The oxygen cost of a continuous sprint and a series of intermittent sprints during road race cycling.

Mark Anthony Babcock

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LA THÈSE A ÉTÉ MICROFILMÉE TELLE QUE NOUS L'AVONS RÉCU
THE OXYGEN COST OF A CONTINUOUS SPRINT AND A SERIES OF INTERMITTENT SPRINTS DURING ROAD RACE CYCLING

by

Mark Anthony Babcock

A Thesis submitted to the Faculty of Graduate Studies and Research through the Department of Human Kinetics in Partial Fulfillment of the requirements for the Degree of Master of Human Kinetics at the University of Windsor

Windsor, Ontario, Canada

1984
ABSTRACT

THE OXYGEN COST OF A CONTINOUS SPRINT AND A SERIES OF INTERMITTENT SPRINTS DURING ROAD RACE CYCLING

by

Mark Anthony Babcock

Performance in cycle racing is affected by a variety of factors, including aerobic and anaerobic capacity, muscular strength and endurance, and body composition. Bicycle races range from a 200 m sprint to approximately 5000 Km. In a road race each individual desires to get to the finish line first. In order to achieve this the individual must try to create a gap between himself and the rest of the cyclists. Creating this gap can be accomplished in many ways, two of these methods being: a) a continuous high level effort, or b) a series of short intensive efforts.

The physiological costs of the above two efforts and road race cycling in general have apparently not been determined (Faria 1984). A testing apparatus, consisting of a bicycle frame, a stand in which the bicycle frame is attached, and a Monark bicycle ergometer, has been developed to ascertain, a) the oxygen cost of a one hour race paced ride, b) the physiological cost of the above 2 methods of breaking away and c) which of these 2 efforts is more physiologically efficient.

Five subjects gave their consent to participate in this study. The results revealed that a one hour race pace ride required 124.5 l of oxygen to be consumed. The 2 sprint
protocols did not cause a significant increase in the amount of oxygen consumed during the hour exercise period or the recovery. Results of repeated sprint ride tests were not significantly different from one another.

The feasibility of testing cyclists in a laboratory setting has been shown here. With proper cooling, ie constant airflow, cyclists are able to work over a long period of time without over heating. While no significant differences were found between the 3 ride protocols a trend toward greater O2 consumption during the intermittent sprint ride was evident.
Acknowledgements

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Chapter I

Introduction

"The winner is the person who went the fastest, even if it was only for a small part of the race. Unless one was the fastest in the field one would win only by luck, or by surprise, and one cannot leave things to luck or surprise," (Woodland, 1975).

In a cycle race to be the fastest rider, one must be able to cover the race distance in the least possible time. One technique used to achieve this goal is that of constant "sprint attacks". These sprint attacks will usually allow a rider to get away from the main group of cyclists. This main group of cyclists, usually called the "bunch", sets the baseline pace during a race. Once a rider breaks away, or creates a gap between himself and the bunch, that rider only has to match the pace of the bunch to stay ahead and thus win the race.

All cyclists try to warm up prior to a race by stretching and short intensive rides. Then after a short break, necessary for pre-race instructions, the race begins. The speed of the race will be governed by four major variables. These are: a) terrain, b) climatic conditions, c) the physiological condition, and d) the psychological outlook of each rider in the race.
Current literature appears to offer very little information regarding the physiological condition of an individual during race cycling (Faria 1984). It is known that sprint cycling causes depletion of adenosine triphosphate (ATP) and creatine phosphate (CP), as well as, muscle glycogen (Lamb 1978). The effects of cycle sprinting on the rider's amount of oxygen (O2) consumed have not apparently been reported.

A scientist is faced by many difficulties when contemplating the investigation of some of the above problems and in particular that of oxygen uptake. For example, the bulkiness of the equipment necessary for measuring oxygen uptake rules out the measurement under road conditions or during competition. In the laboratory, the racing cyclist is required to ride a laboratory cycle ergometer. Since a racing specialist usually has a custom designed bike frame, then the unfamiliarity and discomfort associated with testing on the bicycle ergometer may cause him to become biomechanically inefficient and hence physiologically inefficient during the laboratory testing. The alternative is to ask a cyclist to ride his cycle on either rollers or a treadmill. The roller methodology requires the cyclist to balance on cylindrical rollers while riding. These rollers are constructed so that they are practically frictionless. As a result, a cyclist's rate of work cannot be accurately set. The treadmill method is dangerous and requires a great deal of time to learn.
Hence, a system which could eliminate these measurement problems, would allow a better assessment of the physiological condition of the racing cyclist.

Such a system has been devised in our laboratory and it is described more completely in Appendix A. By eliminating some of the methodological problems mentioned earlier, it may now be possible to investigate some physiological responses of cyclists apparently not reported in the literature. These responses are directed specifically at 1) what is the total cost of a simulated one-hour race pace cycle event? 2) what is the physiological, (in terms of the amount of oxygen consumed), cost of two methods of breaking away from the bunch: the first method a continuous supermaximal oxygen uptake effort; and the second a series of short supermaximal oxygen uptake efforts. 3) which of these two sprint methods is more physiologically efficient?
Chapter II
Review of Literature

In order to ascertain the amount of O2 consumed during a one hour race-paced cycle event one must measure the O2 consumption during the exercise period and the recovery period. The length of the recovery period must also be determined. A short review of the literature examining the O2 uptake curve, the recovery O2 uptake and the reliability of the recovery O2 uptake will help establish guidelines to achieve the above objectives.

Pre-Exercise

A perusal of the literature reveals a large variation in the recovery oxygen uptake values reported. There could be many reasons for these variable reports. One of these could be the pre-exercise condition of the subjects. For example subjects usually report to the laboratory after a meal, but the time period which lapses between the meal time and reporting is inconsistent, it ranges from 2-8 hours (Knuttgen 1970, Davies et al. 1972). An attempt should be made to standardized the pre-exercise conditions of the subjects. This idea is especially relevant here as the subjects are tested a number of times and the results are compared.

