The study was designed to directly understand the effect of various crank-speeds on the maximal oxygen consumption (VO₂ max) of trained competitive cyclists. Seven trained competitive cyclists, aged 18-35, participated in one direct measurement, progressively-loaded maximal oxygen consumption determination at each of 60, 80, and 100 RPM, for a total of three tests on separate days, with a minimum of 48 hours between tests. To be considered for the investigation, each subject completed a minimum of 100 miles during each of four weeks previous to the first day's testing.

Each determination was preceded by a ten minute warm-up. Loading in each test started at 1,500 kilo-pound-meters (kpm), and was advanced 100 kpm every other minute until the test was terminated. Test termination
was based on a drop or a plateau in the maximal oxygen consumption reading. A respiratory quotient (RQ) of one or above, a maximal heart rate, and a plotting of the VO₂ ascertained that a maximal value had been attained.

An ANOVA procedure showed no significant difference between the treatment crank-speeds at any time for maximal oxygen consumption of trained cyclists. Although not significant, (P < .05) maximal oxygen consumption values were highest at 80 RPM and, on the average, cyclists rode for a longer period of time and attained a higher average load at 80 RPM. There were no recognizable differences in any of the other parameters. The findings indicated that a crank-speed of 80 RPM should be recommended for long distance competitive cyclists during a maximal oxygen determination. However, further detailed study is recommended in order to more fully demonstrate and support these findings.
The Effects of Various Crank-speeds (60, 80, 100 RPM) on Maximal Oxygen consumption in Trained competitive Cyclists

by

Gregory G. Reese

A THESIS submitted to Oregon State University

in partial fulfillment of the requirements for the degree of Master of Science

Completed: July 22, 1986

Commencement: June 1987
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>I. Introduction</strong></td>
<td>1</td>
</tr>
<tr>
<td>The Physiological Testing of Athletes</td>
<td>2</td>
</tr>
<tr>
<td>Statement of the Problem</td>
<td>3</td>
</tr>
<tr>
<td>Significance of the Study</td>
<td>4</td>
</tr>
<tr>
<td>Methodology</td>
<td>4</td>
</tr>
<tr>
<td>Delimitations</td>
<td>5</td>
</tr>
<tr>
<td>Limitations</td>
<td>6</td>
</tr>
<tr>
<td>Assumptions</td>
<td>6</td>
</tr>
<tr>
<td>Operational Definitions</td>
<td>7</td>
</tr>
<tr>
<td>Research Hypothesis</td>
<td>9</td>
</tr>
<tr>
<td>Statistical Hypotheses</td>
<td>9</td>
</tr>
<tr>
<td><strong>II. The Review of Literature</strong></td>
<td>10</td>
</tr>
<tr>
<td>The Muscle Physiology of Cycling</td>
<td>10</td>
</tr>
<tr>
<td>Introduction</td>
<td>10</td>
</tr>
<tr>
<td>Fuel Choice and Muscle Fiber Type</td>
<td>11</td>
</tr>
<tr>
<td>Muscle Fiber Type and Enzymology</td>
<td>11</td>
</tr>
<tr>
<td>Muscle Fiber Type and Energy Production</td>
<td>13</td>
</tr>
<tr>
<td>Muscle Fiber Type and Physical Activity</td>
<td>14</td>
</tr>
<tr>
<td>Maximal Testing of Oxygen Consumption</td>
<td>16</td>
</tr>
<tr>
<td>History of Crank-speed Controversy</td>
<td>18</td>
</tr>
<tr>
<td>A Cyclist's Protocol</td>
<td>22</td>
</tr>
<tr>
<td>Summary</td>
<td>24</td>
</tr>
<tr>
<td><strong>III. Methods and Procedures</strong></td>
<td>25</td>
</tr>
<tr>
<td>Introduction</td>
<td>25</td>
</tr>
<tr>
<td>Subjects</td>
<td>25</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>27</td>
</tr>
<tr>
<td>Experimental Design</td>
<td>27</td>
</tr>
<tr>
<td>Test Description and Procedures</td>
<td>28</td>
</tr>
<tr>
<td>Statistical Analysis</td>
<td>30</td>
</tr>
<tr>
<td><strong>IV. Results and Discussion</strong></td>
<td>32</td>
</tr>
<tr>
<td>Introduction</td>
<td>32</td>
</tr>
<tr>
<td>Results</td>
<td>33</td>
</tr>
<tr>
<td>Discussion</td>
<td>36</td>
</tr>
</tbody>
</table>
V. Summary, Conclusions, and Recommendations

Summary
Conclusion
Recommendations

Bibliography

Appendices

A. Statement of Current Training
B. Informed Consent Release
C. Cycle Ergometer Maximal Oxygen Consumption Protocol
D. Application for Approval of the Human Subjects Board, Oregon State University
E. Figure 1. Cyclist Participating in a Maximal Oxygen Consumption Determination
## LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Summary Table of Relevant Subject Data</td>
<td>26</td>
</tr>
<tr>
<td>2. Summary Table of Riding Time and Power Output</td>
<td>30</td>
</tr>
<tr>
<td>3. Summary Table of Randomized ANOVA and Group Means</td>
<td>33</td>
</tr>
<tr>
<td>4. Summary Table for Ten Parameters Including</td>
<td>34</td>
</tr>
<tr>
<td>Maximal Oxygen Consumption at 60 RPM Crank-speed Treatment</td>
<td></td>
</tr>
<tr>
<td>5. Summary Table for Ten Parameters Including</td>
<td>35</td>
</tr>
<tr>
<td>Maximal Oxygen Consumption at 80 RPM Crank-speed Treatment</td>
<td></td>
</tr>
<tr>
<td>6. Summary Table for Ten Parameters Including</td>
<td>36</td>
</tr>
<tr>
<td>Maximal Oxygen Consumption at 100 RPM Crank-speed Treatment</td>
<td></td>
</tr>
</tbody>
</table>
The Effect of Various Crank-speeds (60, 80, 100 RPM) on Maximal Oxygen Consumption in Trained Competitive Cyclists

CHAPTER ONE

Introduction

Competitive cycling is the second most popular sport in the world, after soccer. In the United States cycling was the most popular in the 1920's and 1930's, featuring the famous six day indoor velodrome races. However, the United States until recently has never been a power in either international or Olympic cycle competitions. European countries have dominated the sport and only in the 1980's has the United States begun to emerge as a major force. However, the rise in the quality of American cycling is not confined to performances abroad, but may be seen in the United States through the increasing numbers of competitors and coaches at the amateur level and through the realization that success at this level also requires quality training and coaching (Faria, 1978a).
As both interest and participation have continued to expand the sport of competitive cycling in this country, coaches and athletes have increasingly come to recognize the vital role that physiological testing plays in the successful preparation of the amateur cyclist.

The Physiological Testing of Athletes

Athletes from many sports have been physiologically tested for the purpose of providing information to the athlete and coach and to add to the fund of scientific theory and knowledge concerning the human organism. The physiological characteristics of both recreational joggers and competitive runners have been extensively detailed and we have come to recognize the distinct differences between them (Faria, 1978a). The physiological research needed to ascertain the distinct differences between recreational cyclists, athletes from sports other than cycling, fit individuals not currently on a regular training regimen, and the competitive cyclist has not been conducted.

One of the most frequently measured parameters of the competitive cyclist is the laboratory assessment of maximal oxygen consumption, or ergometric determination, which is an established and reliable instrument used to evaluate aerobic fitness (Astrand, 1977). The protocol for this test has been validated using physical education students or athletes from sports other than cycling (Faria, 1978a).
Due to competitive cycling's long period of dormancy in the United States, little is known of the optimal protocol for testing competitive cyclists.

