THE EFFECT OF CADENCE ON TIME TRIAL PERFORMANCE IN NOVICE FEMALE CYCLISTS

by

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A Thesis Submitted to the Faculty of

The College of Education

in Partial Fulfillment of the Requirements for the Degree of

Master of Science

Florida Atlantic University

Boca Raton, Florida

May 2010
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This thesis was prepared under the direction of the candidate's thesis advisor, Dr. Michael Whitehurst, Department of Exercise Science and Health Promotion, and has been approved by the members of her supervisory committee. It was submitted to the faculty of the College of Education and was accepted in partial fulfillment of the requirements for the degree of Master of Science.

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ACKNOWLEDGEMENTS

The author wishes to express her gratitude to her Thesis advisor, Dr. Michael Whitehurst, and to her committee, Dr. Robert Zoeller and Dr. Patrick Jacobs. The author is grateful to Dr. Sue Graves, Department Chair, for her support and encouragement. She would additionally like to thank her peers, especially Dara Wittenberg and Korey Kilsdonk for their assistance, and her family for their continual support.
ABSTRACT

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Title: The Effect of Cadence on Time Trial Performance in Novice Female Cyclists
Institution: Florida Atlantic University
Thesis Advisor: Dr. Michael Whitehurst
Degree: Master of Science
Year: 2010

The purpose of this study was to determine the effect of cadence on time trial performance in novice female cyclists. Ten novice female cyclists volunteered to participate in this study. Participants performed 3 sessions: one VO_{2peak} and two time trials (TT). Cadence was randomly selected and fixed for each TT (60 or 100 rpm) while power output (PO) was adjusted by the participant, as tolerated. Finish time, HR, blood lactate, PO, VO_{2}, and RPE were measured throughout the time trials. The major finding of this study was the significantly faster (p<0.05) finish time (minutes) during the 60 rpm condition (34:23) versus the 100 rpm condition (37:34). Also the 60 rpm TT resulted in significant (p<0.05) differences for HR (155.9 vs 161.2 bpm), gross efficiency (21.1% vs 17.7%), and PO (147 vs 129 watts). These results indicate that novice female cyclists benefit from adopting a low cadence during an 8k TT.
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INTRODUCTION

Performance in competitive road cycling is thought to hinge on several factors including maximal oxygen consumption (VO2max), cycling efficiency, and lactate threshold (LT) (9, 20). Together these factors enable elite male cyclists to generate and sustain high workloads and relatively fast cadences (9, 20). Interestingly, the extent to which cadence or revolutions per minute (rpm) determines performance in cycling, appears to be equivocal (5, 6, 9, 10, 12, 13, 18-20, 25, 29, 34). Thus, while VO2max, LT, and peak power output (PO) explain much of the variance associated with performance in road cycling, the impact of cadence or pedaling frequency remains unclear in male cyclists and virtually unknown in novice female cyclists.

Measuring physiological responses to exercise is a valid and reliable method to indirectly predict performance (10). The most commonly measured responses include heart rate (HR), ratings of perceived exertion (RPE), oxygen uptake (VO2), lactate threshold (LT), and blood lactate (Bla). Similarly, cadence selection has been shown to play a role across metabolic responses by affecting efficiency, onset of fatigue, and maximal sustainable power output (4, 5, 10). However, most studies have not directly measured the effects of cadence selection on performance. That is, studies investigating the effects of cadence typically do not include a time trial (TT) (6, 13, 25, 29). The TT is widely viewed as the best indicator of cycling performance in that the participant attempts to cover a set distance (e.g. 40 km) as quickly as possible. As such, inferences made from indirect performance markers are speculative and warrant further investigation.

In addition to the metabolic responses to high and low cadences, the association between efficiency and cadence selection is a topic that has received much attention. Studies on cycling cadence and efficiency have focused primarily on the effects of cadence on gross efficiency (GE), the ratio of work rate/rate of energy expenditure, and delta efficiency (DE), ratio of the change in work accomplished/change in energy expended. These studies have identified the most efficient cadence to be lower than the cadence used by many cyclists, in spite of training status (6, 10-12, 13). Moreover, attempts to modify cadence in search of maximum efficiency has not guaranteed improved performance (10).
The impact of cadence selection on fatigue (muscle recruitment, metabolic acidosis) development is also an area of debate. While research has shown cadence to affect the recruitment of type I and type II fibers (10, 16, 20, 33), current investigations have been unable to identify, indisputably, which pedaling rate is associated with delaying the onset of this fatigue. A number of studies have shown low pedaling rates to be advantageous (6, 13, 18, 23-25, 30), while other studies have reported low pedaling frequencies to increase the recruitment of type II fibers, production of lactate, and to accelerate fatigue (10, 19). Likewise, the data on high cadence are also unclear.

In conclusion, research targeting the relationship between cadence and performance, as well as factors known to influence performance, appears to be unclear or equivocal. Further, the majority of the research to date has focused on the male population, particularly professional, elite, or well-trained male cyclists. Fewer studies have examined trained non-cyclists and untrained males (20, 22, 23, 26, 28, 29, 32). Published data on female cyclists is particularly scarce. Those studies examining female cyclists have been restricted to identifying characteristics of the professional and/or elite female cyclist (2, 3, 14) with only one study detailing the power output demands of female road cycling (8). Thus, it appears that no data exists regarding the effects of cadence on female cycling performance, regardless of training status. Furthermore, although women cyclists have shown similar characteristics to their elite male counterparts, making the assumption that novice female cyclists perform similarly to trained females is unsound. Therefore, the primary purpose of this study is to determine the effects of low vs. high cadence on TT performance in novice female cyclists. Finally, the impact of cadence on other indices of cycling TT performance (e.g. oxygen consumption, LT, PO, and HR) will also be determined.

Hypotheses: 1) 60 rpm compared to 100 rpm will result in a faster TT performance in novice female cyclists. 2) 60 rpm as compared to 100 rpm will result in lower HR, VO2 and Bla response during the TT in novice female cyclists. 3) 60 rpm as compared to 100 rpm will result in a lower RPE during the TT in novice female cyclists. 4) 60 rpm as compared to 100 rpm will result in a greater PO during the TT in novice female cyclists. 5) 60 rpm as compared to 100 rpm will result in a more efficient (GE) TT performance in novice female cyclists.
REVIEW OF LITERATURE

Determining the factors contributing to the performance of cycling events is multi-faceted and inter-related. For the purpose of this study, only some of those factors will be examined in detail. Although the following studies have addressed many of the same topics, the literature review has been separated by general headings for clarity.

PHYSIOLOGICAL RESPONSES

Measuring physiological responses to exercise is a widely investigated area as these responses have been used to predict future performance. More specifically, heart rate (HR), oxygen consumption (VO₂), and lactate threshold (LT) are valid and reliable indirect markers of performance.