Exercise

Figure 1 represents a hypothetical oxygen uptake (VO2) curve (Lukin and Ralston 1962, Astrand and Rodahl 1977). The total energy cost of the exercise period is delineated
Fig. 1  Oxygen Uptake Curve.

Exercise  Recovery

Time min.

Rest VO₂

Exercise starts

exercise stops

VO₂
1/min.

A
B₁
B₂

C

E

D
by the area D. At the onset of exercise the oxygen uptake increases exponentially, (line E), and therefore cannot provide the total energy for the performance of the task. This discrepancy between energy required and energy provided is known as the oxygen deficit, and is represented by the area A in the diagram. The portion of the total energy not provided directly by oxygen is supplied by stored energy sources, ATP, CP, and muscle glycogen. B1 represents the energy supplied by oxygen uptake (aerobic energy), and B2 is the energy provided by glycolysis and stored energy (anaerobic energy).

Examination of the kinetics of the VO2 curve during the transition from rest to work has shown a half-time, \( t_\frac{1}{2} \), of about 30 seconds (Whipp and Wasserman 1972, Cerretelli et al. 1977, Diamond et al. 1977). After training at a level requiring 50% of VO2 max the \( t_\frac{1}{2} \) may be reduced by 50% its value prior to training (Hagberg et al. 1980a). Therefore the cardiovascular fitness level of the individual will influence the \( t_\frac{1}{2} \) of the VO2 during the transition from rest to steady level work.

Many factors may affect the shape or the size of the VO2 curve. Some of the factors which are more relevant are:

a) Intensity level of the exercise, b) duration of the exercise bout, c) the level of the subject's physical fitness.

An increase in the intensity of the exercise bout will result in an elevated recovery VO2 (Piiper and Spiller 1970,
Whipp and Wasserman 1972, Hagberg et al. 1980b). The O2 deficit is affected by exercise intensity in a similar manner as the recovery VO2 (Knuttgen and Saltin 1972, Martin 1974). McMiken (1976) found that work intensity was the most significant factor in O2 repayment, accounting for 69% of the variance.

There is a continuous increase in the VO2 with increased work duration at a constant intensity (Knuttgen 1970). However, when work time is extended to about one hour, the VO2 can be maintained at the level reached after about five minutes work providing the VO2 is not above 50% of the maximal oxygen uptake value (Astrand and Rodahl 1977). Highly trained endurance athletes can maintain steady level work at a higher percentage of their maximal oxygen uptake, i.e., up to 85% of the VO2 max for elite cross country skiers (Astrand and Rodahl 1977). Prolonging work time beyond one hour causes the VO2 to progressively increase to the maximal value, fatigue will occur soon after this.

A delay in achieving steady state VO2, a decrease in VO2 at any time during exercise, (before asymptotic value is reached), and a prolonged elevated VO2 are characteristic of a relative lack of fitness (Whipp and Wasserman 1972). Hagberg et al. (1980a) noted, that training in humans caused a reduction in the magnitude of the O2 deficit and the recovery VO2 resulting from the same absolute submaximal exercise. A more rapid adjustment in O2 uptake and the return to rest VO2 also took place (Hagberg et al. 1980a).
Recovery

The area labelled C in Figure 1 represents the recovery portion of the oxygen uptake curve. Its size and shape are variable. Some of the factors which affect it are outlined below.

The recovery \( t_{\frac{1}{2}} \), for the fast component of recovery was reported to be 30 seconds (Davies et al. 1972, DiPrampero et al. 1973, Cerretelli et al. 1977). In the transition from a heavy work load to a lighter work load the \( t_{\frac{1}{2}} \) for the recovery curve was reported to be 45 seconds, (Davies et al 1972, Hagberg et al. 1980a). No one appears to know for certain why this move, from a heavy work load to a lighter work load, causes the decrease in VO2 to be slower. One could speculate that the total VO2 was not being used to replenish energy stores, hence part of the VO2 may be used to maintain the work rate. Therefore the VO2 would remain elevated for a longer period of time so a portion of the energy stores could be replaced.

The concept of a two component recovery VO2 curve was presented by Margaria et al. in 1933. They reported the rapid decline in oxygen uptake in the first few minutes of recovery was due to replacement of the intramuscular stores of O2, CP and ATP, this was termed the alactacid debt. Further work has confirmed the existence of a fast component of O2 recovery (Piiper and Spiller 1970, Ikegami et al. 1980).

Margaria et al. (1933) showed that the oxidation of the accumulated lactate in blood and muscle were responsible
for the second portion of the curve. This was the slow component and was called the lactacid portion of the oxygen debt.

The O2-debt concept may be more complex than originally thought, based on the observation that after moderate exercise the amount of O2 consumed during recovery was too large to be totally accounted for by anaerobic metabolism (Stainsby and Barclay 1970, Brooks et al. 1971a, b, Hagberg et al. 1980a). When lactate removal by the liver was blocked, only a fast component was expected but a slow component was evident for 45-60 minutes of recovery (Barnard et al. 1970).

In human subjects a decrease in blood lactate during exercise has been reported (Knuttgen 1970, Segal and Brooks 1979). Theoretically a portion of the O2-debt was being repaid, but the total O2 consumption during recovery did not diminish. In fact it increased in size with a similar increase in the proportion of the slow component of the recovery O2 curve (Knuttgen 1970).

The potential causes of this third component are varied, the most conspicuous factor being the effects of temperature on the rates at which biochemical reactions proceed, the Q10 effect (Brooks et al. 1971a, b, Knuttgen 1971, Martin 1974). Other factors are work of breathing, metabolic turnover and synthesis, work of the heart, electrolyte balance, increased activity of sympathetic nervous system, ie, increased levels of circulating epinephrine, (Welch et al 1970, Katch et al. 1972, Hagberg et al. 1980). The
above factors individually may supply a very small amount to the postexercise VO2 but collectively may contribute substantially to it.

