnergy	149.88	23.47	0.675
	TraNetEnergy	148.07	16.55	
Pair 4	ProGrossEnergy	192.68	28.34	0.467
	TraGrossEnergy	189.17	15.89	
Pair 5	ProVent	63.01	9.98	0.031*
	TraVent	57.73	10.06	
Pair 6	ProEPOC	1.89	0.91	0.566
	TraEPOC	1.78	0.94	
Pair 7	ProHR	140.83	20.31	0.531
	TraHR	139.61	18.83	
Pair 8	ProRPE	11.83	1.47	0.043*
	TraRPE	12.17	1.61	

*significance $p \leq .05$. The males showed no differences in efficiency but did show significantly lower ventilation using the traditional pedal. However, their perception of exertion was lower on the prototype even though the data didn't reflect this.

Power Output

Forty subjects performed a 30 second Wingate Anaerobic test on each pedal and the results were recorded with the Wingate software. The data recorded measured mean watts and peak watts, anaerobic capacity, anaerobic power, lactate levels, fatigue index peak RPM, mean RPM, minimum RPM and total work done (Table 4). Amongst these eleven categories, the only variable that showed a statistically significant difference was lactate level (p=.045). The average lactate level on the prototype pedal was 11.57 mmol and the traditional pedal had a lactate level of 11.05 mmol.

Table 4. Overall power data. *N=40*

N=40		**Mean**	**Std. Deviation**	**Sig. (2 tailed)**
Pair 1	ProMeanWatts	618.45	136.36	0.349
	TraMeanWatts	622.15	136.81	
Pair 2	ProPeakWatts	987.56	250.44	0.122
	TraPeakWatts	972.18	243.24	
Pair 3	ProMinWatts	438.18	102.05	0.985
	TraMinWatts	438.33	110.02	
Pair 4	ProAnaerCap	8.16	0.99	0.265
	TraAnaerCap	8.22	0.95	
Pair 5	ProAnaerPow	12.9	1.21	0.146
	TraAnaerPow	12.72	1.27	
Pair 6	ProTotWork	18202.39	4865.48	0.997
	TraTotWork	18199.93	5054.09	
Pair 7	ProFatigueIndex	18.67	6.94	0.094
	TraFatigueIndex	17.81	6.21	
Pair 8	ProPeakRPM	174.9	17.62	0.258
	TraPeakRPM	172.7	17.24	
Pair 9	ProMeanRPM	111.48	13.65	0.275
	TraMeanRPM	112.18	12.89	
Pair 10	ProMinRPM	79.03	13.99	0.409
	TraMinRPM	79.95	13.41	
Pair 11	ProLactate	11.57	2.35	0.045*
	TraLactate	11.06	2.18	

*significance $\leq$.05. **Peak Power** – The highest mechanical power seen during Wingate test. **Mean Power** – The average mechanical power during Wingate test. **Anaerobic Capacity** – The mean power divided by body weight (Watts per kilogram of body weight. **Anaerobic Power** – Peak power divided by body weigh (Watts per kilogram of body weight). **Fatigue Index** – Peak watts minus Minimum Watt divided by test duration (30 seconds).

Similar to the efficiency results, when broken down between men and women, there were some significant differences. The male riders did not show any significant difference between the two pedals. The female riders were statistically different in anaerobic capacity and mean RPM (Table 5), favoring the traditional pedal.