In 1998, Bishop et al. (2) conducted a study to determine the relationship between plasma lactate parameters, peak power output (W_peak), and 1-hour cycling performance in women. Twenty four women cyclists participated in two different tests: the first test was an incremental test used to determine VO₂peak and lactate parameters, while the second test (one hour cycle test) determined endurance performance. Of the six lactate parameters, LTD (point on the regression curve that yielded the maximal perpendicular distance to the straight line formed by the two end data points or D-max method) correlated best with endurance performance. A significant relationship between W_peak and endurance performance was found. In addition, all six lactate parameters and W_peak were correlated with a one-hour endurance test (OHT) more strongly than VO₂peak. Of greater importance is the finding that every lactate parameter measured correlated more strongly with the average PO during the one hour cycle test than VO₂peak.

In 2000, Bishop et al. (3) expanded on their earlier findings in order to examine the relationship between aforementioned lactate parameters (LPs) and muscle characteristics. In accordance to their previous results Bishop et al. showed a stronger correlation between the LPs and performance when compared to VO₂ and performance in this population. Type II fiber diameter was shown to be negatively related with endurance performance; however, there was no significant relationship found between any of the LP’s measured and muscle fiber type composition. In addition, percentage and diameter of type I fibers
were not related to endurance performance. Physiological adaptations to training in this population (increased oxidative capacity and decreased diameter of type II fibers) were suggested as possible explanations for the lack of significance between lactate parameters and muscle characteristics.

In 2006 Dumke et al. (7) tested ten male cyclists in one incremental test to fatigue and two simulated time trials: 30 minutes and 60 minutes. The incremental test was used to identify VO\textsubscript{2peak}, HR\textsubscript{max}, and LT. During the two time trials, subjects were instructed to give maximal effort. Heart rate (HR), cadence, blood samples, and RPE were recorded every 5 minutes. Subjects maintained significantly higher lactate levels, % HR\textsubscript{max}, and RPE during 30 minute time trial (30TT) when compared to 60 minute time trial (60TT). Ventilation (V\textsubscript{E}), VCO\textsubscript{2}, and RER were also significantly higher during 30TT. A large variability in lactate between 30TT and 60TT was reported, while HR was consistently at 90% and 85% of HR\textsubscript{max} during 30TT and 60TT, respectively. The relationship between HR and cycling performance coupled with the highly variable lactate responses suggest that %HR\textsubscript{max} may be a superior index of relative exercise intensity.

The impact of cycling cadence on the previously mentioned metabolic variables is a topic of great interest. Measuring and comparing the effects of high and low cadences on these variables have allowed researchers to conclude that cadence selection plays a key role in endurance cycling success (8).

SUPPORT OF HIGH CYCLING CADENCE

In 1996 Gotshall et al. (13) examined the effects of different cadences at fixed workload on hemodynamics. Seven experienced male cyclists (~100 miles/week) participated in the study. Subjects performed three, five-minute exercise bouts at three different cadences (70, 90, and 110 rpm) and 200W. Each subject rested for five minutes in between each bout to minimize fatigue. Higher HR, stroke volume (SV), cardiac output (Q), and decreased vascular resistance were seen in response to increases in cadence. Mean arterial blood pressure was also significantly higher at 110 rpm when compared to 70 and 90 rpm. Oxygen extraction increased in response to the onset of exercise; however, at 110 rpm, the a-vO\textsubscript{2} difference was significantly lower from that found in the 70 and 90 rpm trials. Increases in cycling cadence at a constant workload of 200W increased cardiac output, decreased vascular resistance, and was associated in a progressive drop in oxygen extraction. Although the faster cadence was associated with higher metabolic cost at 200W, the authors suggested that increases in cadence may promote increases in muscle blood flow.
and venous return. Thus, enhancing the skeletal muscle pump action via increased cadence may be beneficial for cyclists.

In a later study, Lucia et al. (19) examined the effect of cadence in professional road cyclists. At high power outputs (366 ± 37W), mean VO2, HR, RPE, and lactate decreased at the higher pedaling rate of 100rpm: comparisons showed a significant cadence effect for VO2, HR, RPE, lactate, and rms-EMG activity of vastus lateralis (VL) and gluteus maximus (GM). Gross efficiency of professional road cyclists at high workloads increased at fast cadences and decreased at slow cadences. The slow cadences was associated with higher levels of blood lactate and rms-EMG activity of the VL and GM, both of which are the primary muscles involved in the down-stroke phase of pedaling. At high workloads a faster cadence may enable cyclists to reduce the forceful muscle contractions. Adopting a high pedaling is suggested to play an increasing role in delaying fatigue when cycling at high workloads.

FAILURE TO SUPPORT HIGH CYCLING CADENCE

In 1986, Coast et al. (6) examined the importance of cadence selection in endurance cycling. Five trained cyclists were tested in order to determine which factors might contribute to the selection of an optimal pedaling rate. Subjects performed five sessions at different cadences (40, 60, 80, 100, 120 rpm). Each session of prolonged cycling (20 to 30 minutes) was set at a workload of 85% VO2max. Heart rate, RPE, efficiency, and blood lactate responses were measured at predetermined intervals and contrasted. Gross efficiency was shown to be highest between 60 and 80 rpm and significantly lower at 120 rpm. Heart rate was shown to vary with pedal rate with the lowest HR at 80 rpm at both 10 and 20 minutes. Perceived exertion also varied significantly among the various cadences: 80 rpm was reported to be the least difficult and 40 and 120 rpm the most difficult. At 20 minutes, 80 rpm was significantly different from all other cadences. Blood lactate levels were significantly higher at 120 rpm after 10 minutes of cycling and after 20 minutes, blood lactate levels were lower at 80 rpm versus 60 rpm. During prolonged bouts of cycling at high workloads 60 to 80 rpm were found to be optimal or most efficient.

Woolford et al. (1999) (34) examined similar physiological responses but examined high performance junior endurance cyclists. Ten junior cyclists were tested using three different ergometers, each with specific cadence requirements: road dual chain ring ergometer (90-100 rpm); track dual chain ring (120-130 rpm); track single chain ring (90-130 rpm). At a steady state VO2, highest PO was obtained
at the lower pedaling cadence (90-100 rpm). At a given PO, VO₂ values were lower at lower pedaling rates when compared to faster cadences. Recruitment of stabilizing trunk musculature, decreased efficiency of the active muscles, and the increased oxygen cost associated with moving limbs at higher rates, were some reasons put forth by the research team to explain the increased VO₂ values at the faster cadences. Additionally, the significantly higher blood lactate levels at 120-130 rpm suggested an increase in anaerobic metabolism. It is important to highlight that the low cadences (90 rpm) tested in this study were higher than what has been considered low in other studies (50-70 rpm) (2, 5, 10, 13-15, 17). In addition, 90 rpm is generally accepted to be the preferred cadence among highly skilled cyclists (12, 15); hence, the favorable results seen using 90-100 rpm in this treatment are not surprising.