The data indicate the presence of a 2 component O2-debt, when very short high intensity work bouts are employed. Therefore one could speculate that the effects of temperature change and the other factors previously mentioned had no opportunity to contribute significantly to the recovery VO2. One could conclude, in a very short high intensity burst of activity the 2 component recovery VO2 would be evident but as the duration of the activity increased, regardless of the intensity, the number of factors contributing to the recovery VO2 also would be increased. It would then become a 3 component function, (third component consolidates all other factors together, these factors are mentioned above). This concept of a more complex recovery O2 uptake curve may be applicable to this study as the subjects will work for an extended amount of time and some of the above mentioned, i.e. temperature, factors may have a significant effect on the recovery O2 uptake.

Recovery Baseline

The magnitude of the recovery VO2 can be affected by the choice of a baseline from which to measure. Stainsby and Barclay (1970) declared one has 3 different baselines from which to choose. The first is the basal metabolic rate (BMR) which is difficult to obtain both in pre-exercise and in postexercise. The resting VO2 baseline is used most
often. It assumes whatever created the resting metabolic rate continues unchanged throughout the exercise and the recovery period. The definition of an appropriate baseline for recovery has been a major restraint to the establishment of a universally acceptable method for the quantification of the recovery VO2 (Roberts and Morton 1978). One factor which contributed to the inaccuracy was the failure to reach a basal state during the control period preceding exercise, (Thomas et al. 1965). To alleviate this problem one could use a light exercise baseline for recovery (Hagberg et al. 1980). Cowan and Solandt (1937) reported the recovery time was reduced by 50% when use was made of a work baseline.

When subjects performed aerobic work during recovery from exhaustive exercise there was a marked increase in the lactate removal compared to subjects who rested during recovery, (Royce 1969, Davies et al. 1970, Weltman et al. 1978).

There may be an optimal active recovery level which enhances lactate removal. It has been reported this optimum level was 35-45% of the individual's VO2 max. (Davies et al. 1970, Belcastro and Bonen 1975). Weltman et al. (1979) stated a recovery exercise level below the anaerobic threshold was more effective compared to exercise above the anaerobic threshold.

Establishing a recovery baseline allows one to more precisely determine the amount of "excess" O2 consumed during recovery. Using a light work level O2 consumption
not only provides a baseline to measure from but also provides a point at which to terminate the recovery period. Reliability of Recovery VO2 Measurement

As with any scientific measure one must consider if the recovery VO2 test is repeatable. Berg (1947) stated the average recovery constant for different duration of exercise, showed no significant difference. This showed comparisons of recovery constants of subjects who attained steady state are feasible (Berg 1947). More recent studies have confirmed this to be true (Welch et al. 1970, Pearce and Milhorn 1977).

Others have shown there was a wide variability among subjects for the recovery VO2 test (Graham and Andrews 1973). The authors stated the variability of the data from the repeated measurements of the recovery VO2 clearly demonstrated that extreme caution must be exercised in the interpretation of maximal O2-debt (Graham and Andrew 1973). The above information has lead to the formation of the following hypotheses.

Hypotheses
1. H : The total oxygen uptake will not be significantly different between the 6 supramaximal efforts, 20 seconds duration each, (IR), and the continuous supramaximal effort of 120 seconds duration, (CR).

H a) During the IR the total oxygen uptake will be significantly greater than during the CR.

b) During the CR the total oxygen uptake will be
significantly greater than during the IR.

2. H : The oxygen uptake during the work phase will not be significantly different between the IR and the CR.
   
   H a) The work phase oxygen uptake during the IR will be significantly greater than during the CR.

   b) During the CR the work phase oxygen uptake will be significantly greater than during the IR.

3. H : There will be no significant difference in the recovery oxygen uptake in either the IR or the CR.
   
   H a) The oxygen uptake in recovery after the IR will be significantly greater than after the CR.

   b) After the CR the recovery oxygen uptake will be significantly greater than after the IR.

4. H : The oxygen cost of a) the steady paced submaximal ride (SR), b) the IR and c) the CR, will not be significantly different from each other.
   
   H a) The oxygen cost of the SR, IR and the CR will be significantly different from each other.
Chapter III
Methodology

Subjects

Five competitive cyclists served as subjects for this study. Collection of anthropometric and physiological data, (age, height, weight, % body fat, VO2max), was undertaken prior to the start of the race pace data collection. The subjects were given a standard University of Windsor consent form (Appendix D) which included an escape clause to permit voluntary withdrawal from the testing at any time. The criteria used to distinguish racing cyclists from others was the ability to pedal 90 + rpm continuously throughout the simulated one hour race pace period.

Workload

During cycling tests, the workload has a tendency to fluctuate. Pugh (1974) studied a group of racing cyclists on the road and in the laboratory. An observer was used during the laboratory tests to count the revolutions and to control the workload. Therefore, when using a mechanically braked bicycle ergometer one must have a means to; a) count the revolutions of the pedals, and b) control the workload, so that an accurate workload may be calculated. Therefore during this study an electromagnetic counting device was used to count pedal revolutions and the workload setting was checked periodically during the experiment.

Environmental Effects

When one tries to extrapolate test results from the
laboratory to the real world, the effects of environmental conditions, (temperature, humidity and wind), are often not considered. The differences found between laboratory tests and a real life situation (Boston marathon) could be attributed to environmental variables; a) wind resistance, b) thermal stress and c) terrain (Costill and Fox 1969). Whitt (1971) has reported that a cyclist on the road is capable of producing 0.35 horsepower (hp.) to maintain a road speed of 23 miles per hour (mph) but in the laboratory on a bicycle ergometer the cyclist could produce 0.35 hp. for only 30 minutes. It was felt this was due to the fact that on the road the cyclist encounters the cooling effect of forced air passage. Whereas in the laboratory he is stationary and encounters only free convection effects. Therefore it seems essential, in order to replicate the conditions encountered during cycle road racing one must be able to reproduce environmental effects (i.e. temperature, humidity and wind), in the laboratory. To simulate air flow pass the cyclists a fan was placed in front of the subjects during all testing sessions.