Highly trained competitive cyclists prefer crank-speeds of 90 revolutions per minute (RPM) or above, but the current ergometer protocol calls for 50 to 60 RPM. This crank-speed may not be specific enough for cyclists who spend hours training and racing at 90 RPM and higher. As the sport of competitive cycling continues to grow, an increasing number of amateur coaches and athletes have begun to understand the importance that science plays in performance. Therefore as more volunteers are asked to act as subjects for ergometric determination evaluations, more competitive cyclists will volunteer as subjects in the hope of discovering their maximal oxygen consumption (Faria, 1978a). This study is an effort to assist in bridging this gap in knowledge concerning the validity of aerobic fitness tests for competitive cyclists.

Significance of the Problem

The primary purpose of this study was to measure the maximal oxygen consumption of trained competitive cyclists of amateur standing, while varying crank-speeds (i.e., 60, 80, and 100 RPM), in order to produce a valid and standard measurement of VO2 max for trained competitive cyclists.
Significance of the Study

Competitive cyclists and their coaches are beginning to recognize the role science can play in eliciting higher levels of performance. Coaches are recommending that their riders stay abreast of current scientific information on competitive cycling and visit the local universities for physiological testing, including the assessment of body fat, blood testing, and maximal oxygen consumption determinations (Faria, 1978a).

There must be a determination of the validity of the 50-60 RPM crank-speed in maximal oxygen consumption for the expanding population of amateur competitive cyclists, or the establishment of a new standard measurement. Failure to accomplish this task will render all research done with volunteer trained competitive cyclists invalid (Faria, 1978a).

Methodology

The subjects were seven trained competitive cyclists, aged 18-35, who participated in one continuous and progressively loaded maximal oxygen determination test at 60 RPM, 80 RPM, and 100 RPM. Each subject was tested at each crank speed on separate days, with a minimum of 48 hours rest between tests (Astrand, 1977). Each subject was a current Oregon State University student and was a volunteer. The
study was conducted in the Human Performance Laboratory of the School of Health and Physical Education, Oregon State University, Corvallis, Oregon, and all laboratory work was completed during the spring term of 1986.

Prior to the start of the first day's testing, each subject signed a "statement of current training" (see Appendix A) and an "informed consent release" (see Appendix B), after reading the proposed outline of the protocol (see Appendix C). The mechanics of the proposed study were approved by the Oregon State University Human Subjects Board (see Appendix D).

Each test was preceded by a ten minute warm-up. The continuous and progressive loading of each test started at 1,500 kilo-pound-meters (kpm), and was advanced 100 kpm every 2 minutes until termination of the test. Test termination was based on a drop or reaching a plateau in the VO$_2$ max. A respiratory quotient (RQ) reading of one or above, a maximal heart-rate, and plotting of the VO$_2$ max ascertained that maximum value had been attained.

**Delimitations**

1. All subjects were competitive cyclists.

2. All subjects were male.

3. All research data was collected from Oregon State University students who were competitive cyclists.

4. All research data was taken in spring term, 1986.
Limitations

1. Seven trained competitive cyclists were used for this investigation.

2. Results of this study were not used to draw inferences other sport athletes beyond the sports of competitive cycling and tri-athletics.

3. Results of this study were not used to draw inferences regarding female athletes of any sport.

4. The volunteer status of the cyclists was a limitation to the external validity.

Assumptions

The following assumptions were made in this study:

1. Cyclists currently training to be competitive in competitions scheduled in the near future and complying with the current training minimums (see Appendix A), were considered "trained competitive cyclists".

2. The physical capabilities of the sample were within the normal range of collegiate trained competitive cyclists.

3. The continuous and progressive loading test used for VO₂ max determinations in this investigation was a valid test for competitive cyclists because it was a close representation of the conditions of competition.

4. Subjects understood all directions before beginning the VO₂ max testing protocol.
5. Subjects followed all directions such as refraining from eating for two hours prior to a VO\textsubscript{2} max determination and training lightly the day before taking a VO\textsubscript{2} max determination test.

6. Random assignment of the three RPM factors among the sample population effectively counter-balanced the crank-speed treatments among the subjects.

7. The limitations of this investigation did not prevent sufficient external validity (generalization) to cycling populations beyond the collegiate population.

Operational Definitions

1. **Aerobic metabolism**: Oxidative metabolism producing 38 moles of adenosine tri-phosphate (ATP) for every mole of glucose entering glycolysis and 148 moles of ATP for every mole of free fatty acids directly entering the citric acid cycle when sufficient oxygen is present.

2. **Anaerobic metabolism**: Non-oxidative metabolism in which the lack of oxygen at the tissue level prevents the entrance of pyruvate into the citric acid cycle, promoting the conversion of pyruvate to lactate and diffusing it into the blood.

3. **Competitive; competitiveness**: To successfully place in cycle competitions.

4. **Competitive cyclists**: Cyclists who have adapted
to the physical and mental stresses imposed by long-term, high-intensity and high-volume cycle training, and who often display these adaptations in competitions (O'Shea, 1982).

The triathlete was considered a competitive cyclist because of the high volume cycle training undertaken, in addition to swimming and running activities.

5. **Extra carbon dioxide**: (ECO₂) Carbon dioxide production/output above and beyond resting conditions. This measurement has been positively correlated with performance in competitive cycling (Pandolf, 1984).

6. **Maximal oxygen consumption**: (VO₂ max) The highest oxygen up-take a subject can attain during physical work while breathing air at sea level (Astrand, 1977). This measurement is often expressed in relation to body weight in kg, which is the form most useful to the investigation.

7. **Respiratory quotient** (R, RQ, also RER): The ratio of carbon dioxide (CO₂) produced to the volume of oxygen (O₂) utilized (Astrand, 1977).

8. **Trained amateur competitive cyclists**: Competitive cyclists who have: a) trained a minimum of 4 times per week and accumulated no less than 100 miles in each week one month prior to testing, and b) who have continued such a training regimen for the entire duration of the study.
Research Hypothesis

Increasing cycle crank-speed from 60 to 100 RPM will result in increased maximal oxygen consumption by trained competitive cyclists.

Statistical Hypotheses

The experimental design dictated one null hypothesis and three alternate hypotheses expressed in terms of population mean differences among treatment groups:

1. $H_0$: $UT_3 \leq UT_2 \leq UT_1$
2. $H_{1a}$: $UT_3 > UT_2$
3. $H_{1b}$: $UT_2 > UT_1$
4. $H_{1c}$: $UT_3 > UT_1$

The null hypotheses was $H_0$ and $H_{1a}$-$H_{1c}$ represented the three alternate hypothesis. Treatments were represented by $T_1$, $T_2$, and $T_3$ and were the crank-speeds of 60, 80 and 100 RPM (independent variable). The dependent variable was maximal oxygen consumption.
CHAPTER TWO

The Review of Literature

The Muscle Physiology of Cycling

Introduction

Faria (1978a) has suggested that there are definite physiological differences between the cyclist and non-cyclist or the athlete of another sport. Competitive cyclists spend a great deal of time in the cycle saddle prompting the physiological changes unique to this population. Among these characteristics are a well developed oxygen transport system, a high VO$_2$ max and possession of ideal muscle fiber composition. All of these athletic qualities are affected by the physiology of muscle tissue.

In general, athletes select sports based on their natural endowments and physiological characteristics. All sports can be divided into two categories, anaerobic or aerobic, each of which, respectively, uses glucose or fatty-free acids as fuel (Astrand, 1977; Faria, 1978a).
Fuel Choice and Muscle Fiber Type

The fuel used to accomplish muscular work is dependent on the frequency and strength of muscular contraction which in turn dictates recruitment of either fast-twitch muscle fibers or slow-twitch muscle fibers or a combination of the two (Sjogaard, 1984).