In 2001, Lepers et al. (18) conducted a study on tri-athletes to determine the effects of cadence on specific physiological responses. Eight well trained tri-athletes performed three high intensity (80% maximal sustained PO) endurance tests (30 minutes each). The initial session was used to determine the VO₂max while subsequent three sessions were used to measure the effects of three different cadences (freely chosen cadence or FCC and FCC ± 20) on HR, Vₔ, VO₂, and RER. No significantly different responses to the three cadences were reported. However, a significant effect of time on HR and Vₔ was found at the freely chosen cadence (FCC) and FCC ± 20%. The cadence effects on Vₔ and RER were seen only during the first part of the test, with FCC+20% bringing forth significantly greater Vₔ and R at minute 5 and 15 when compared to FCC-20%. Similar to Coast et al. (6) and Woolford et al. (34), higher pedaling frequencies were associated with increases in anaerobic metabolism, specifically at the onset and middle of the cycling tests.

Nielsen et al. (29) investigated pedaling rate and endurance performance at high-intensities to test the hypothesis that endurance time would be extended at a freely chosen pedaling rate (FCPR). Twenty healthy men performed three pre-sessions and three endurance sessions over a 10 week period. Endurance sessions consisted of cycling at a workload corresponding to 90% VO₂max (W90) at a randomly assigned cadence of FCPR or FCPR ± 25. Endurance time was determined as time up to the point at which cadence was 10% lower for a 3s period or until volitional exhaustion. Results revealed longer endurance time at FCPR (~78 rpm) and FCPR – 25% (~59 rpm) when compared to FCPR + 25% (~98 rpm): at W90, FCPR...
and FCPR – 25% resulted in better endurance as opposed to FCPR +25%. Additionally, at exhaustion, VO2 and blood lactate were highest at FCPR + 25% and lowest at FCPR – 25%.

In 2006, Mora-Rodriguez et al. (25) also found similar physiological responses to high pedaling rates by examining the relationship between peak power development and cadence in well-trained cyclists. Nine trained road cyclists performed four incremental tests: preliminary test was performed to determine VO2max at freely chosen pedaling rates and three experimental incremental tests (separated by 72h) to exhaustion at three randomly selected cadences (80, 100, and 120 rpm). Maximal cycling power output (Wmax), ventilation (Ve), lactate threshold (LT), and tidal volume (Vt) were measured. Results revealed that 120 rpm condition significantly decreased Wmax by 9% at VT2 (PO at ventilatory anaerobic threshold) when compared to 80 and 100 rpm. Ve was greater by 10-20 L/min, at 120 rpm over the 80 and100 rpm trials, respectively. VCO2 also increased, although to a lesser degree than Ve. In addition, arterial blood lactate was significantly higher at 300W during the 120 rpm when compared to 80 rpm, although not significantly different than 100 rpm. Fast pedaling cadence of 120 rpm was associated with greater blood lactate production, hyperventilation, and decreased Wmax.

The following year Majerczak et al. (20) substantiated earlier findings (6, 25, 29, 34); although at much lower workloads (30-120W). At moderate intensity cycling higher pedaling rates (120 rpm) significantly increased rate of lactate accumulation and oxygen cost when compared to the lower (60 rpm). In this study, 21 healthy males were divided into two groups according to the content (high or low) of myosin heavy chain isoform (MyHC). The results of two incremental tests at high and low cadence revealed that subjects with high MyHC II content had significantly higher O2 cost of cycling and greater increases in plasma lactate accumulation. In support of Mora Rodriguez et al. (25), Majerczak et al. concluded recruitment of type II muscle fibers induced by increases in pedaling rate is associated with increased oxygen cost and rate of lactate accumulation during cycling at moderate intensities. Subjects with high content MyHC II had lower VO2/PO values when compared to those with low MyHC II content.

Most recently, in 2008, Moore et al. (24) determined the effects of cadence and workload on cardiac output (Q), stroke volume (SV), heart rate (HR), VO2, and a-vO2 difference. Eleven male cyclists were tested at two submaximal workloads (50 and 65% VO2max) at 80 and 100 rpm. Highlighting that SV generally plateaus at approximately 40% VO2max, the authors hypothesized that any increases in Q in
response to faster cadences would be due to elevations in HR and oxygen extraction. The results appeared to support their hypothesis: VO$_2$ and HR were higher at 100 rpm at both workloads when compared to 80 rpm; however, no changes in SV were reported. Also, at 100 rpm, a-VO$_2$ difference was higher at the higher workload. Blood lactate was higher during 100 rpm and the 80 rpm trial conducted at 65% VO$_2$max but was unaffected at the lower workload. These findings provide evidence contrary to earlier findings by Gottshall et al. (13).

EFFICIENCY

Maximizing efficiency is a popular approach to improve performance; minimizing frivolous energy expenditure (reducing efficiency) allows athletes to capitalize on limited energy stores. In cycling, performance is usually measured by time to distance or velocity. Power is a key factor that affects velocity and efficiency. Performance power, as explained by Joyner and Coyle in their review of endurance exercise performance (11), is the rate of power production during a specific amount of time and is a function of performance VO$_2$ and efficiency. Thus, efficiency can affect the amount of power that can be produced for a given amount of oxygen consumption.

Due to the relatively basic movement pattern in cycling, the effects of cadence selection on efficiency have received much attention (5, 22, 28, 30, 33). Current research has primarily focused on gross efficiency (GE) and delta efficiency (DE). Additionally, the impact that cycling experience or training status may have on efficiency is also an area of great interest.

In 1996, Nickleberry et al. (28) investigated the relationship between training status and cycling efficiency at similar intensities and cadences. Twelve college-aged men participated in the study (6 competitive, 6 recreational cyclists). Two peak oxygen consumption tests were conducted at 50 and 80 rpm along with two endurance tests at 50 and 80 rpm. Both endurance tests were set at 75% VO$_{2\text{peak}}$. The authors reported no significant differences in delta efficiency at any cadence or power output, regardless of training status. Mean gross efficiency decreased as cadence increased in competitive and recreational cyclists. Both groups had increased endurance while pedaling at 80 rpm versus 50 rpm in bouts of graded exercise and a sub-maximal (75% VO$_2$) endurance test.