Core Temperature

Data from the literature indicate that the rise in core temperature during long term exercise, (one hour duration), appeared to be a function of the workload (Saltin and Hermansen 1966, Saltin et al. 1968, Astrand and Rodahl 1977). For example when subjects worked at 50% of maximal oxygen uptake ($VO_2_{max}$) the rectal temperature increased
about 1.5 C and at 70% of VO2 max it increased about 2.0 C above rest core temperature (Saltin and Hermansen 1966). One should therefore expect the core temperature to rise during strenous exercise and in the laboratory setting it should be continously monitored to make sure it does not fluctuate too much.

Expired Gas Collection

For all gas collections the subject breathed through a Rudolph #2700 mouthpiece. On the inspired side the mouthpiece was connected to a dry gas volume meter which contained a linear potentiometer connected to a Beckman 2-channel recorder. This measured the inspired volume. An air tight plastic container of warm water was placed between the volume meter and the mouthpiece so the inspired air was humidified.

At the times noted in the experimental protocol separate gas samples were collected in meterological balloons and analyzed for O2 and CO2 content. The electronic analyzers were calibrated before and during use with a gas of known mixture. The percentage of O2 and CO2 of the reference gas had been determined previously using a Lloyd-Gallenkamp analyzer.

Parameters Measured

Heart Rate

Heart rate was monitored utilizing electrodes placed at the level of the fifth intercostal space. The measurement of the heart rate utilised a cardiometer 275
manufactured by Cardionics ab, Stockholm, Sweden. The heart rate was read directly from the dial of the cardiometer and recorded during each gas collection.

Workload Determination

Telemeteric electro-cardiogram studies of European racing cyclists have provided information with respect to the heart rate during competition. Two studies have shown that: a) mean heart rate during competition reached 70% of the subject's maximal heart rate and b) that at no time during a race did the heart rate exceed 80% of the maximal heart rate (Pirnay et al. 1975, Dumas et al. 1980). Based on this information, during the SR the workload was set to elicit 70% of the individual's maximal heart rate which had been determined during the VO2 max. test.

Core Temperature (Tc)

The Tc was registered using a rectal probe (Yellow Springs Instr. #701 thermistor), inserted 10 centimeters (cm) and connected to a Cole Parmer thermometer, (8502-50). Core temperature was read off the digital readout of the thermometer and recorded during each expired gas collection. An electric fan was placed approximately one meter in front of the subject to provide a constant air flow. The air flow generated by the fan was measured with a wind guage.

Baseline for Recovery

In this study exercise was performed during recovery in order to facilitate the determination of the end point of the recovery period. It was also chosen based on the fact
most cyclists try to warmup and cool down by riding several miles prior to and after a race. The workload chosen was light, (35-40% VO2max), so it would not cause production of lactate.

Maximal Oxygen Uptake Test

A progressive bicycle VO2 max. test was administered to each subject as part of the first lab visit. The subject pedalled at 90 rpm at each workload for 5 minutes, with a gas collection during the last 30 seconds. The workload was set at 1.0, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, kg. etc, until the subject experienced volitional fatigue or the VO2 levelled off. At this point a final 30 second gas collection was taken. The HR was monitored at each workload. The method for gas collection and analysis have been mentioned previously.

Experimental Protocol

The subjects visited the laboratory 5 times with a week elapsing between visits, (trying to return the same day, at the same time etc.). Each subject had his maximal oxygen uptake level determined during the first visit. During this test the individual's maximum heart rate during cycling was established. This information provided the base for the setting of the experimental condition workload.

The subjects performed the one hour steady paced ride during the second visit. Upon entering the laboratory the subject was asked to sit quietly for 5 minutes after inserting a rectal probe and having electrodes for the
cardiometer positioned. An expired gas sample was collected during the 5 minutes of the rest period, the resting $T_c$ and HR were recorded. The subject then mounted the modified bicycle and pedalled at 90 rpm at a load requiring 35-40% of the subject's VO2 max for 15 minutes, a total of 5 gas samples were taken during the last 5 minutes. These samples were used to establish the endpoint for recovery. To simulate actual race conditions the subjects took a 10 minute break before starting the test. The subjects remounted and rode at a constant rate and load for 1 hour. Heart rate and $T_c$ were recorded over the whole time period, and the workload was adjusted accordingly. Gas collections were taken (30 second intervals) continuously for 3 minutes, then every minute for the next 7 minutes and every 5th minute till the end of the hour.

At the end of 1 hour the workload was adjusted to a level requiring 35-40% of the subject's VO2 max. The subject continued to pedal until the VO2 level dropped to the same level as was measured in the pre-hour period. Expired gas collections were taken every 30 seconds for the first 3 minutes post exercise, then every minute till 10 minutes post exercise, then every 5th minute till the pre-exercise VO2 was recorded for 2 consecutive collections.

The next 3 visits used the same protocol except the 1 hour ride was varied in the following ways; i) a constant supramaximal effort (120% RPM level) of 120 sec. in length was placed astride the 30 min. mark of the one hour period,
ii) a series of 6 supramaximal bursts lasting 20 seconds were placed each 5 min. from the 20 min. mark to the 45 min. mark. Expired gas samples were collected throughout the time the elevated effort lasted and for 3 minutes after the effort. The above 2 conditions were presented randomly to the subjects. Each subject also rode one of the above conditions (chosen randomly) a second time in order to study the reproducibility of the results.

Statistical Analysis

A one way analysis of variance with repeated measures was used to analyze the data. The Duncan's post hoc test was used to test points of significance. The repeated ride tests were compared using a one way Anova with repeated measures and the Pearson product moment correlation. The level of significance was set at the 0.05 level.
Chapter 4

Results

Five subjects participated in this study, their anthropometric and physiological characteristics are presented in Table 1. The maximal heart rate (HRmax) reported was the HRmax recorded during the continuous progressive VO2 max test.