Table 5. Female power data

N=17		**Mean**	**Std. Deviation**	**Sig. (2 tailed)**
Pair 1	ProMeanWatts	485.71	57.03	0.052
	TraMeanWatts	492.24	53.91	
Pair 2	ProPeakWatts	756.29	104.85	0.537
	TraPeakWatts	749.94	95.26	
Pair 3	ProMinWatts	356.12	61.49	0.553
	TraMinWatts	349.06	70	
Pair 4	ProAnaerCap	7.87	0.94	0.034*
	TraAnaerCap	7.99	0.94	
Pair 5	ProAnaerPow	12.16	0.91	0.594
	TraAnaerPow	12.08	0.89	
Pair 6	ProTotWork	13929.42	3642.29	0.223
	TraTotWork	14766.32	1619.48	
Pair 7	ProFatigueIndex	13.49	3.98	0.436
	TraFatigueIndex	13.13	3.23	
Pair 8	ProPeakRPM	164.24	14.84	0.968
	TraPeakRPM	164.36	12.28	
Pair 9	ProMeanRPM	107.41	12.81	0.027*
	TraMeanRPM	109.06	12.66	
Pair 10	ProMinRPM	78.59	14.89	0.387
	TraMinRPM	79.76	13.33	
Pair 11	ProLactate	10.82	2.23	0.079
	TraLactate	10.19	2.16	

*significance $\leq$.05

Discussion

The prototype pedal was engineered and designed to allow for better efficiency and a greater power output but the data did not support this claim. The concept of the traversing was well thought out but several things could be improved upon by further testing. The current model traverses 1.5 inches but more research might be necessary to find the optimal distance for an increase in efficiency and/or power output. It may be possible that 1 inch is a more advantageous distance than 1.5 inches so further engineering designs could prove to be beneficial.

Also, the difference in hip angles of men and women could be a factor in determining the traversing distance. The females performed better on the traditional pedal in terms of efficiency and power. One possible reason is due to the wider hip angle. When the women pedal their legs already come in at an angle so the outward motion might not be advantageous for them. This may have contributed to their power output during the Wingate test because they weren't able to pedal as fast.

The mean pedal rates were very similar between the men and the women and ranged from 82-86 RPM. A previous study conducted by Busko found that net efficiency and gross efficiency were highest at 80RPM. The cyclists in the current study were very close to this speed. However, Kohler and Boutellier's research showed that the lowest oxygen consumption was between 42-60RPM. Marsh and Martin's data suggested that a pedal rate of 70-80 rpm minimized oxygen consumption, however, cyclists continue to select a pedal rate between 85-100rpm.

In order to produce more power, some riders prefer to stand when they approach a hill with a very steep grade. After the test was explained to them, about half of the subjects asked if they were allowed to stand during the Wingate test. The subjects were specifically instructed to stay seated throughout the entire test because that is the standard Wingate protocol. However, there is some merit to the cyclists' desire to stand because McLester et al. found that standing significantly improved the mean power, minimum power and fatigue index. Reiser et al. also concluded that standing greatly impacts the pedal force, almost doubling it.

There was some variability among the riders that were tested. Several were ironmen competitors, others were tri-athletes, some trained all year and others only rode seasonally. Of the highly trained male athletes, the prototype seemed better than the traditional pedal. Furthermore, some were road cyclists while others were off road riders.

A pedal design in 2002 was tested to determine whether efficiency could be increased if the crank length changed during the pushing and pulling phase of the 360-degree pedal rotation. The prototype pedal that was tested in 2011 had a similar theory and design. The data from the previous study showed no significant efficiency difference at low intensities (up to 200 Watts) and this matched the data collected on the current prototype for this research project.

The difference in power output between the men and women can be explained by lean body mass and muscle fiber size. In a study conducted by Miller, MacDougall, Tarnopolksy and Sale, it was found that women's lower body strength was only 66% as strong as men and that males had larger type I fiber areas (1993). The power results of the men and women in this study were consistent with these findings and the men did have a larger power output.

CHAPTER V

SUMMARY & CONCLUSION

Forty cyclists took part in this study to determine whether a new, prototype pedal was more efficient and allowed for more power output than a traditional pedal. After analyzing the data from all forty riders, no significant efficiency or power output differences were found between the two pedals. When the data was separated by gender, there were a few categories that showed significant differences. The women performed better on the traditional pedal and showed significant differences in net and gross efficiency. The men had a better ventilation rate with the traditional pedal but perceived the ride on the prototype pedal to easier. While the RPE was significantly different on the prototype, their performance was not. The data showed that 20 people performed better with the traditional pedal and 20 people performed better on the prototype. The efficiency and power output hypotheses were both rejected because there were no statistically significant differences found between the prototype and traditional style pedal.