Similarly, in 2000 Marsh et al. (22) examined the effects of cadence, cycling experience, and aerobic power on delta efficiency (ratio of the change in work done to the change in energy expended). The
authors recorded delta efficiency (DE), preferred cadence (PC), and gas exchange on three separate occasions in three different populations: 11 trained male cyclists, 10 trained male runners, and 10 less trained male non-cyclists. The trained male subjects (cyclists and runners) were tested at 100, 150, and 200 W, whereas the less trained subjects cycled at 75, 100, and 150 W. During each session the subjects pedaled at randomly assigned cadences (50, 65, 80, 95, and 110 rpm) for bouts of 5 minutes. An average steady state VO2 value was considered for determining economy at each cadence. To minimize fatigue participants rested 5 minutes between exercise bouts. Contrary to their hypothesis, the authors found that in the trained subjects (cyclists and runners) DE was not maximized at the higher cadences (similar to their preferred cadence). In fact, DE was not significantly different regardless of workload, cadence, or cycling experience. Significant differences were reported in the preferred cadences at different workloads in trained versus less trained subjects: Cyclists and runners pedaled between 96-92 rpm at 100 and 200 W, respectively, while the less trained subjects lowered their preferred cadence from 80 to 69 rpm as power output increased from 75 to 150W, respectively.

The impact of cadence on efficiency was also addressed by Chavarren et al. (5) in 1999. Cycling efficiency and pedaling frequency were examined in seven road cyclists. Subjects performed six sessions over a period of four weeks. The first two sessions were used to familiarize the subjects and to determine VO2 and Wmax. During the four subsequent sessions, subjects performed six bouts of exercise at different intensities at a randomly selected cadence (60, 80, 100, 120 rpm). Subjects rested for 3-5 minutes between bouts to minimize fatigue. At a given intensity, increases in cadence caused increases in VO2, with the lowest VO2 occurring at 60 rpm. Delta efficiency (ratio of change in work and the change in energy expenditure) increased with increases in cadence while gross efficiency (ratio between external work and total energy consumption) decreased as a result of increases in pedaling rate. Interestingly, at a given cadence, there was an improvement in GE as PO increased; as intensity increased the effect of cadence on GE was reduced. Thus, the impact of efficiency appears to be enhanced as intensity increases.

Research by Moseley et al. (26) corroborated findings by Nickleberry et al. (28) and Marsh et al. (22) reporting that training status does not significantly affect cycling efficiency. Sixty-nine male subjects performed an identical incremental test to exhaustion at a fixed cadence between 80-90 rpm. Participants were divided according to VO2 (low, medium, and high). No differences were found between GE (at
absolute mechanical power or at relative intensity), DE, and economy in any group; the metabolic cost of producing a given mechanical power output did not differ significantly among the subjects despite their wide range of aerobic capacities. Thus, the authors concluded that superior efficiency is not predictive of success in high level cycling.

In 2004, Foss et al. (11) expanded on earlier findings by Chavarren et al. (5) and reported an increase in the most economical cadence as workload was increased. Six elite road cyclists were tested on four different occasions. At every session, participants performed a sub-maximal and maximal test at one of four randomly chosen cadences (60, 80, 100, 120 rpm) at workloads ranging from 100W to 350W. Blood lactate, HR, $V_e$, $\text{VO}_2$, and time to exhaustion were recorded. As workload increased from 0W to 350W, the cadence that elicited the best work economy (lowest oxygen consumption) also increased from 60 to 80 rpm, respectively; 80 rpm resulted in best performance (longest duration during max test) and best work economy at the highest sub-maximal workload of 350 W. Endurance time during max test was shown to be 14, 8, and 25% shorter at 60, 100, and 120 rpm, respectively, when compared to 80 rpm.

The previous studies have several pertinent findings as they relate to the present topic: efficiency is not significantly different in elite and novice cyclists; the effect of cadence on efficiency is most evident at high intensities; the most efficient cadence increases with increases in workload in elite cyclists. However, earlier research by McNaughton et al. (23) may provide support indicating otherwise. The benefit of increasing cadence in response to increases in workload in the novice cyclist remains unclear.

POWER OUTPUT

Power output (PO) production is widely accepted to be strongly and directly correlated with cycling performance. More specifically, power output at lactate threshold, peak power output, and peak power output at lactate threshold have been shown as valid indicators of competitive cycling potential. Considering that power is the product of velocity and force, at constant power output, increasing cadence (velocity) must be accompanied by a decrease in force or workload. As such, at high power outputs and low pedaling frequencies, force exerted on the pedal must increase dramatically. On the other hand, increases in pedaling frequency will decrease the force necessary to achieve a desired PO. As a result, manipulating cadence to maximize PO has been a central theme in many studies, especially those interested in defining the relationship between PO, cadence, LT, and performance.
In 1996, McNaughton et al. (23) examined the effects of cadence on power-duration relationship of high-intensity cycling. Eight male participants with no cycling experience performed thirteen tests over eight weeks. The first test was used to determine the range of power outputs for subsequent sessions. Twelve exercise bouts at four previously determined power outputs for each cadence were performed. Subjects pedaling at a slow cadence had a significantly longer time to exhaustion when compared to 90 or 110 rpm. There was a 16% (33W) and 6% (12W) increase between 50 and 110 rpm and 50 and 90 rpm, respectively. Thus, the non-cyclists males in this study had greater endurance and higher power outputs at low versus intermediate and high cadences.

The relationship between neuromuscular activation and pedaling rate was examined by Neptune et al. (27) in 1999. Utilizing a musculoskeletal model the authors measured neuromuscular quantities in response to varying cadences. Examination of nine quantities of muscle activation (average, integrated, and peak activation; average and peak force; average and peak stress; average and peak endurance) showed that in all 14 muscles, except average vastus lateralis and gastrocnemius muscles, activation quantities were reduced at 90 rpm. The authors suggested, in agreement with cited work by Takaishi et al. (31), that in order to maintain constant PO, increases in cadence will be accompanied by decreases in torque or corresponding muscular force. The lower forceful muscular contraction, seen in the nine of 14 muscles, supports the premise by Alquist et al. (1): muscle fibers are recruited based on the force required to perform a given task and type II fibers are recruited in those tasks requiring higher force production. These results support the selection of faster pedaling rates as they may be responsible in delaying fatigue: faster pedaling rates decrease the recruitment of type II fibers which have been shown to promote glycolysis, lactate production, and other deleterious responses for endurance cycling.

In 2000, Zoladz et al. (35) examined the power generating capacity of human muscle at different cadences and determined that a faster cycling cadence is beneficial when cycling at high intensities. Seven healthy males performed two series of tests. The first tests were performed to identify maximal power output at different pedaling rates (40, 60, 80, 100, 120, 140 rpm). Participants performed 10s max sprints at these six cadences. The second series of tests were used to measure VO₂, blood lactate concentrations, and the forces exerted on the pedals at each of the cadences except 140 rpm. At low power outputs, VO₂ was lowest at the lowest cadence (40 rpm) and highest at the highest cadence (120 rpm). As PO increased, the
difference in VO2 between the slow and fast cadence diminished such that there was no significant
difference between 40 and 100 rpm at or near VO2max. During the 10s sprints, maximum peak power output
increased as cadence increased with the highest values seen during 100 and 120 rpm. However, at 140 rpm
peak PO was significantly reduced. Maximum mechanical PO at VO2max was not significantly different at
60-100 rpm, but was significantly reduced at 40 and 120 rpm. Thus, the maximum power increases with
increases in cadence up to 120 rpm; available power reserve to achieve VO2max decreases from 55% at 40
rpm to 29% at 120 rpm. Power output corresponding to 2 and 4 mmol/l blood lactate concentrations was
significantly lower at 120 rpm when compared to 100 rpm. Although fast cadence of 120 rpm permits an
increased reserve of PO (71%), this cadence is associated with increased anaerobic metabolism. These
findings were supported by Mora-Rodriguez et al. (25) and provide evidence that very high pedaling rates
(120 rpm) reduce the maximal cycling PO and the LT in highly trained cyclists, both of which can
negatively affect performance. In addition, similar findings were reported for very low cadences of 60 rpm.