The method used to calculate the O2 consumption values is outlined in Appendix B. Also the equations and methods used to compute the VO2, VCO2, respiratory exchange ratio (RER) can be found in Appendix B.

The laboratory ambient temperature and the humidity level were monitored during each testing session. The mean room temperature was 22.2 (1.7)°C for the test sessions and the relative humidity was 51.0 (11.9) %.

Prior to the start of the one hour ride each subject rode for 15 minutes at 40% of his individual VO2 max. Five expired gas samples were collected during the last 5 minutes of this warm up period. This pre-exercise calculated mean VO2 value was used as the recovery baseline VO2 value. The mean VO2 baseline value for all the rides for all the subjects was 21.3 (4.6) ml·min⁻¹·kg⁻¹. For all the rides the mean workload which elicited the required VO2 was 90 (20.5) watts.

The workload for the one hour race paced ride was set at a level which required 70% of the maximum heart rate (Dumas et al., 1980). This work level, (150 (3.5) watts), required
Table 1: Anthropometric and physiological characteristics of the subjects who participated in this study.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Age (yrs.)</th>
<th>Height (cms.)</th>
<th>Weight (kgs.)</th>
<th>Body Fat (%)</th>
<th>VO₂ max. (ml kg min)</th>
<th>Max HR (bpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24</td>
<td>191.80</td>
<td>77.10</td>
<td>8.90</td>
<td>61.00</td>
<td>175</td>
</tr>
<tr>
<td>2</td>
<td>29</td>
<td>182.90</td>
<td>80.50</td>
<td>12.80</td>
<td>49.10</td>
<td>170</td>
</tr>
<tr>
<td>3</td>
<td>37</td>
<td>179.10</td>
<td>74.50</td>
<td>13.20</td>
<td>48.60</td>
<td>180</td>
</tr>
<tr>
<td>4</td>
<td>19</td>
<td>177.10</td>
<td>61.50</td>
<td>15.60</td>
<td>52.10</td>
<td>175</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
<td>173.00</td>
<td>70.80</td>
<td>12.60</td>
<td>58.90</td>
<td>175</td>
</tr>
<tr>
<td>X</td>
<td>25</td>
<td>180.80</td>
<td>72.90</td>
<td>12.60</td>
<td>53.90</td>
<td>175</td>
</tr>
<tr>
<td>SE</td>
<td>±7.10</td>
<td>±7.30</td>
<td>±2.40</td>
<td>±5.70</td>
<td>±6.1</td>
<td></td>
</tr>
</tbody>
</table>
the subjects to use 52.2 (5.2) % of their VO2 max.

The liters of O2 consumed during the exercise phase (60 min.), the recovery phase, (15 min.), and the total ride, (exercise phase + recovery phase, 75 min.), for the SR, CR and the IR are reported in table 2. The patterns of the VO2, HR and the RER versus time for each ride can be found in Figs. 2-4. Each point is the mean value for the five subjects.

The liters of O2 consumed (Table 2) indicate the IR required the largest consumption of O2 over the 75 min. collection period. This difference is evident in the exercise, recovery and the total liters of O2 consumed.

The sprint portions of the CR and the IR imposed a mean additional workload of 98.4 (44.4) watts min. on the subjects. This increased workload was accomplished by having the subjects increase their cadence to 120 + RPM while the pendulum load setting was not increased. The number of revolutions, during the sprints, were electronically counted and recorded.

The graphical representation of the VO2 (Fig.2) and the HR (Fig.3) illustrate that the SR steady work level did impose a steady stress on the subjects. This is evident by the relative flatness of the line during the exercise period (0-60 min.).

The Figs. 2-4 show a similar pattern during the sprint portions of the CR and the IR. During the sprint, the VO2, the HR and the RER increase and usually peak during the post
Table 2: The liters of O2 consumed in each of the test protocols. Values are the means and standard error.  

\( n = 5 \)

<table>
<thead>
<tr>
<th></th>
<th>SR</th>
<th>CR</th>
<th>IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exercise</td>
<td>106.2</td>
<td>107.6</td>
<td>114.9</td>
</tr>
<tr>
<td></td>
<td>(28.2)</td>
<td>(31.1)</td>
<td>(22.7)</td>
</tr>
<tr>
<td>Recovery</td>
<td>18.3</td>
<td>16.2</td>
<td>19.1</td>
</tr>
<tr>
<td></td>
<td>(4.1)</td>
<td>(3.4)</td>
<td>(4.5)</td>
</tr>
<tr>
<td>Total</td>
<td>124.6</td>
<td>124.5</td>
<td>134.1</td>
</tr>
<tr>
<td></td>
<td>(31.8)</td>
<td>(34.3)</td>
<td>(26.4)</td>
</tr>
</tbody>
</table>
Fig. 2: Graph of the oxygen uptake (VO2) in liters per minute versus time in minutes. The data points are mean values and the vertical bars are the standard errors. (n = 5)
Fig. 3: Graph of the heart rate (bpm.) versus time (min.). Data points are mean values and the vertical bars are standard errors. (n = 5)
Fig. 4: Graph of the respiratory exchange ratio (RER) versus time (min.). The data points are mean values and the vertical bars are standard errors. (n = 5)
sprint recovery and by the end of the recovery period (3 min.) the values have returned to pre-sprint values. The exception being the HR during the IR, and in this case one can see an increase in the HR with each succeeding sprint.

In all the figures it is evident that at the onset of recovery the slopes of the lines for all the rides change (increase sharply in a negative direction) as the body reacts to the decreased workload. The VO2 and the HR curves both decline rapidly whereas the RER curve shows increases for the first few samples and then it too declines rapidly. The VO2 curve reaches the baseline level (40% VO2 max) very quickly and the data show that most subjects reached the baseline level within 2 minutes of the start of recovery.