The ultimate recruitment combination of fiber types dictates the fuel combination used (Forester, 1984), which is described by the respiratory quotient (RQ) (Astrand, 1977).

The RQ is defined as the ratio of carbon dioxide produced to the volume of oxygen utilized. Under normal conditions, only carbohydrates, fats and proteins are used for muscular contraction (Forester, 1984). If the energy supply is adequate, the body uses protein for cell repair, enzymes, and hormones. The body tries to spare protein for this purpose by utilizing large amounts of carbohydrate and free-fatty acids for muscular contraction. The scale of measurement for the respiratory quotient during all-out physical effort begins at .7 for the exclusive combustion of fats and extends above one for the exclusive combustion of carbohydrates (Astrand, 1977).

Muscle Fiber Type and Enzymology

Muscle physiology research describes enzymatic differences between fast-twitch and slow-twitch muscle fibers.
(Astrand, 1977). Slow-twitch muscle fibers are high in the Kreb cycle enzyme succinate dehydrogenase, which indicates the mitochondrial oxidative potential of muscle. In addition, pyruvate dehydrogenase is the critical enzyme acting as the gate between the inefficient anaerobic glycolysis, which transforms pyruvate to lactate, and aerobic glycolysis, which transforms pyruvate into acetyl-coenzyme A. The fate of acetyl-coenzyme A is the Kreb cycle, in which it is ultimately converted to carbon dioxide (CO₂), water, and 38 moles of adenosine tri-phosphate (ATP) for every mole of glucose which enters the system (Faria, 1978a). Faria notes that Purnay has suggested that given a lack of the glycolytic enzyme pyruvate dehydrogenase, lactate may begin to accumulate even in the presence of sufficient oxygen (Faria, 1978a).

Energy liberation is much faster during the glycolytic breakdown of a substrate than in the oxidative breakdown of the same substance. This is the major reason that fast-twitch muscle fibers have a greater glycolytic capacity than slow-twitch muscle fibers, since they need the ability to turn over great quantities of energy during fast muscular contraction or in loads too severe for slow-twitch muscle fibers to work against (Sjogaard, 1984). However, the metabolic capacities of the muscle fiber types can change within limits, dependent upon the types of chronic activity to which they have been exposed.
Research has focused on four enzymes which appear to be directly affected by training: a) hexokinase (HK), b) lactate dehydrogenase (LDH), c) citrate synthetase (CS), and d) B-hydroxy-acyl-CoA dehydrogenase (HAD). HK catalyzes the first step of glucose breakdown, while LDH catalyzes the formation of lactate. The enzyme CS is a kreb cycle enzyme, as is succinate dehydrogenase, and it affects the distribution of electron carriers to the electron transport chain. The enzyme HAD is critical because it catalyzes the breakdown of fat. It has been reported that CS and HAD are up to 50 percent more active in trained cyclists than in physical education students. The activity of HK has been shown to be higher among cyclists. The observation that LDH levels in competitive cyclists were below the levels of the average population is even more striking, indicating that the cycle training adapted the muscle fibers to produce less lactate (Sjogard, 1984).

**Muscle Fiber Type and Energy Production**

Research has shown that aerobic athletes have a higher percentage of slow-twitch muscle fiber than do non-athletes or athletes of more anaerobic oriented sports in which fast-twitch muscle fibers predominate (Parker, 1981). Fast-twitch muscle fiber is poorly supplied with the Kreb cycle enzymes, but is richly supplied with the glycolytic enzymes important to anaerobic metabolism. Weight lifters and sprint athletes of both running and
cycling have been shown to have predominantly fast twitch muscle fibers (Faria, 1978a). The power output in these athletes is high, but of short duration (30 seconds to 2 minutes) due to the quick accumulation of high levels of lactate. With work the rate of glycolysis increases exponentially to 110 percent of the VO₂ max and activity at 90 percent of the VO₂ max produces a steady increase of blood lactate, until the activity is stopped or slowed down due to accumulation of fatigue causing lactate. (Astrand, 1977, Faria, 1978a).

Research has demonstrated that road cyclists possess a predominance of slow-twitch muscle fibers. Cyclists tested through muscle biopsy techniques have been shown to possess 73 percent slow-twitch muscle fibers compared to non-endurance individuals possessing a 50 percent ratio of slow to fast-twitch muscle fiber (Faria, 1978a).

Muscle Fiber Type and Physical Activity

It is possible for a certain fiber type to hypertrophy, a property also dependent upon the type of chronic activity to which the muscle has been exposed. Fast-twitch muscle fiber is naturally larger in size than its slow-twitch counterpart and while the surface area of fast-twitch muscle fiber in the competitive cyclist is nearly identical in size to that of physical education students, competitive cyclists had a relatively larger muscle mass. The difference was largely due to the hypertrophy of the
slow-twitch muscle fibers of the competitive cyclists (Sjogaard, 1984). This indicates that the relative surface area of slow-twitch muscle fiber within the thighs of the competitive cyclist is larger than would be indicated by measuring slow-twitch muscle fiber as a percentage. With repeated muscle fiber testing throughout a competitive season, Sjogaard reported that the mean percentage of slow-twitch fibers in a group of cyclists actually increased as the fast-twitch surface area decreased. With the increase in the surface area of oxidative metabolism, there is a greater need for oxygen and substrates. To meet this need there is an increase in capillary density and cyclists have been reported to possess a capillary density that is 30 percent higher than that of physical education students. (Sjogaard, 1984).

The cyclist with a predominance of slow-twitch muscle fiber is also efficient at burning free-fatty acids at 60 percent of VO₂ max, using great quantities of oxygen to convert the fats to carbon dioxide, water and ATP (Forester, 1984). A high VO₂ max and a low RQ at high work loads is characteristic of the ability to burn large quantities of fats as the main fuel (Malhotra, 1984). The availability of oxygen in large amounts is critical because the oxidation of free fatty acids requires oxygen as the hydrogen acceptor. This mechanism minimizes carbohydrate consumption, which exist in limited quantities when compared with the body pool
of fats, and it also allows the trained cyclist to ride in the peloton at 25 mph for four hours and then sprint for the line at 35 mph for the win. Since the ability to use fats is dependent on the availability of oxygen at the time of muscular contraction, the choice of fuel used by the muscle depends on the individual's VO₂ max (Astrand, 1977). Most amateur cyclists have VO₂ max readings in the low to high 60's (O'Shea, 1982), but the better amateurs and professional cyclists may top 80 ml-kg/min (Faria, 1978a).

Non-cyclists often complain of quadriceps pain, especially around the knee, when engaging in the severe cycling of a maximal oxygen test. The muscle in this area is specifically stressed in cycling and may prevent a subject from continuing long enough to attain VO₂ max (Pandolf, 1973). In the sedentary subject lactate begins to accumulate, extra carbon dioxide (ECO₂) is produced, and the respiratory quotient rises. Individuals differ in their lactate tolerance, but it is generally considered that when the RQ level exceeds 1.0, lactic acid has accumulated within the blood in quantities sufficient to hinder further activity at the current intensity. Among elite cyclists the RQ may peak at 1.20 before activity must slow or stop due to excessive lactate production and fatigue (Malhotra, 1984).

Maximal Testing of Oxygen Consumption

The high speeds required in cycle competitions require high energy outputs in the body. Physical work which extends
over a few minutes requires oxygen consumption by the actively involved muscle cells and oxygen consumption increases in direct proportion to energy expenditure and the work accomplished. The higher the VO₂ max, the lower the stress on metabolism, the quicker the body adapts, and the longer the load can be sustained, especially if it is sub-maximal (Sjøgaard, 1984).