PERFORMANCE

Thus far, the majority of the literature examining cadence and cycling has focused primarily on the
aforementioned indirect markers of performance. Although this research has provided useful information
about metabolic responses to varying exercise, it has not supplied sufficient evidence regarding the effects
of cadence on performance.

As previously mentioned, the effect of cycling cadence on endurance performance in recreational
cyclists was addressed in 1996 by McNaughton et al. (23). More specifically, the authors were interested in
determining the relationship between cycling cadence and the power-duration relationship among an
inexperienced population. Contrary to some studies done on experienced cyclists (17, 29), the results of this
study showed significantly greater endurance at a low pedaling rate of 50 rpm when compared to 90 or 110
rpm. In addition, all subjects obtained higher PO at the low cadences when compared to the higher pedaling
rates.

In 2005, Foss et al. (12) addressed the lack of research examining cycling performance. The
research team examined two different groups of elite male cyclists in two separate experiments: the first
experiment (n=7) consisted of five time trials at randomly selected cadences of 60, 80, 100, 120, and freely
chosen cadence (FCC) used to examine performance. Each time trial was separated by two to three days.
Since no statistical significance was observed between the performance of the 80 and 100 rpm trials, a second experiment \((n=7)\) was performed to test performance at 80 and 100 rpm only. Maximal lactate steady state (MLSS) was identified in all participants during a graded sub-maximal test at 90 rpm. Maximal oxygen consumption was determined during an incremental test to exhaustion of approximately five minutes. Heart rate was also measured continuously and time to exhaustion was recorded. Each time trial began at a fixed workload corresponding to subject’s MLSS or \(\sim 79\% \text{ VO}_2\text{max}\). Afterwards, participants were instructed to complete the trial as fast as possible; subjects adjusted workload in increments of 10 W as needed. Cadence was randomly selected and fixed throughout time trial of 30 minutes. Results showed a 3-10% improvement in performance at the 80/100 rpm (indistinguishable) when compared to 60 and 120 rpm in experiment 1. In experiment 2, 80 rpm protocol produced 1.7% superior performance in comparison to 100 rpm. Gross efficiency was significantly greater at 80 rpm than any other cadence in both experiments (1 and 2) at high workloads. Energy turnover rate was not different in the first experiment, but was higher at 100 rpm in the second experiment. HR was also higher at 100 rpm in the second experiment, while no difference among cadences was observed in the first experiment.

The authors reported a cadence effect on efficiency and energy turnover rate. However, it was noted that cadence affected efficiency and turnover rate differently. For example, efficiency was greatest at 80 rpm while superior energy turnover rate was seen at 100 rpm; at 80 rpm efficiency was 3.4% greater while turnover rate was 1.7% higher at 100 rpm which translated to a 29 second faster finishing time at 80 rpm. Even so, the authors mentioned the discrepancy between their ‘optimal cadence’ of 80 rpm and that seen amongst professionals on the field (90-100 rpm) highlighting that professional cyclists compete at much greater workloads than those observed in their study. Their previous finding [11] that the most efficient cadence increases with increases in workload supported their proposed explanation.

In summary, review of current literature on cycling has revealed that, in experienced and non-experienced cyclists, cadence selection has significant effects on metabolic responses to cycling exercise. Previous research has shown these responses to be predictive of athletic performance. The relationship between cadence and cycling is complex and multi-faceted, as evident in the inter-relationship between cadence, duration, and intensity of exercise. If delaying local muscle fatigue is accepted to be a key factor affecting cycling performance, it may be plausible to conclude that adopting a high cadence is preferred.
This theory suggests that by reducing the number and duration of muscle fibers activated, a high cadence permits extended periods of ‘recovery’ or rest within the crank cycle, ultimately extending time to exhaustion. The increased pedaling rate, however, has been associated with increased metabolic cost. As previously mentioned, if local fatigue is considered the most important factor affecting performance, then it may be beneficial to increase cadence to reduce muscle activation duration despite overall increases in energy turnover. Conversely, if energy conservation is the most important factor in endurance performance then selecting a lower cadence may be prudent. In order to maintain a competitive PO (or velocity), cyclists must increase workload if they decrease their cadence. However, at high workloads, some studies have shown lower cadences to produce deleterious responses (4, 19, 28). It appears that a cyclist has a choice: conserve energy at the expense of power or maximize power at increased metabolic cost (13, 16).
METHODS

PARTICIPANTS

Ten novice female cyclists, recruited from the Florida Atlantic University student population, and surrounding community, volunteered to participate in this study (see Appendix A). Physical and performance characteristics are presented in Table 1. An initial screening (see Appendix B - questions administered over phone or in person) was employed to identify subjects suitable for inclusion in this study. Criteria for classification as novice cyclist was based on VO₂peak and cycling experience. More specifically, participants participated in indoor or outdoor cycling between 2-8 hours/week, cycled less than 100 miles/week, were between 18-40 years of age, and had an aerobic capacity < 50 ml/kg/min (11). Subjects were excluded if they had any previous history of musculoskeletal or cardiorespiratory disorders that could otherwise affect testing procedures or outcomes.

The study was approved by the Florida Atlantic University Institutional Review Board for Human Subjects prior to data collection. Subjects were informed of the study, including risks prior to providing written informed consent (Appendix C).

STUDY DESIGN

Participants attended three laboratory sessions including a VO₂peak test and two testing sessions, time trial 1 (TT1) and time trial 2 (TT2), each one week apart and all performed on the same cycle ergometer (Excalibur Sport V2 cycle: Lode BV, Groningen, Netherlands). Both of the TT replicated a “distance” of 8K (as determined from an algorithm programmed into the ergometer). The TT differed only in the cadence at which they were performed (60 vs. 100 rpm) with participants able to freely choose power output at any time. The order of the time trials was randomized.

Prior to administering the VO₂peak test, all requisite paperwork was reviewed and completed by each participant, including an Informed Consent (Appendix C), Physical Activity Readiness Questionnaire or PAR-Q (Appendix B), and Physical Activity Questionnaire (Appendix D). Participants were instructed on the study protocol and testing procedures including dietary intake. Specifically, participants were
reminded to follow their usual pre-training/racing diet strategies while limiting the amounts of protein, dairy, and fats in the 0-2 hours prior to testing sessions.