During each test period while the subjects were working an electric fan was placed approximately 1.0 meter in front of them to prevent over heating (Whitt, 1971). The core temperature (Tc) was monitored and during the test period it rose a mean value of 0.94 (0.31) °C, (difference between rest and peak Tc). Fig. 5 is representative of what happened to the core temperature during the SR, the CR and the IR. During each ride the Tc rose continuously. During recovery it decreased slowly and remained above rest value.

The liters of O2 consumed data were statistically analyzed using the SPSS version of the one way analysis of variance (ANOVA) with repeated measures. The analysis revealed there was no significant difference in the number of liters of O2 consumed by the subjects for the 3 rides.
Fig. 5: Graph of the core temperature ($T_c$) in degrees Celsius versus time (min.). ($n = 1$).
This was true for the exercise period, the recovery period and the total number of liters of O2 consumed, (Tables 3-5).

During the sprint portions of the CR and the IR the pedal revolutions were counted and the work done during the sprint was calculated, for the CR the mean value was 236.7 watts and the IR mean work output was 248.4 watts. One way Anova with repeated measures showed there was no significant difference between the two rides with regards to the amount of work done. The Pearson product-moment correlation coefficient gave an r of 0.96 which means there was a strong relationship between the amount of work done during the sprints.

The results of the repeated sprint tests (ie. CR1 vs CR2) were compared using an one way Anova with repeated measures to indicate if any difference existed between the repeat rides. Also a Pearson product-moment correlation coefficient was calculated to show how close the test results were to each other.

The results of the one way Anova with repeated measures showed there was no significant difference at the 0.05 level between the repeated tests with regards to the amount of O2 consumed and the amount of work done during the sprint portions of the tests, (Tables 6-13).

The correlation coefficient for the amount of O2 consumed during the exercise, recovery and the total period for the CR repeats were high in all cases, (0.97, 0.84 and 0.94 respectively) The correlation coefficients for the workloads for the CR were also high, (0.99).
Table 3: One way Anova repeated measures, exercise O2 consumption

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>4</td>
<td>8469.77</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>2</td>
<td>222.92</td>
<td>111.5</td>
<td>1.38</td>
</tr>
<tr>
<td>Interactions</td>
<td>8</td>
<td>647.83</td>
<td>80.9</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>9340.52</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ F(0.95)(2,8) = 4.46 \]
Table 4: One way Anova repeated measures, recovery O2 consumption

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>4</td>
<td>186.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>2</td>
<td>9.5</td>
<td>4.8</td>
<td>2.29</td>
</tr>
<tr>
<td>Interactions</td>
<td>8</td>
<td>16.7</td>
<td>2.1</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>212.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $F_{(0.95)(2,8)} = 4.46$
Table 5: One way Anova repeated measures, total O2 consumption

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>4</td>
<td>10916.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>2</td>
<td>282.2</td>
<td>141.1</td>
<td>1.59</td>
</tr>
<tr>
<td>Interactions</td>
<td>8</td>
<td>711.4</td>
<td>88.9</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>14</td>
<td>11910.1</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**$F(0.95)(2,8) = 4.46$**
The results of the two IR tests were also highly correlated for the amount of O2 consumed during the exercise period (r=0.97), the recovery period (r=0.97) and the total (r=0.99). The total amount of work done during the 6 sprints was also highly correlated between the two tests (r=0.98).

Hypothesis

Based on the data of this study the following statements can be made concerning the proposed hypothesis.

1) Hypothesis #1 is accepted as the statistical analysis revealed no significant difference in the total oxygen uptake between the IR and the CR.

2) Hypothesis #2 is accepted because the exercise phase O2 consumption of the IR and the CR were not significantly different.

3) Hypothesis #3 is accepted since during the recovery from the IR and the CR there was no significant difference in the recovery O2 consumption.

4) Hypothesis #4 is accepted since the total O2 costs of the i) SR, ii) IR, iii) CR were not statistically different from one another.
Table 6: One way Anova repeated measures, exercise O2 consumption

\( (CR_1 \text{ vs } CR_2) \)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>2</td>
<td>2161.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>1</td>
<td>39.6</td>
<td>39.6</td>
<td>0.65</td>
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<tr>
<td>Interactions</td>
<td>2</td>
<td>122.5</td>
<td>61.2</td>
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</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>2323.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ * \* F_{(0.95)}(1,2) = 18.5 \]
Table 7: One way ANOVA repeated measures, recovery O2 consumption

\( \text{CR}_1 \ vs \ \text{CR}_2 \)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>2</td>
<td>17.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>1</td>
<td>0.2</td>
<td>0.2</td>
<td>0.18</td>
</tr>
<tr>
<td>Interactions</td>
<td>2</td>
<td>1.7</td>
<td>0.87</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>19.7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\* * \( F(0.95) (1,2) = 18.5 \)
Table 8: One way Anova repeated measures, total O2 consumption

\((CR_1 \text{ vs } CR_2)\)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>2</td>
<td>2506.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>1</td>
<td>21.3</td>
<td>21.3</td>
<td>0.24</td>
</tr>
<tr>
<td>Interactions</td>
<td>2</td>
<td>178.6</td>
<td>87.8</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>2703.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\*\* \(F(0.95, 1, 2) = 18.5\)
Table 9: One way Anova repeated measures, exercise O2 consumption

\( (IR_1 \ vs \ IR_2) \)

<table>
<thead>
<tr>
<th>Source of Variations</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>2</td>
<td>2422.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>1</td>
<td>59.5</td>
<td>59.5</td>
<td>2.53</td>
</tr>
<tr>
<td>Interactions</td>
<td>2</td>
<td>46.9</td>
<td>23.5</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>2529.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ F_{0.95} (1, 2) = 18.5 \]
Table 10: One way ANOVA repeated measures, recovery O2 consumption

(\(IR_1\) vs \(IR_2\))