Tests of maximal oxygen consumption normally start with a sub-maximal load, which serves as the warm-up. After this load, the loading may be increased in several ways: a), the load may be increased step-by-step, with several sub-maximal loads added each minute or every other minute; b) the loads may be increased as above, but each load is sustained for five to six minutes; and c) immediately following warm-up, loading is increased to a level that prior testing has predicted as the maximal load for the subject (Astrand, 1977).

The bicycle is the modality of choice when engaging in routine tests or studies. In sub-maximal work, 50-60 RPM produces the lowest oxygen up-take, but during heavy or maximal work the optimal pedal frequency is higher, and should not fall below 60 RPM. Many ergometers produce a constant load, regardless of pedal RPM. This is a disadvantage when a subject becomes fatigued and is unable to maintain crank-speed, because as the pedal rate falls the force needed for each pedal revolution increases (Astrand, 1977).
History of Crank-speed Controversy

Over the years a variety of research concerned pedal frequency and efficiency, almost all of it using non-cyclists as subjects. It has been documented that very little change in efficiency occurs between 50 and 80 RPM (Garry, 1931). But some tests have found that maximal oxygen consumption rises at less than 30 and greater than 40 RPM (Pandolf, 1973). Evidence also exists that individuals who can maintain 100 to 120 RPM throughout the test until termination exhibit higher oxygen consumptions (Pandolf, 1973). It is also a fact that well-trained cyclists prefer crank-speeds between 90 and 100 RPM (Faria, 1978a). Non-cyclists generally prefer crank-speeds of 50 to 60 RPM.

The evolution of the human body does not lend itself to cycling as a natural activity. The non-cyclist’s preference for low crank-speeds represents the low speed, full range motion of the hill-climbing walk, during which the brain sends a message to the muscles "to operate at 120 steps a minute or 60 RPM" (Forester, 1984, p. 143). The experienced cyclist has overcome this reflex by out-smarting evolution, and in doing so, can produce more power longer than by any other human movement (Forester, 1984).

The typical VO₂ max laboratory testing protocol calls for the placing of a subject on the ergometer and running
him through a series of progressively increasing loads at between 50 and 60 RPM. The test lasts about 12 minutes, by which time the subject has ridden about 4 miles and will collapse from exhaustion (Forester, 1984). The trained and competitive cyclist may ride 5 miles before terminating the test in exhaustion. However, this is not equal to the length of even the shortest race. Stage races may last six hours per day for many consecutive days and the longest stage race in Europe lasts for 23 days.

Researchers use 50 to 60 RPM in the protocol because it maximizes mechanical efficiency and oxygen efficiency (Astrand, 1977; Forester, 1984). Force and speed are interchangeable in power production within machines, but are not physiologically equivalent. The fact that the trained cyclist deliberately chooses to pedal at a considerably faster rate tells us that oxygen is sufficiently present and that there is no reason to economize it (Forester, 1984).

As the velocity of contraction in non-aerobically trained muscle increases, fast-twitch fibers are recruited over slow-twitch fibers because fast-twitch muscle fibers develop tension at a much faster rate than do slow-twitch muscle fiber (Parker, 1983). In addition, muscle force is controlled by the number of motor units recruited by the central nervous system. The higher the number of motor units and muscle fibers recruited for a task, the higher are the chances that a greater percentage of fast-twitch fiber
will be recruited to complete the task. The more fast
twitch muscle fiber involved in a task, the more anaerobic
it becomes and increasing amounts of glycogen are split.
Endogenous carbohydrate storage is limited, and when work
depletes the supply, anaerobic activity using high numbers
of fast-twitch muscle fibers must end (Astrand, 1977,
Forester, 1984). The experimental subject required to ride
the typical protocol of 50 to 60 RPM during a maximal
oxygen consumption test is being asked to ride "25 mph
in a 140 in. gear, a feat we know to be impossible"
(Forester, 1984, p.140), since the world record for 25
miles was set using a 112 in. gear at 90 RPM attaining
thirty miles per hour. In the face of declining carbohydrate
stores and greater need of carbohydrates imposed by
increasing loads, termination is brought on by the depletion
of glucose and glycogen, and the required power can not be
maintained at the required cadence. (Forester, 1984).

Preference for higher crank-speeds was noted in
non-competitive but fit cyclists tested at 60 and 80 RPM.
In order to attain an equivalent power output at a lower
RPM, greater resistance must be applied to the brake wheel
whereby greater muscular force is required to overcome the
resistance (Pandolf, 1973). Pandolf noted that the
perceived exertion of his subjects was higher at 60 RPM
than at 80, due to muscular joint discomfort. In addition,
he suggested that the higher crank-speeds may be more a
function of local muscular strength.

In a study using only trained competitive cyclists with maximal oxygen consumptions in the low seventies, Perez (1981) measured the effects on VO$_2$ max of the cyclists' training regimen. The subjects were tested 3 times during the 23 week 1980 competitive cycling season. Oxygen debt rose and VO$_2$ max declined at midseason, suggesting a decline in aerobic efficiency. This occurred despite the fact that riders were spending more time in the saddle at midseason than earlier in the year. Perez noted that early season training was done in low gear ratios using high RPM. At midseason, the cyclists reversed this practice by slowing their RPM and increasing the gear ratio in order to build the muscular strength and power critical to successful time trials. Perez concluded that resistance in the form of heavier loads applied to muscles previously trained for endurance work, results in a decline of VO$_2$ max and an increase in oxygen debt, "presumably due to the recruitment of fast twitch muscle fibers" (p. 167). The untrained cyclist prefers a crank-speed high enough to avoid perceived joint discomfort, but low enough that the speeds of contraction do not recruit large quantities of fast twitch muscle fibers. The trained cyclist attempts to achieve an RPM rate high enough to avoid joint discomfort and benefit from the aerobic system for which he has spent so many hours training.
A Cyclist's Protocol

The treadmill produces the highest maximal oxygen consumption in all experimental subjects except trained cyclists. Trained competitive cyclists are most logically tested on a cycle ergometer with a narrow racing saddle, drop-handlebars, rat-trap pedals with toe-clips, and the opportunity to stand on the pedals as needed to maintain proper pedal frequency (Faria, 1978a; Shephard, 1984).

It has been demonstrated that the seated body position assumed during cycling effects $V\text{O}_2$ max, which has been measured for trained subjects in: a) the "top-bar" position and b) in the drops. In the top-bar position, $V\text{O}_2$ was was 93 percent of the $V\text{O}_2$ max attained in the drops (Faria, 1978b). Faria concluded that the 15 percent forward lean attained from cycling in the drop portion of the racing handle-bar produces a 4 percent increase in expiratory reserve volume, a 1.26 ml-kg/min increase in $V\text{O}_2$ max, and an increase in cardiac output. It should be noted that all testing was done using toe-clips and cleated cycling shoes.

Work load and the duration of testing has been described for the trained subject. Oxygen up-take increases during the first minutes of exercise until the oxygen up-take and delivery equal the need at the tissue level. The characteristic leveling off of oxygen up-take is referred to as the "steady state" of exercise. As the exercise intensity
increases, the use of fast-twitch muscle fibers rises in proportion to slow-twitch and the activity becomes anaerobic (Astrand, 1977). Astrand notes that for the trained subject there is no need for a progression of resistances to assess VO₂ max. Aerobic capacity in the trained subject may be measured with an exercise bout of two to eight minutes, dependent on the conditioning of the individual and the exercise load (1961a,b). Astrand (1977) concluded that "an all-out test is not necessary for the assessment of an individual's maximal aerobic [consumption]" (p. 297). In repeated oxygen consumption tests on the same subject, under a variety of loads and durations (duration being inversely related to load), Astrand observed that a standard deviation of three percent could be attributed to biological and methodological variables. A warm-up of 10 minutes, however, was critical to proper results (1961a).