Application

The design and concept of the pedal does show some advantages for certain riders, more specifically, male riders. It is unknown how effective it could be and further research is recommended in order to fully grasp the benefit of this device. There is something that makes this design work for some and not as well for others; it is important to find out what that aspect is and then use it to it's full potential.

Limitations

1. Variation in training; Each rider maintained different training regimens and some may not have been training as hard in the winter months, when the testing was conducted.
2. The type of athletes tested; Some of the subjects were strictly cyclists while others competed in Ironmen events and triathlons. This could have had an effect on their level of training or riding proficiency.
3. The type of cyclist; There was a mix of road and off-road cyclists in the population that was tested. Some did not have much experience with riding shoes and being clipped into pedals so it could have affected their performance.
4. The type of pedals the subjects normally use; The subjects all ride different styles of pedals during their normal training and some use a type of pedal that pivots and has some degree of motion. Those riders are used to movement while the riders who use a fixed pedal are not. This could have affected their RPE and performance.

5. The testing occurred over a period of two months and was based on schedule availability. The second test was not always conducted at the same time of day as the first. Previous research showed that it was better to test subjects in the afternoon because power considerably increased from the morning to mid-day. The variability of testing times could have had some effect on performance but the order in which each person tested the different sets of pedals also could be a contributing factor when combined with the time of day. It is difficult to isolate the two factors.

Future Recommendations

Based on the results of this study, the pedal showed more promise for male riders than female. To test this theory, it might be beneficial to give a few of the riders their own set of pedals to train and compete with to fully understand the potential benefits of the design. It may also be important to design a second prototype that traverses a different distance in order to find the optimal distance for efficiency and power output.

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APPENDIX A

Assessment of prototype bicycle pedal to standard bicycle pedal for efficiency, power output, muscle activation and fatigue, and kinematics

Informed Consent

This study is being implemented by Dr. Kenneth Sparks, Director of the Human Performance Laboratory, and Graduate Student Renee Goldstein.

Purpose of the Study: I understand that the purpose of this study is to examine differences in power output and energy consumption between two different types of bicycle pedals (traditional pedal vs. newly developed prototype pedal).

I understand that I must inform the investigator if I am allergic to adhesive tape. In that case I cannot participate in the study. I will be asked my age and required to complete the American Heart Association/American College of Sports Medicine prescreening questionnaire to determine whether I am at low risk for the occurrence of a cardiovascular problem as a result of exercise. If I am found to be at anything other than a low risk level, I will not be allowed to participate in this study.

I understand that I will be asked to come into Cleveland State University for two sessions. Each session will be about an hour. This is a total time commitment of approximately 2 hours. I also understand that I will be using either the prototype pedal or the traditional bicycle pedal in each set of sessions.

Procedures

Sessions I & II: Measurement of Power Output and Exercise Intensity

I understand that during the first two sessions, I will come to the Human Performance Laboratory. The bicycle seat height will be adjusted properly for me.

I will warm-up with 5-10 minutes of low-intensity cycling interspersed with 5 second bouts of all-out pedaling. Then I will then be allowed 2-5 minutes to rest before starting the actual test of pedaling power output.

For this test, I will begin pedaling as fast as possible without any resistance. Within 5 seconds, the tester will set the stationary bike resistance to the higher level of resistance required for this test, which is determined based on my body weight. As soon as the resistance is applied, I will cycle as fast as possible for 30 seconds.

After I complete the 30 second test, the resistance will be decreased and I will pedal at a comfortable rate for several minutes following the test to allow my heart rate and blood pressure to return to normal.

In addition, my blood lactate, a blood marker of exercise intensity, will be measured both before and after this pedaling test. Blood will be taken using a finger prick with a blood lancet to acquire a small drop of blood. My finger will be cleaned prior to the stick with alcohol and dried with gauze. A bandage will be placed over the wound.