TESTING PROTOCOLS

The VO_{2peak} test and time trials (TT) took place at the Exercise Science and Health Promotion Laboratory located in Field house 11A on the FAU Boca Raton Campus. The time of day for testing was held constant within subjects. Again, the order was randomized.

VO_{2peak} TEST

After reviewing the testing protocol with the subject, an incremental/peak exercise test was administered using an electrically breaked cycle ergometer (Excalibur Sport V2 cycle: Lode BV, Groningen, Netherlands). The cycle ergometer was adjusted (e.g. seat position height and fore/aft, handlebars vertical and fore/aft) to reflect the participant’s own road bicycle. The ergometer was modified to include clipless pedals standard road handlebars with brake hoods and racing saddle.

Subjects placed a HR transmitter strap around their chest (Polar HR monitor, Kempele, Finland) then sat on the cycle ergometer with feet in pedals (clipped) and hands on handlebars. During the test, respiratory gases were monitored and continuously analyzed by open-circuit spirometry (True One 2400+ Metabolic Measurement System, Parvo-Medics Inc., Provo, UT). The metabolic system measured minute ventilation (V_E), oxygen consumption rate (VO_2), carbon dioxide expiration rate (VCO_2), and respiratory exchange ratio (RER). Data were averaged over 30-s intervals. The metabolic cart was calibrated prior to each test with room air for flow rate and gases (i.e. O_2, CO_2) of known volume and concentration.

Three minute stages, with an initial workload of 25 W, were employed with increases in workload of 25 W added at each stage. Subjects pedaled at a fixed cadence of 80 rpm. Respiratory gases were measured by open-circuit spirometry (as described above). Heart rate (HR), power output (W), blood lactate (Bla) and ratings of perceived exertion (RPE, Borg 20-point scale) were recorded at the end of every stage (last 30s). Blood lactate was measured from fingertip capillary blood samples drawn using micro-capillary tubes and analyzed immediately with a YSI-2300 Stat Plus Lactate Analyzer (Yellow Springs Instruments, Yellow Springs, OH). Tests were terminated when the pedal cadence of 80rpm could not be maintained for > 10 seconds or subject requested to stop test. Tests were accepted as peak tests if participants met any of two of the following criteria: leveling of VO_2 despite an increase in workload (<150
ml/min); RPE ≥ 17; exercise Bla > 8mmol/L; RER > 1.15; HR ≥ 95% of age-related maximum (220-age).

After the test, participants performed active cool-down on the cycle ergometer at 50 W as needed. Additionally, peak heart rate (HR_{peak}) and peak power output (W_{peak}) were measured and/or calculated coincident with VO_{2peak}. Peak power output was calculated from the formula (17): \[ W_{\text{max}} = W_f + \left(\frac{t}{180}\right) \cdot 25 \] where \( W_f \) = the value of the last completed workload (W); \( t \) = the time the last workload was maintained (seconds), and 25 = the power output difference between the last two workloads (W). Similarly, gross efficiency was calculated using the formula: \[ \text{GE} (\%) = \left(\frac{\text{work rate in watts}}{\text{energy expended kJoules}}\right) \times 100. \]

**TIME TRIAL TESTS**

Having met the inclusion criteria and completed the peak oxygen consumption test on the ergometer, participants were asked to return for two TT sessions. The randomized testing sessions were completed one week apart and were described as an 8K TT performed at either 60 or 100 rpm. The “distance” of 8K was based on output provided directly by the cycle ergometer. The estimated distance was calculated from an algorithm developed by the manufacturer (Lode, Netherlands) that incorporates estimates of wind resistance and frictional resistance of the road surface.

Prior to each TT, participants warmed up for five minutes at a freely chosen PO and cadence. Immediately after the warm-up, subjects began pedaling at the predetermined randomly assigned cadence (60 or 100 rpm condition) with the instruction to complete the TT as quickly as possible. Although the cadence was fixed, participants were given continuous access to the ergometer control panel thereby enabling them to adjust PO at their discretion. This was done to better replicate the conditions of an actual road test. Visual feedback, including distance completed, power output (watts), and rpm was continuously displayed on the control panel during the TT. In addition, verbal feedback for distance completed was provided approximately every five minutes. Expired gases were collected continuously throughout the TT using the previously described methods. Heart rate, PO, and RPE values were recorded every three minutes. Blood samples (fingertip capillary) were taken before, every three minutes, and at four minutes post TT. The TT ended at the moment the ergometer control panel displayed 8k. At the end of each TT, subjects actively recovered on the cycle ergometer as needed.
DATA ANALYSIS

The statistical analysis employed in the study was a one-way ANOVA with repeated measures for each of the dependent variables. A significance level of $p<0.05$ was accepted as statistically significant and was determined using the Statistical Package for Social Sciences (SPSS) for Microsoft Windows (Version 15.0, 2006; SPSS, Inc., Chicago, IL).
RESULTS

Table 1 displays the physical characteristics of the subjects as well as the results of their VO\textsubscript{2peak} test.

Table 1. Participant Characteristics and Results of VO\textsubscript{2peak} Test

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>34 (2.03)</td>
<td></td>
</tr>
<tr>
<td>Height (cm)</td>
<td>165.48 (1.57)</td>
<td></td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.68 (4.33)</td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m\textsuperscript{2})</td>
<td>26.45 (1.40)</td>
<td></td>
</tr>
<tr>
<td>VO\textsubscript{2peak} (L/ min)</td>
<td>2.76 (.09)</td>
<td></td>
</tr>
<tr>
<td>HR\textsubscript{peak} (bpm)</td>
<td>179.4 (3.52)</td>
<td></td>
</tr>
<tr>
<td>BL\textsubscript{peak} (mmol/L)</td>
<td>6.81 (.481)</td>
<td></td>
</tr>
<tr>
<td>W\textsubscript{peak} (watts)</td>
<td>198.04 (8.90)</td>
<td></td>
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</tbody>
</table>

Values are means (± SE)

TIME TRIAL PERFORMANCE

Performance time as well as other measures for both of the TT is presented in Table 2.