In an attempt to measure the anaerobic power of two trained cyclists with VO₂ max readings in the high 60's, O'Shea (1982) placed the riders on a cycle ergometer for 15 minutes at a load of 2,400 kpm. O'Shea demonstrated the need for "specific physical performance assessment tests," because trained athletes who had adapted to the physical and mental stress imposed by long-term, high-intensity, high-volume training may be inadequately stressed by laboratory tests used to measure the "physiological performance of normal individuals" (p. 160).
Adaptation of the RQ occurs in the initial minutes of exercise. Issekutz (1961) determined that three phases of change occurred in his subjects while riding the cycle ergometer. During moderate to heavy work, an initial increase was followed by a secondary fall. A final slow but steady increase to a steady state occurred within four minutes (Issekutz, 1961). The rise in RQ was determined to be logarithmic with increased work load. Similarly, Issekutz perceived a positive linear trend between ECO₂ and increases in blood lactate. Pandolf (1984), defining ECO₂ as the CO₂ output over and above testing conditions, positively correlated ECO₂ with cycling performance (.86), VO₂ max with cycling performance (.87), and combined, VO₂ max and ECO₂ correlate with cycling performance (.92).

Summary

The review of literature suggests the need to consider the competitive cyclist as a population separate from all other subject type when determining VO₂ max. This study is required in order to alert disciplines such as human nutrition and the human movement sciences which may use VO₂ max oxygen consumption as a means to test and establish theories, that failure to ascertain that established protocols are valid for the competitive cyclist will render all research done with this population invalid (Faria, 1978a).
CHAPTER THREE

Methods and Procedures

Introduction

The purpose of this study was to compare the effect of various crank-speeds (60, 80, 100 RPM) on the maximal oxygen consumption of amateur trained competitive cyclists. This study was conducted in the spring of the 1986 academic year at Oregon State University, Corvallis, Oregon. Testing of the subjects was conducted in the Human Performance Laboratory of the College of Health and Physical Education. This chapter will describe the subject selection procedures and provide information concerning instrumentation, testing procedures, and statistical analysis.

Subjects

Seven trained competitive cyclists aged 18 to 35 volunteered as subjects for this research (see table 1). All subjects were male students at Oregon State University. Each subject signed a statement describing the minimum standards of current training necessary: a) for inclusion
in the study and b) for maintaining proper fitness for the duration of the study (Appendix A). In addition, each subject stipulated that he had trained during the preceding year with the intention of being competitive in some future cycling event. All subjects were currently enrolled Oregon State University students and each signed an informed consent release form (Appendix B) after reading an outline of the protocol (Appendix C). The proposed outline of the study was approved by the human subjects committee of Oregon State University (Appendix D).

**Table 1. Summary Table of Relevant Subject Data.**

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (years)</th>
<th>Height (inches)</th>
<th>Weight (pounds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M.K.</td>
<td>23</td>
<td>71.75</td>
<td>149.00</td>
</tr>
<tr>
<td>A.K.</td>
<td>19</td>
<td>69.50</td>
<td>151.50</td>
</tr>
<tr>
<td>R.K.</td>
<td>19</td>
<td>66.00</td>
<td>136.00</td>
</tr>
<tr>
<td>C.B.</td>
<td>21</td>
<td>72.25</td>
<td>184.25</td>
</tr>
<tr>
<td>R.B.</td>
<td>22</td>
<td>66.75</td>
<td>143.75</td>
</tr>
<tr>
<td>B.K.</td>
<td>34</td>
<td>68.25</td>
<td>176.25</td>
</tr>
<tr>
<td>G.R.</td>
<td>28</td>
<td>71.00</td>
<td>161.00</td>
</tr>
</tbody>
</table>

Average: 23.7  69.36  157.39  
Standard Deviation: 5.5  2.45  17.51  
Range: 19-34  66.00-72.25  136.00-184.25  

All records were taken on the initial day of testing.
Instrumentation

In measuring the VO$_2$ max of the subjects, the following instrumentation was strictly observed in accordance with appropriate procedural manuals. An Applied Electrochemistry SA-1 Oxygen Analyzer and a Beckman LB-2 Carbon Dioxide Gas Analyzer (gas analysis) were connected to a Parkinson-Cowen Flow Meter to measure the volumes of gas (intake and output). A Daniel's Three Way Valve connected the subject to the gas analysis system.

The above gas analysis system was interfaced with an Apple II+ computer for on-line, continuous minute-to-minute VO$_2$ max oxygen consumption determinations using the Rayfield Computational Software Program (Rayfield Equipment, Chicago, IL). A Quinton #845 Instrument Electrical Ergometer was used, fitted with rat-trap pedals with toe-clips and straps for use with each subject's cleated cycling shoes. The gas analysis system was calibrated after each subject test and prior to testing the next subject.

A Physio-Control Lifepak Seven heart-rate monitor was used to measure exercise heart-rate throughout the test, producing Electro-cardiograph (ECG) printouts. Heart-rates were calculated with the use of a ruler and a standardized ECG heart-rate table.

Experimental Design

A one factor repeated measures design, using three
levels of the factor (60, 80, 100 RPM), served to test the hypotheses of this investigation. Subjects were randomly assigned to one of six treatment combinations counterbalanced for order. Counter-balancing controlled for possible carry-over effects by ensuring that no two riders received the same order of RPM.

Participant mortality was minimized by using only competitive cyclists, which also allowed generalization of the results for that population.

Test Description and Procedures

Each of the seven subjects participated in one direct measurement, progressively-loaded maximal oxygen up-take test at 60 RPM, 80 RPM and 100 RPM, for a total of three tests on separate days. A minimum of 48 hours was given for rest between each test. Details of the study were explained verbally and in writing to all subjects prior to the signing of the informed consent release.

Initially, on the first day the resting heart rate was recorded, electrodes for heart-rate monitoring were applied, and individual body weight, height, and age were recorded (see table 1). Thereafter, only the resting heart rates were recorded and electrodes were applied before the commencement of subsequent tests. The recorded body weight was entered in the computer for use in the computation of the VO₂max, and was duplicated for each
of the subsequent tests, unless a subject reported the gain or loss of five pounds or more. In that case, the two recorded body weights were averaged. Three electrodes were then placed on the rider: just under the left clavicle in the mid-clavicular position and on each side at the fifth rib in line with the mid-clavicular region.

The ergometer was adjusted to the rider's body size. Saddle height was adjusted to accommodate leg length by placing the heel on the pedal at the six-o-clock position and achieving a slight bend in the knee (Powell, 1982). The handle-bar was adjusted to the comfort of the rider and for a slight bend in the elbow when the cyclist was connected to the gas analysis system. Each measurement was recorded and duplicated for each subsequent test. Each subject assumed a comfortable racing position and maintained it until the completion of the test.

Each subject warmed up for ten minutes in a high RPM and at a subject-selected kpm, in order to establish free respiration and perspiration prior to the test. The subject was then connected to the gas analysis system and the heart rate monitor and began pedaling at the prescribed RPM following the guidance of a metronome placed in front of the ergometer. Subjects pedaled at 1,500 for two minutes, at which time the load was increased by 100 kpm. The load was increased thereafter by 100 kpm increments every two minutes until a maximal oxygen consumption was evidenced and the test
could be terminated (see Table 2). Subjects were encouraged to continue pedaling the prescribed RPM even if the kpm had to be reduced, in order that a plateau or fall in VO₂ max could be readily evidenced and testing for the day terminated. An RQ rise considerably above 1.0, and a plotting of VO₂ max calculations ascertained that a VO₂ max plateau was reached. The VO₂ max was taken as the highest oxygen consumption reading during the test and all readings were registered as ml·kg/min (VO₂ max).