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>2</td>
<td>38.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>1</td>
<td>0.16</td>
<td>0.16</td>
<td>0.03</td>
</tr>
<tr>
<td>Interactions</td>
<td>2</td>
<td>9.60</td>
<td>4.81</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>48.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(**F(0.95)(1,2) = 18.5**\)
Table 11: One way Anova repeated measures, total O2 consumption

\((IR_1 \text{ vs } IR_2)\)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>2</td>
<td>3216.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>1</td>
<td>4.90</td>
<td>4.90</td>
<td>0.09</td>
</tr>
<tr>
<td>Interactions</td>
<td>2</td>
<td>113.5</td>
<td>56.8</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>3334.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ * * F(0.95) (1,2) = 18.5 \]
Table 12: One way Anova repeated measures, work done in sprints

\((\text{CR}_1 \text{ vs } \text{CR}_n)\)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>(F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>2</td>
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<td>64.0</td>
<td>1.09</td>
</tr>
<tr>
<td>Conditions</td>
<td>1</td>
<td>64.0</td>
<td>64.0</td>
<td>1.09</td>
</tr>
<tr>
<td>Interactions</td>
<td>2</td>
<td>117.9</td>
<td>58.9</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>14902.6</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ \star \star F(0.95) (1,2) = 18.5 \]
Table 13: One way ANOVA repeated measures, work done in sprints

\( \text{IR}_1 \) vs \( \text{IR}_2 \)

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>Degrees of Freedom</th>
<th>Sum of Squares</th>
<th>Mean Square</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subjects</td>
<td>2</td>
<td>49475.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conditions</td>
<td>1</td>
<td>1066.7</td>
<td>1066.7</td>
<td>0.85</td>
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<tr>
<td>Interactions</td>
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<td>2511.4</td>
<td>1255.7</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
<td>53053.9</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\* \* \( F(0.95) (1,2) = 18.5 \)
Chapter 5
Discussion

The anthropometric and physiological characteristics of the subjects in this study are shown in Table 1. They are similar to data reported in the literature on high level cyclists (Hagberg et al, 1979, Davies, 1980, Perez, 1981). The only exception being the VO2 max level, the value given for international level cyclists being between 63.7 - 70.3 ml\cdot kg^{-1}\cdot min^{-1} compared to 53.9 ml\cdot kg^{-1}\cdot min^{-1} reported here. This is to be expected as the sample was drawn from members of the local cycling club and not from international calibre competitors.

Stainsby and Barclay (1970) have recommended that when measuring recovery O2 uptake, a baseline measure must be defined. Therefore this study used a work baseline in recovery. Furthermore the working recovery baseline in the laboratory simulates the cyclists "cool down" ride during an actual post race period. The work level of 40 % of VO2 max seems to be the optimal level for the recovery work load (Davies et al, 1970, Belcastro and Bonen, 1975). At this level of work the recovery time should be decreased (Gisfoli et al, 1966, Martin 1974). This fact was confirmed by this study as most of the subjects reached the baseline VO2 within 2 minutes from the start of the recovery period.

One problem with data collection in a new concept is the lack of related literature with which to compare the
data. A report by Astrand et al. (1960) is comparable to the SR condition of this study. During the one hour exercise period similar values for the amount of O2 consumed (145.5 l. vs 106.2 l.) and the percentage of VO2 max worked at (53.0% vs 52.2%) were reported. The difference in the O2 consumed is most likely due to the workload used in the two studies. In the present study the subjects worked at a mean work level of 150.0 watts min. in contrast to the 180.0 watts min. level reported by Astrand et al. (1960).

The recovery mode was also different, Astrand et al. used a supine rest which over a 60 minute period consumed 19.9 l. of O2. Whereas the work recovery used in the present study required 18.3 l. of O2 over a 15 minute time period.

The results of the statistical analysis indicated there was no significant difference with regard to the amount of O2 consumed during exercise, recovery and the total period between any two of the three conditions. One would have expected during the CR and the IR that the subjects would have consumed more O2 because of the increased work done during the sprint periods. One reason why the expected results may not have materialized is 4 out of the 5 subjects in this study were unfamiliar with the testing in the laboratory. The results of the experienced subject (number 2) found in Appendix D show that this subject consumed about 25.0 l of O2 less during the SR condition versus the 2 sprint protocols. Based on these data one could speculate
that a significant difference between the SR and the 2 sprint conditions should have been evident. This would only occur if the work level was higher during the exercise period and the sprint portions relied totally on anaerobic energy sources for fuel. This would then mean that any differences between the protocols should show up in the recovery portion of the test.

Another reason why a difference did not occur is the fact the subjects worked just above 50% of their VO2 max. It should also be noted that during the sprint portion of the CR the VO2 reached only 75% of maximum value and the VO2 during the IR sprints ranged from 64% of maximum for the first 20 sec. sprint to 70% of maximum for the sixth sprint session. Therefore the complete exercise portion of each ride was done below 80% of the mean VO2 max. This would mean that at this VO2 level probably 90% of the work done during the exercise period was done using the aerobic energy system. Therefore no increase in recovery VO2 where one expected an increase.

In the literature it has been reported that marathon runners utilize about 75% of their VO2 max during a race (Costill and Fox, 1969). Whitt (1971) reported for a cyclist to maintain a road speed of 24-25 miles per hour the cyclist would have to employ 80% of VO2 max. Therefore these data would suggest that the subjects in this study did not perform a true simulation of a race pace cycle event.

The workload at 70% of HRmax was too low as it only increased the VO2 level requirement 10 - 15% above the work
recovery baseline. The method used to determine HR max may not have given a true value. If the subject did not reach HR max during the VO2 max test a too low workload would have been chosen. The data would suggest this to be the case as the mean VO2 during the SR protocol was 52.2% of VO2 max. The graphical presentations of the VO2 and the HR vs time illustrate the stress placed on the body had no lasting effect. During the recovery period after the sprint rides the work recovery baseline was reached quickly (2 minutes) one would have expected the recovery to be slower and the O2 consumption to be much higher.