Briefly, compared to the 100 rpm TT, the 60 rpm TT produced significantly lower performance times and HR (p = .001 and .04, respectively) but greater PO and GE (p = .003 and .000, respectively). As presented in Figure 1, the 60 rpm condition required a significantly lower percentage of the peak HR yet a higher relative PO compared with the 100 rpm condition.
Table 2. Time Trial Performance Measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>60 rpm</th>
<th>100 rpm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Finishing time (min:sec)</td>
<td>34:23 (4:21)*</td>
<td>37:34 (5:53)</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>155.90 (3.97)*</td>
<td>161.22 (5.20)</td>
</tr>
<tr>
<td>Oxygen consumption (L/min)</td>
<td>1.98 (0.08)</td>
<td>2.06 (0.10)</td>
</tr>
<tr>
<td>Blood lactate (mmol/L)</td>
<td>3.50 (0.32)</td>
<td>4.33 (0.51)</td>
</tr>
<tr>
<td>RPE (Borg scale)</td>
<td>14.61 (0.38)</td>
<td>15.01 (0.44)</td>
</tr>
<tr>
<td>PO (watts)</td>
<td>147.19 (7.06)*</td>
<td>129.00 (10.62)</td>
</tr>
<tr>
<td>GE (%)</td>
<td>21.10 (0.37)**</td>
<td>17.70 (0.85)</td>
</tr>
</tbody>
</table>

Mean (± SE) based on last 30s of each three-minute stage. * indicates p= <0.05 compared to 100 rpm, **indicates p=<0.01 compared to 100 rpm.

Comparisons of the percent of peak values (Figure 1) during the time trials also yielded significant findings. The 60 rpm condition required a significantly smaller percentage of the peak HR than the 100 rpm condition. In addition, a significantly higher percentage of the peak PO was seen during the 60 rpm condition when compared to the 100 rpm condition.

![Figure 1. Percent of peak values during time trial for selected variables.](image)
V. DISCUSSION

The primary purpose of this study was to examine the effects of two different cadences (60 rpm versus 100 rpm) on TT performance in novice female cyclists. The secondary purpose was to explore the differences in metabolic and perceptual responses between the two conditions.

PERFORMANCE

The major finding of this study was the significantly (p<0.05) better TT performance for the 60 rpm condition as evidenced by a faster finishing time. Mean finishing times were 3:18 minutes or approximately 10%, faster during 60 rpm TT (34:23 ± 4:21 minutes) when compared to the 100 rpm TT (37:34 ± 5:53). Similarly, Nielsen et al. (29) found lower cadences to result in longer endurance time at a freely chosen pedaling rate (FCPR) and FCPR -25% when compared to FCPR +25%. This is an important and particularly interesting finding as the subjects in this study (healthy males) were similar to the healthy but novice subjects in the present study. Moreover, the FCPR ± 25% (59 rpm and 98 rpm) was virtually identical to the range of cadences employed in the present study.

HEART RATE

Success in cycling hinges, in part, on being able to maintain a high exercise intensity or % HR_{max}. Yet, an exercise intensity that is too great will ultimately compromise performance. This may have been the case in the present study as the two cadences produced different exercise intensities with the 100 rpm condition producing significantly higher (p<0.05) HR when compared to the low (60 rpm) condition. Perhaps more importantly, the 60 rpm condition required a lower percentage of the maximum HR observed during the VO2 peak test. Thus, the effort or intensity which was elicited during the 100 TT was not only a higher percentage of the peak HR, but represented significantly (p<0.05) greater intensity in comparison to the 60 rpm condition. Finally, the lower HR during the 60 rpm condition TT may be interpreted as less metabolically demanding and represents a more efficient and economical response.
EFFICIENCY AND POWER OUTPUT

The favorable results of the low cadence condition in this study may be explained on the basis of an association between sustained PO (or rate of work) and energy expended (i.e. oxygen consumption) during the TT as quantified by the GE (15). That is, under the 60 rpm condition, the subjects in this study produced significantly more sustainable power for approximately the same oxygen consumption during the TT. Indeed, the 60 rpm condition was found to be significantly more efficient than the 100 rpm condition; comparisons between these two conditions yielded significantly (p<0.01) higher GE during the 60 rpm time trial (21.1%) versus the 100 rpm time trial (17.7%). These findings are supported by previous studies which have shown GE to improve with increases in exercise intensity and lower pedaling rates (5, 11, 12). As such, while performing the 60 rpm TT subjects were able to perform at a significantly higher percentage of their peak PO as compared to the 100 rpm condition and at the same VO2. This data strongly suggest that greater metabolic efficiency associated with the low (60 rpm) cadence condition offset the increased metabolic demand of high-intensity cycling, thereby enabling the novice cyclist to maximize PO and performance (23) without the deleterious effects seen in the high cadence condition.

PERCEPTUAL, BLOOD LACTATE AND OXYGEN CONSUMPTION RESPONSES

Although other investigators (21) have reported a more favorable perception of effort (i.e. RPE), during low versus high cadence cycling, the present study failed to demonstrate a significant difference between conditions for RPE (p = .136). Finally, other investigators have reported favorable differences in oxygen consumption and blood lactate under both high and low cadence conditions (6, 10, 13, 18-20, 25, 29, 34). Similarly, while the current study trended toward lower oxygen consumption and Bla for the 60 rpm condition (p = .169 and .062, respectively) there was not a significant difference between conditions.

SUMMARY

The present study sought to determine whether a low vs. high cadence would produce a better TT performance in a simulated 8K TT in novice female cyclists. The 60 rpm condition resulted in a significantly faster TT performance than the 100 rpm condition. The 60 rpm TT also resulted in greater metabolic efficiency compared with the 100 rpm TT and may, at least in part, explain the differences in PO and performance. That is, the current results emphasize the benefit of a low cadence in maximizing sustainable power output while minimizing exercise intensity. Thus, based on the results of this study it can
be concluded that novice female cyclists enjoy a significant performance benefit from cycling at low versus a high cadence, possibly due to greater metabolic efficiency.

FUTURE DIRECTIONS

It is worthwhile to mention that the relatively short TT employed in this study is considerably shorter than the standard TT distance of 40km (9). Therefore, it is possible that cycling at a low cadence (i.e. 60) over the more traditional TT distance could result in the recruitment of fast twitch muscle fibers, thereby hastening fatigue (9). In contrast, adopting a faster cadence has been shown to favor the recruitment of slow twitch fibers and promote enhanced blood flow (13, 24), a strategy that has been shown to benefit highly trained males over a TT of greater duration (19). Therefore, future research should include attempts to quantify TT performance in novice females while performing other TT distances at a low cadence.
Appendix A

The Effect of Cadence on Time Trial Performance in Novice Female Cyclists

RESEARCH STUDY
FLORIDA ATLANTIC UNIVERSITY

THE EFFECTS OF CADENCE ON TIME TRIAL PERFORMANCE IN NOVICE FEMALE CYCLISTS

Free for participants
- VO2 Test
- Body composition
- Lactate threshold

QUALIFYING CRITERIA:
- FEMALE CYCLISTS
- 2-8 HOURS PER WEEK OF INDOOR/OUTDOOR
  - < 100 MILES/WEEK
  - 18-40 YEARS

IF INTERESTED, PLEASE CALL 305-788-9303

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Appendix B

The Effect of Cadence on Time Trial Performance in Novice Female Cyclists
Physical Activity Questionnaire

1. Are you between the ages of 18-40? Yes No

2. Please provide information about your typical physical activity/exercise habits per week as they pertain to the activities below.