Table 2  Summary Table of Riding Time and Power Output.*

<table>
<thead>
<tr>
<th>RIDING TIME IN MINUTES</th>
<th>POWER OUT-PUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td>1500 kpm (250 watts)</td>
</tr>
<tr>
<td>2-4</td>
<td>1600 kpm (267 watts)</td>
</tr>
<tr>
<td>4-6</td>
<td>1700 kpm (283 watts)</td>
</tr>
<tr>
<td>6-8</td>
<td>1800 kpm (300 watts)</td>
</tr>
<tr>
<td>8-10</td>
<td>1900 kpm (317 watts)</td>
</tr>
<tr>
<td>10-12</td>
<td>2000 kpm (334 watts)</td>
</tr>
<tr>
<td>12-14</td>
<td>2100 kpm (350 watts)</td>
</tr>
</tbody>
</table>

*Continuous-progressive phase; expected aerobic power, 4.00-6.00 liters/ minute.

Statistical Analysis

The statistical analysis was processed by computer in
the Computer Laboratory of the College of Health and Physical Education, Oregon State University, Corvallis, Oregon. The experimental design dictated that a repeated measures analysis of variance (ANOVA) with post hoc comparisons be used to evaluate the data of this investigation (Kirk, 1982). In addition, a trend analysis evaluated the differences between the treatments, providing that significant differences could be observed in the mean scores for each treatment. The alpha level of 0.05 was selected as the level of significance (p < .05) for the acceptance or rejection of the null hypotheses. A power analysis using an alpha level and subject-power table determined that for a power of .80, 23 subjects were needed (Kirk, 1982).
CHAPTER FOUR

Results and Discussion

Introduction

The purpose of this study was to compare the effects of three cranks-speeds (60, 80, 100 RPM) on the maximal oxygen consumptions of amateur competitive cyclists. The results were investigated and statistically analyzed by using an analysis of variance (ANOVA). The research hypothesis was that increasing the ergometer test crank-speed from 60 to 100 RPM would result in an increased maximal oxygen consumption by trained amateur competitive cyclists. The ANOVA was used to determine the need to employ a post-hoc comparison and trend analysis on the data of each crank-speed treatment (Kirk, 1982). The subjects were given three continuously progressive loaded VO₂ max determinations at each RPM with 48 hours allowed for rest between tests. This chapter will present the data obtained and discuss the results obtained.
Results

The averages and standard deviations for 10 parameters, including VO₂ max for each RPM treatment are displayed in Table 3. The ANOVA for the VO₂ max determinations are represented as treatment differences and subject differences and displayed in tables 4 through 6. There were no differences in VO₂ max oxygen consumption between different crank-speed treatments (60, 80, 100 RPM) at the significance level of .05 (p < .05), and consequently the null hypothesis was accepted.

Table 3. Summary Table for Randomized ANOVA and Group Means (Treatment Levels = RPM)

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>GROUPS</td>
<td>1.6842</td>
<td>2</td>
<td>.8421</td>
<td>.1857</td>
</tr>
<tr>
<td>SUBJECTS</td>
<td>624.65</td>
<td>6</td>
<td>104.11</td>
<td>22.96</td>
</tr>
<tr>
<td>ERROR</td>
<td>54.41</td>
<td>12</td>
<td>4.5342</td>
<td></td>
</tr>
<tr>
<td>TOTALS</td>
<td>680.74</td>
<td>20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Notes: SS= Sum of Squares  DF= Degrees of Freedom  MS= Mean Squares  F= Non Randomness

<table>
<thead>
<tr>
<th>Mean of Treatment Level</th>
<th>(RPM)</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (60)</td>
<td>62.3514286</td>
<td></td>
</tr>
<tr>
<td>2 (80)</td>
<td>62.2557143</td>
<td></td>
</tr>
<tr>
<td>3 (100)</td>
<td>62.8985715</td>
<td></td>
</tr>
</tbody>
</table>
Table 4. Summary Table for Ten Parameters, Including Maximal Oxygen Consumption at 60 RPM Crank-speed Treatment.

<table>
<thead>
<tr>
<th>Time</th>
<th>Load</th>
<th>BTPS</th>
<th>V02</th>
<th>CO2</th>
<th>RQ</th>
<th>HR</th>
<th>Resp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub</td>
<td>(min)</td>
<td>(kpm)</td>
<td>(vol)</td>
<td>Max</td>
<td>%</td>
<td>Max</td>
<td>Rate</td>
</tr>
</tbody>
</table>

| R.B. | 8    | 1800 | 136.01| 63.36| 4.42| 1.07| 188  | 53   | 18.06 |
| M.H. | 9    | 1900 | 131.09| 64.83| 4.55| 1.04| 196  | 40   | 18.53 |
| C.B. | 8    | 1800 | 179.45| 56.96| 4.66| .98 | 188  | 49   | 16.27 |
| B.K. | 10   | 1900 | 147.12| 58.07| 4.15| .92 | 167  | 56   | 16.59 |
| A.K. | 6    | 1700 | 140.77| 62.01| 4.58| 1.07| 180  | 58   | 17.72 |
| R.K. | 9    | 1900 | 143.98| 71.53| 4.34| .98 | 188  | 49   | 20.44 |
| G.R. | 10   | 1900 | 153.44| 59.88| 4.49| 1.03| 188  | 45   | 17.10 |

Avg. 8.67 1842 147.40 62.40 4.50 1.00 185 50 17.80
S.D. 1.40 78.68 15.89 4.92 .17 .05 9.18 6.27 1.40
Table 5. Summary Table for Ten Parameters, Including Maximal Oxygen Consumption at 80 RPM Crank-speed Treatment.

<table>
<thead>
<tr>
<th>Time</th>
<th>Load</th>
<th>BTPS (vol)</th>
<th>V02 Max</th>
<th>CO2 %</th>
<th>RQ Max</th>
<th>HR Max</th>
<th>Resp Rate</th>
<th>Mets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub</td>
<td>(min)</td>
<td>(kpm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A.K.</td>
<td>5</td>
<td>1700</td>
<td>144.69</td>
<td>63.17</td>
<td>4.63</td>
<td>1.06</td>
<td>180</td>
<td>48</td>
</tr>
<tr>
<td>B.K.</td>
<td>11</td>
<td>2000</td>
<td>147.79</td>
<td>57.05</td>
<td>4.38</td>
<td>.96</td>
<td>173</td>
<td>61</td>
</tr>
<tr>
<td>G.R.</td>
<td>11</td>
<td>2000</td>
<td>150.40</td>
<td>61.22</td>
<td>4.51</td>
<td>1.01</td>
<td>192</td>
<td>44</td>
</tr>
<tr>
<td>C.B.</td>
<td>8</td>
<td>1800</td>
<td>150.95</td>
<td>55.04</td>
<td>4.50</td>
<td>.98</td>
<td>180</td>
<td>39</td>
</tr>
<tr>
<td>M.H.</td>
<td>11</td>
<td>2000</td>
<td>150.83</td>
<td>67.48</td>
<td>4.82</td>
<td>1.05</td>
<td>188</td>
<td>45</td>
</tr>
<tr>
<td>R.B.</td>
<td>8</td>
<td>1800</td>
<td>109.53</td>
<td>59.15</td>
<td>3.85</td>
<td>.99</td>
<td>180</td>
<td>40</td>
</tr>
<tr>
<td>R.K.</td>
<td>11</td>
<td>2000</td>
<td>166.84</td>
<td>75.73</td>
<td>4.54</td>
<td>.97</td>
<td>196</td>
<td>49</td>
</tr>
</tbody>
</table>

---

Avg. 9.48 1883 145.90 62.70 4.46 1.00 184 47 17.78
S.D. 2.07 132.90 17.49 7.05 .30 .04 8.09 7.38 2.03
Table 6. Summary Table for Ten Parameters, Including Maximal Oxygen Consumption at 100 RPM Crank-speed Treatment.