Finally, my energy consumption will be measured by monitoring my heart rate and how much oxygen I use while pedaling suing each type of pedal. I will wear a heart rate monitor and face mask for these measurements. I will then put on the heart rate monitor and face mask, and sit quietly for five minutes before data collection to obtain resting oxygen consumption and heart rate values. I understand that resting and exercise heart rates along with continuous measurement of oxygen consumption will be recorded throughout the test. Oxygen consumption will be measured using the Cosmed K4 b2 portable oxygen analyzer. After resting data has been collected I will begin pedaling the bicycle ergometer at either 600 kgm (for women) or 750kgm (for men) for 15 minutes.

At the conclusion of the 15 minutes of exercise I will remain on the bicycle and sit for 10 minute to measure recovery data. Then the face mask, heart rate monitor, and all equipment will be removed.

Risks and Benefits:
I understand the potential risks associated with this study include mild muscle soreness resulting from riding the bicycle and discomfort experienced from giving finger sticks for obtaining blood lactate. I also, understand that during exercise testing, there exists the possibility of certain changes occurring; these include abnormal blood pressure, fainting, disorders of the heart rhythm, and rare instances of heart attack, stroke or death (1:20,000 exercise tests). I understand the laboratory has emergency procedures in place and every effort will be made to minimize these risks. The benefit to me as a participant is receiving $50 for my participation.

Responsibilities of the Participant
I will need to complete a medical history using the American Heart Association/ American College of Sports Medicine prescreening questionnaire. This screening tool is used to ascertain that I am at a low risk of experiencing cardiovascular problems as a result of exercising. The information I submit and that is contained therein will be used in the determination of my eligibility to participate in this study.

Confidentiality:
I understand that any information obtained during my testing will be treated as confidential and will not be revealed to any individual without my consent. However, information obtained during my test may be used for research purposes with my right to privacy retained.

The medical and research information recorded about me will be used within Cleveland State University as part of this research. Tests and procedures done solely for this research study may be placed in my file to indicate my participation in this study. Upon completion of the study, I will have access to the research information recorded about me. Any publication of data will only use group data and not identify me by name.

Freedom of Consent:
My participation in this study is voluntary. I know that I am free to stop at any time, if I so desire.

Contacts and Questions:
The researchers conducting this study are Kenneth Sparks and Ann Reinthal. I may ask them any questions concerning this research study. If I have additional questions at a later time, I can reach Kenneth Sparks at 216-687-4831 or k.sparks@csuohio.edu, or Ann Reinthal at 216-687-3576 or a.karas@csuohio.edu.

Participation:
I understand that participation in this study is voluntary and that I have the right to withdraw at any time with no consequences.

I understand that if I have any questions about my rights as a research participant, I can contact Cleveland State University's Review Board at (216) 687-3630.

Patient Acknowledgement:
The procedures, purposes, known discomforts and risks and possible benefits to me and to others have been explained to me. I have read the consent form or it has been read to me and I understand it. I have had an opportunity to ask questions that have been answered to my satisfaction. I voluntarily consent to participate in this study and I have been given a copy of this consent form.

________________________________ ______________

Signature of Participant Date

________________________________ ______________

Signature of Witness Date

APPENDIX B

(Aritcle A)

MotionResolution LLC

Non-Disclosure Agreement

I acknowledge that I have received a copy of the “Prototype Performance Bicycle Pedal Testing Memorandum of Understanding” and have read and understand the document.

I agree that any information disclosed to me by any representative of Motion Resolution LLC in connection with Variable Pedal System (CAM-X) will be considered proprietary and confidential, including all such information relating to the Company's past, present, or future business activities, research, product design or development, prototypes, drawings, and business opportunities.

I will hold all confidential and proprietary information in confidence and will not use such information except as may be authorized by the Motion Resolution LLC and will prevent its unauthorized dissemination. I acknowledge that unauthorized disclosure could cause irreparable harm and significant injury to the Company. I agree that upon request, I will return all written or descriptive matter and supporting documents to the Company.

Accepted and agreed to by:

Signature ____

Printed Name ____

Title ____

Company ____

Date ____