<table>
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<tr>
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<th>&lt; 1</th>
<th>1-2</th>
<th>3-4</th>
<th>5-7</th>
<th>&gt;7</th>
<th>Time</th>
</tr>
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<tbody>
<tr>
<td>A.</td>
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<tr>
<td>B.</td>
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</table>

B1. How long have you been cycling?

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<tr>
<th></th>
<th>&lt; 1</th>
<th>1-2</th>
<th>3-4</th>
<th>5-7</th>
<th>&gt;7</th>
<th>Time</th>
</tr>
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<td>C.</td>
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D. Other, please specify:
Appendix C

INFORMED CONSENT FOR SUBJECTS

CONSENT TO PARTICIPATE IN RESEARCH STUDY

Title of Research Study: The Effect of Cadence on Time Trial Performance in Novice Female Cyclists

Investigators: Dr. Michael Whitehurst, Professor, (954) 236-1030
Patricia L. Graham, 786-263-0577

Purpose: The purpose of this study is to determine the effects of a high and low cycling cadence on time trial performance by novice female cyclists.

Procedures: The study will require you to make three visits to the Human Performance Lab in room 408 in the Education and Science Building at Florida Atlantic University, Davie Campus. Each visit will last approximately 30 to 90 minutes. There will be one familiarization session and 2 testing sessions. At the familiarization session you will be asked to read and sign an informed consent, as well as complete a Physical Activity Readiness Questionnaire and Physical Activity (mode) Questionnaire. Also, the study protocol will be reviewed and explained at this time and future participants will perform a maximal incremental cycle test to exhaustion.

The exercise protocol for testing of subjects is as follows:

Prior to the start of the max test, resting values of heart rate will be recorded. Also, resting blood lactate will be determined from a blood sample collected from the ring finger tip. Next, height and weight will be measured and recorded using a standard physician’s scale. Body composition (percentage of fat and lean body tissue) will be estimated by measuring the skinfold fat thickness at the back of the upper arm (triceps), the hip (suprailliac) and thigh. Each area will be measured three times with the average used to calculate body fat and lean body weight. Finally, you will warm-up on the cycle ergometer for five minutes prior to the start of the max test.

Initials:___________________
Immediately following the warm-up, the max test will begin. It will consist of 10-20 minutes, approximately, of cycling in which the resistance will be increased systematically until volitional exhaustion. During this test, blood lactate will be measured using fingertip capillary blood samples taken every three minutes. In addition, your peak oxygen consumption will be collected using the metabolic cart in room 408. Heart rate will also be collected continuously using a Polar heart rate monitor which you will be asked to put on prior to the test.

From the results of the max incremental test, eligibility will be determined. If all inclusion criteria are met, you will be asked to return for two testing sessions, each one week apart.

Time Trial 1 and 2:

The subsequent testing sessions (time trial 1 and 2) will begin with measuring and recording of resting heart rate and blood lactate values. A five minute warm-up on the cycle ergometer will precede the ten mile time trials. Each time trial will require that you maintain a randomly selected cadence of either 60 or 100 rpm. You will be able to adjust workload (W) as tolerated. Heart rate, expired gases, perceived exertion, and blood lactate will be collected and recorded throughout the time trial. After the time trial you will be asked to cool-down on the cycle ergometer as necessary.

**Benefits:** Those students who meet the inclusion criteria (18-40 years, 40-50 ml/kg/min, female, indoor/outdoor cycling < 100 miles/week) and are FAU students in the Exercise Science and Health Promotion Department can receive extra credit, if their instructors agree. All subjects can receive valuable knowledge on different testing procedures and research methods related to cycling. This research may help increase our current knowledge on the effects that cycling cadence may have on time trial performance in the novice female cyclist population. Students who elect (or do not meet inclusion criteria) will be given an alternate extra credit opportunity of equal value.

**Risks:** Although unlikely, during the incremental test and each trial it is possible the participant may experience dizziness and nausea or other symptoms associated with maximal physical exertion. Risks will be minimized through the preliminary screening and by observation and monitoring during testing. Furthermore, the research staff is CPR and First Aid trained and practiced in responding to an emergency. There is a risk the participant will experience musculoskeletal soreness 24-72 hours following testing. Brief isolated pain or soreness/discomfort and infections from the finger stick (lancet) are also a possibility, although unlikely. This risk will be minimized by following standard safety.

Initials: ____________________
and sterilization procedures with blood collection supplies; each blood sample will be collected using sterile, single-use lancets which will be disposed of immediately in a hazardous waste container.

**Data Collection & Storage:** Information from the Health History Questionnaire, Informed Consent Form, Physical Activity Questionnaire, Dietary recall, and data from the study will be given to the principal investigator and the study staff only. Initial information generated from the study will be used to determine qualifications for your participation in the study. All personal information will remain in your study chart and will not be released in any form unless requested by you or required by law. Name or initials outside the laboratory records will not identify you. The signed consent form will be kept on file, locked in the principal investigator’s office.

**Contact Information:** For related problems or questions regarding your rights as a subject, the Office of Sponsored Research at Florida Atlantic University can be contacted at (561) 297-2310. For other questions about the study, you should call the principal investigators, Dr. Michael Whitehurst, Ed.D. (954) 236-1030; or Patricia L. Graham at (786) 263-0577, (305) 788-9303.

**Consent Statement:** You are making a decision whether or not to participate in this study. You should not sign until you understand all the information presented in the previous pages and until all your questions about the research have been answered to your satisfaction. Your signature indicates that you have decided to participate, having read the information provided above and your participation is voluntary and that you are free to drop out at anytime. You assure that to the best of your knowledge, you do not have any physical condition that would increase the risk to you participating in this study.

I have read or had read to me the preceding information describing this study. All my questions have been answered to my satisfaction. I am 18 years of age or older and freely consent to participate. I understand that I am free to withdraw from the study at any time without penalty. I have received a copy of this consent form.

Signature of Subject _________________________ Date ________________

Signature of Investigator ______________________ Date ________________

Initials _______________
Appendix D

MEASURING BIKE DIMENSIONS

Instructions for measuring your bike prior to your first exercise test.

1. Measure distance from tip of seat to center of handle bar (see line labeled A).

2. Measure distance from center of crank to top of seat directly in line with seat tube (see line labeled B).

3. With your bike positioned upright and on level surface, drop a plumb line from tip of seat so that it falls behind the crank. Measure the distance from the plumb line to the center of the crank (see line labeled C).

4. Place a 3’ level or board (e.g. 2x4) over the top of your seat so that it reaches at least beyond the steerer tube. Measure the distance from the bottom of the level or board and the top of the steerer tube (see line labeled D).
REFERENCES