<table>
<thead>
<tr>
<th>Sub</th>
<th>Time (min)</th>
<th>Load (kpm)</th>
<th>BTPS</th>
<th>VO2</th>
<th>CO2</th>
<th>RQ</th>
<th>HR</th>
<th>Resp Rate</th>
<th>Mets</th>
</tr>
</thead>
<tbody>
<tr>
<td>G.R. 12</td>
<td>2000</td>
<td>147.51</td>
<td>59.88</td>
<td>4.51</td>
<td>1.02</td>
<td>201</td>
<td>42</td>
<td>17.11</td>
<td></td>
</tr>
<tr>
<td>A.K. 6</td>
<td>1700</td>
<td>144.63</td>
<td>62.74</td>
<td>4.54</td>
<td>1.05</td>
<td>180</td>
<td>46</td>
<td>17.92</td>
<td></td>
</tr>
<tr>
<td>M.H. 10</td>
<td>1900</td>
<td>156.74</td>
<td>68.07</td>
<td>4.80</td>
<td>1.04</td>
<td>188</td>
<td>47</td>
<td>19.45</td>
<td></td>
</tr>
<tr>
<td>R.B. 8</td>
<td>1800</td>
<td>140.84</td>
<td>66.12</td>
<td>4.29</td>
<td>.99</td>
<td>180</td>
<td>47</td>
<td>18.89</td>
<td></td>
</tr>
<tr>
<td>B.K. 9</td>
<td>1900</td>
<td>151.51</td>
<td>54.43</td>
<td>4.31</td>
<td>.99</td>
<td>167</td>
<td>53</td>
<td>15.55</td>
<td></td>
</tr>
<tr>
<td>C.B. 9</td>
<td>1900</td>
<td>137.53</td>
<td>57.19</td>
<td>4.89</td>
<td>1.02</td>
<td>188</td>
<td>39</td>
<td>16.34</td>
<td></td>
</tr>
<tr>
<td>R.K. 8</td>
<td>1800</td>
<td>144.45</td>
<td>71.86</td>
<td>4.45</td>
<td>1.00</td>
<td>196</td>
<td>49</td>
<td>20.53</td>
<td></td>
</tr>
<tr>
<td>Avg. 8.9</td>
<td>1857</td>
<td>146.10</td>
<td>62.90</td>
<td>4.50</td>
<td>1.00</td>
<td>185</td>
<td>46</td>
<td>17.90</td>
<td></td>
</tr>
<tr>
<td>S.D. 1.86</td>
<td>97.59</td>
<td>6.46</td>
<td>6.20</td>
<td>.23</td>
<td>.02</td>
<td>11.29</td>
<td>4.56</td>
<td>1.80</td>
<td></td>
</tr>
</tbody>
</table>

Discussion

The results failed to show any difference between the three crank-speed treatments and they tend to support the general belief that all subjects, including trained competitive cyclists, may be maximally tested using 50-60 RPM. These results contradict the recommendations of Faria (1978a), Forester (1984), and Pandolf (1973), who noted.
that special characteristics inherent to competitive cyclists should dictate unique protocol adaptations when maximally testing the oxygen consumption of this population.

These results may be explained in part by an observation noted by Sjogaard (1984), which suggested that when trained cyclists choose their own crank-speed, they select an RPM in direct proportion to that speed. Additionally, Hagberg (1985, cited in Sjogaard) reported that the VO₂ max of the trained cyclist may actually be at its lowest at 90-100 RPM and Forester (1984) suggested that oxygen was more efficiently conserved at lower crank-speeds. Moreover, Forester reasoned that muscle energy substrates and not oxygen were the limiting factor in the laboratory VO₂ determinations. Ultimately, it has been generally accepted that the most efficient crank-speed is lower than the self-selected RPM's which cause minimal perceived exertion (Sjogaard, 1984).

Sjogaard (1984) noted that the muscular consumption of phosphocreatin (CP) and adenosine tri-phosphate (ATP) is related to load and not to crank-speed. However, the production of muscular lactate has been found to be related to crank-speed, and it has been shown that 60 RPM elicits the lowest concentrations of muscular lactic acid. Sjogaard (1984) concluded that when increased muscular lactate is
considered in combination with the relative drop in VO₂ max at higher RPMs, long distance racing could be more efficiently accomplished by riding at a crank-speed of less than 80 RPM. This recommendation is obviously of little utility in tactical situations in which the cyclist must accelerate or for the final sprint in a race. The review of literature and the data provided by this investigation lead to the conclusion that the optimum crank-speed for the trained competitive cyclist measuring VO₂ max, may be a combination of the crank-speed affording the most comfort from perceived exertion and the crank-speed allowing the optimum in energy conservation. Based upon the current scientific evidence, a crank-speed of 80 RPM is thus recommended during the ergometric testing of VO₂ max in trained amateur competitive cyclists. However, further study is needed to demonstrate this theory.
CHAPTER FIVE

Summary, Conclusions, and Recommendations

Summary

In Chapter 2 of this investigation it was suggested that trained competitive cyclists should be considered as a special population, with unique characteristics and therefore requiring protocol adaptions when testing VO_2 max on the bicycle ergometer. These cyclists spend a great deal of time in cycle training, prompting changes in body structure and chemistry, such as an efficient oxygen transport system, a high maximal oxygen consumption, and the possession of an ideal muscle fiber ratio (Faria, 1978a).

This study investigated the need to increase the crank-speed protocol from the established 50-60 RPM to 90 to 100 RPM for the purpose of optimizing maximal oxygen consumption testing in trained competitive cyclists.

The methodology of the investigation, described in chapter 3, required that seven trained cyclists
participate in VO₂ tests at each 60, 80, and 100 RPM with appropriate rest periods between each test.

Each test, preceded by a ten minute warm-up, called for continuously progressive loads, beginning at 1,500 kpm and increased by 100 kpm every 2 minutes until termination. Test termination was based on a drop or plateau in the VO₂ max, ascertained when an RQ of 1.0 or more, a maximal heart-rate and a plotting of the VO₂ indicated that a maximum value had been reached.

Results were analyzed by the ANOVA procedure to determine the need for further data analysis by post hoc comparison and trend analysis. The ANOVA failed to show any significant group differences between the three treatment crank-speeds (p < .05), therefore the post hoc comparison and trend analysis were not undertaken.

**Conclusions**

Based on the results of the three treatment crank-speeds administered to the seven subjects, it was concluded that the currently accepted crank-speed of 60 RPM used in VO₂ max testing should not be altered to successfully accommodate competitive cyclists. The null hypothesis that the maximal oxygen consumption at 60 RPM would be greater or equal to the maximal oxygen consumption at 80 RPM and 100 RPM was accepted.
Recommendations

The following are recommendations for future research, based on the findings of this investigation:

1. Future research should be conducted with a greater number of subjects in order to assure that the sample adequately represents the population.

2. Include runners and swimmers in future investigations to determine if the trained competitive cyclist reacts similarly or differently than these athletes.

3. Include fit non-athletes in future investigations to determine if the trained competitive cyclist reacts similarly or differently than the fit population not currently on a competitive training regimen.

4. Conduct a study to determine the biochemical (enzymatic and substrate) differences in the leg musculature of the trained cyclist and non-cyclist or non-athlete in order to compare the results to their respective VO₂ max readings and assess any relationship which may exist.

5. Replicate this study with a test administrator who is highly familiar with his/her subjects, in order that the subjects may be immediately placed at a post warm-up load sustainable for only two to six minutes.
6. Replicate this study, allowing trained competitive cyclists to use their racing machines in the field, in order to compare differences between laboratory and field VO₂ max readings.

7. Conduct a study to determine the average RPM cyclists use over a series of VO₂ max determinations, on order to compare the VO₂ max between the average RPM and other selected crank-speeds.


APPENDIX A

Statement of Current Training

IN CONSIDERATION OF THE REQUIREMENTS OF THIS INVESTIGATION, THE UNDERSIGNED CONCEDES TO THE FOLLOWING POINTS CONCERNING HIS CURRENT PHYSICAL CONDITIONING AND FUTURE TRAINING DURING THE DURATION OF THIS RESEARCH:

POINT ONE: As a trained competitive cyclist, qualifying for admission into the project as stated, admit to having trained a minimum of four days a week, and accumulating no less than 100 miles at near 100 RPM for four weeks prior to my testing.

POINT TWO: As a participant in the project as stated, will concede to training in this manner for the duration of the study.

POINT THREE: As a competitive cyclist, I admit to have trained in the preceding year with the intentions of being competitive in some future cycle competition.

.......................... ........................................
PARTICIPANT DATE
APPENDIX B

Informed Consent Release

In consideration of the benefits to be derived and the data generated, a student of Oregon State University, agrees to participate in the research project, "The Effect of Various Crank-speeds (60, 80, 100 RPM) on Maximal Oxygen Consumption in Trained Competitive Cyclists", under the direction of J.P. O' Shea, Professor of Physical Education, Oregon State University.

The undersigned states that he has read an outline of the proposed study, including the possible benefits and risk, and is participating voluntarily and consents to following the testing protocol and schedule as outlined. The undersigned also agrees to the use of the data generated as the above agencies desire.

At any time during the study, if circumstances should arise and the undersigned cannot complete the study, he is free to discontinue.

PARTICIPANT

DATE
APPENDIX C

Cycle Ergometer Maximal Oxygen Consumption Protocol

**Detailed Steps for Administration of the Test:**

1. The purpose and procedures were explained verbally and in writing to all subjects prior to the signing of the informed consent release.
2. The subject had any questions answered and then signed the informed consent release and statement of current training.
3. Initially, body weight was taken prior to the first test and fed into the computer. Height was also recorded for each subject. Resting heart rates were taken before each test.
4. Three electrodes were placed on each subject before each test: one just under the left clavicle in the mid-clavicular region and one on the right and left fifth rib in line with the mid-clavicular region (V5).
5. The cyclist was introduced to the instrumentation:
   A. The cycle ergometer was adjusted to the subject:
      1. Saddle height was adjusted to leg length.
      2. Handle-bars were adjusted to upper-body reach.
      3. The subject assumed a comfortable racing position for the test.
      4. All measurements were recorded under the identification number of the subject and duplicated.
The breathing apparatus was fitted comfortably to the subject, and he was instructed how to respire freely through it.

Each subject warmed-up for ten minutes in a high RPM and any subject-selected kpm such that he was respiring and perspiring freely prior to the test.

The subject was connected to the gas analysis system.

Each subject began pedaling at the prescribed RPM following a metronome placed within eye-sight.

Each subject began pedaling at 1500 kpm for two minutes, at which time the load was increased 100 kpm. The load was increased every two minutes by 100 kpm until the termination of the test.

Subjects were encouraged to continue pedaling the prescribed RPM even if the kpm had to be reduced, such that a plateau or fall in maximal oxygen consumption was readily evidenced.

A final plateau and fall in maximal oxygen consumption constituted termination of the day's testing.

A computer respiratory quotient reading considerably above one and a plotting of maximal oxygen consumption calculations ascertained that a plateau in VO2 max was reached.

The VO2 max was taken as the highest oxygen consumption reading during the test and was recorded as oxygen uptake in relation to bodyweight (ml-kg/min).
14. Each subject was allowed to cool down for a few minutes before the commencement of the next subject's maximal oxygen determination.
Application For Approval of the Human Subjects Board,
Oregon State University

The Protocol of Maximal Oxygen Consumption for
Trained Competitive Cyclists

Methods and Procedures

Test Description and Procedures.

Seven Oregon State University students who regularly trained for competitive cycling acted as subjects. Each of the seven subjects participated in one continuous progressively loaded maximal oxygen up-take test at 60 RPM, 80 RPM and 100 RPM for a total of three tests. Each subject was randomly assigned to one of six possible RPM combinations, thereby counter-balancing the treatments. Each test was conducted on separate days and be separated by at-least 48 hours. Details of the study were explained verbally and in writing to all subjects prior to the signing of the informed consent release.

Body weight was taken before the initial test and the datum was fed into the computer and duplicated for each test. Resting heart rates were recorded before the testing each day. Height was recorded before the initial test and recorded. Three electrodes were then placed on the
rider: just under the left clavicle in the mid-clavicular position and on each side at the fifth rib in line with the mid-clavicular region.

The ergometer was adjusted to the rider's body size. Saddle height was adjusted to accommodate leg length by placing the heel on the pedal at the six-o-clock position and achieving a slight bend in the knee (Powell, 1982). The handle-bar was adjusted to the comfort of the rider for a slight bend in the elbow when the cyclist was connected to the gas analysis system. Each measurement was recorded and duplicated for each subsequent test. Each subject assumed a comfortable racing position during the entire duration of the test.

All subjects warmed up for ten minutes in a high RPM and any subject selected kpm, such that he was respiring and perspiring freely prior to the test. The subject was then connected to the gas analysis system and began pedaling at the prescribed RPM following a metronome placed in front of the rider. The subject began pedaling at 1500 kpm for two minutes, by which time the load was increased 100 kpm. The load was increased thereafter by 100 kpm every two minutes until a maximal oxygen consumption was evidenced.

Subjects were encouraged to continue pedaling the prescribed RPM even if the kpm had to be reduced; such that a plateau or fall in maximal oxygen consumption could
readily be evidenced. This constituted termination of the day's testing. A respiratory quotient rise considerably above one, a maximal heart-rate and a plotting of maximal oxygen consumption calculations ascertained that a plateau in VO2 max was reached. The VO2 max was taken as the highest oxygen consumption reading during the test. All readings were recorded as ml-kg/min (VO2 max).

**Riders Benefit and Risk**

The benefits to the cyclist participating in this study included gaining the knowledge of his current maximal oxygen consumption. Such information gave the rider insight into his current conditioning, his slow-twitch/fast-twitch muscle fiber ratio, and some indication of his potential in his chosen sport; competitive cycling. Maximal oxygen consumption is highly correlated to performance in the sport of competitive cycling. Any and all riders participating in this research ran the risk of experiencing such discomforts as fatigue and muscle cramps.

**Anonymity**

Each subject was given an identification code which was his alone. All data was entered under the identity code of each subject. None of the experimenters spoke to a subject about any other subject or his data. All data was kept confidential and freely available only to the subject who produced it and to the experimenters who analyzed it.
Figure 1. Cyclist Participating in a Maximal Oxygen Consumption Determination

Sjogaard (1984) page 28