The classical concept of the O2-debt as stated by Margaria et al. (1933) indicates a two function curve is representative of the recovery VO2. Recently a third component has been proposed to account for other metabolic changes (Stainsby and Barclay, 1970, Hagberg et al., 1980). Using this information and the recovery portion of the VO2 vs time graph one could conclude that only an alactacid component was replenished during recovery. But this conclusion can only be made guardedly because no measure of blood or muscle lactate levels were made.

There is a greater O2 consumption (not statistically significant) during the IR vs CR (Table 2) for all subjects. This difference could be explained by the fact that the kinetics of the VO2 curve are slower during the transition from heavy work to light work as compared to the transition from heavy work to rest (diFrampero et al., 1970, Davies et
al, 1972). The IR required the subject to make this transition (heavy work to lighter work) 7 times during the testing session whereas the CR only required 2 transitions. Therefore the greater number of transitions from heavy work to lighter work would require a greater O2 consumption.

There was no significant difference in the amount of work done in the CR or the IR therefore this could not of been the cause for the difference in the O2 consumption. The high correlation (r=0.96) may indicate the amount of work done during the sprint portions of the two rides was similar.

The data reported here indicate the two sprint protocols are repeatable with regard to the amount of O2 consumed and the amount of work done during the sprint portions. Graham and Andrews (1973) indicated the results of their repeat tests were variable and they felt one should approach the results with some caution. In contrast utilizing the same protocol used here a series of repeat tests should produce results which are similar.

One of the purposes of this study was to determine the O2 consumed during an hour of cycling at a race pace. The criteria used for setting the workload was not appropriate for the sample used here and therefore the subjects worked below race pace. But the ability to collect the data on cyclists in a laboratory without any excessive increases in core temperature has been shown to be feasible. Even through the Tc did increase during both sprint conditions
(Fig. 5) this increase would not be detrimental to the subject. It is known that the enzyme systems in the body operate more effectively up to 40°C. (body temperature) (Brooks and Fahey, 1984). Therefore the increase in Tc was not physiologically significant.

The data have shown that the two sprint methods of breaking away require similar amount of O2 to be consumed. The difference between the two rides was not significant but the trend among the subjects was a lesser consumption of O2 during the continuous sprint protocol. One could speculate that these differences would be more pronounced at a higher workload.

With regards to which method of breaking away (continuous sprint vs intermittent sprint) is more efficient, the data would lead one to conclude that in physiological terms there is no difference between the two methods. However as mentioned above at a higher workload greater differences may be evident.

Finally one could speculate that repeating this study and correcting for the workload and having familiarized the subjects with all the testing situations, different results would be found. Further a clearer delineation between the sprint conditions may be found if the sprint portions use anaerobic energy sources. So that a cyclist could be advised as to which sprint protocol was more suited to him physiologically. Also recommendations could be made with regard to specific training procedures to follow in order to adapt the cyclist to the less suited sprint method.
Summary and Conclusions.

Five subjects performed a steady work level ride and two other rides consisting of either: i) a 2 minute continuous sprint or ii) 6 intermittent sprints, each 20 seconds in length. The total O2 consumption for the work and the recovery period was calculated.

The results indicated: i) the O2 consumption during exercise was not significantly different among the rides, ii) the O2 consumption was not significantly different during the recovery from the three different conditions, iii) the sprint tests (CR and IR) were found to be repeatable with regard to both the O2 consumption and the physical work done during the sprints.
Appendix A

Prior to this study very little work has been reported which attempted to study racing cyclists performing race pace work in the laboratory. The main reason appears to be the lack of a means: i) to allow the cyclist to use his own bicycle, ii) for the research scientist to stress the subject at a known level of work.

Hagberg et al. (1981) trained a group of road racing cyclists to ride on a treadmill at 20 mph and have the grade increased to elicit the required workload. Subject safety required 4 assistants to be available in case the cyclist lost his balance.

Another sport specific testing device has been introduced by Firth (1981). This system utilizes a commercially available training device and calibrates it so the workload at a specific gear ratio and pedal rate can be calculated. The problem with this system is the equipment used for calibration, i.e., an electric motor and braking system may be prohibitively expensive for most laboratories.

The system developed in this laboratory requires a standard Monark bicycle ergometer, a stand on which the cyclists' bicycle frame is attached and a longer than normal bicycle chain. The bicycle frame is attached to the stand using the front forks and the bottom bracket of the frame. The bottom bracket sits in a cradle and is secured by a plate across the chain stays and is affixed by a long bolt and a nut. The chain is passed through the rear derailleur
(to take up the slack in the chain) around the fixed cog of the ergometer flywheel and forward around the large chainring of the pedal crank. Use was made of a standard sized front chainring (52 teeth) to facilitate the workload calculation. A length of cord was wrapped around the flywheel, the pedals were moved through one complete revolution and the length of cord unwrapped from the flywheel was measured. This length of cord represented the distance the flywheel would have travelled as a result of one pedal revolution (in this case 5 meters).
Appendix B

Calculations

In this section all of the calculations used in this study will be explained. In most cases standard equations used extensively in exercise physiology have been utilized in a programme written for a micro-computer. In other instances new programmes have been written to solve problems encountered.

In the former case noted above the calculations of VO2, VCO2 and the RER have been accomplished using the standard equations listed below.

These equations are:

\[
\begin{align*}
    VO2 &= Vi \left( FiO2 - FiN2 / FeN2 * FeO2 \right) \\
    VCO2 &= Vi \left( FiCO2 - FiN2 / FeN2 * FeCO2 \right) \\
    RER &= VCO2 / VO2
\end{align*}
\]

The above equations were used in a Fortran programme for the Apple IIe micro computer.

The calculation of the amount of O2 consumed during the exercise phase, recovery phase and the total test period used the VO2 calculated for samples during the test period. Figure B-1 represents a typical O2 uptake curve drawn from the data collected in this study. The vertical lines divide the graph into blocks representing the time period represented by the expired gas sample. The VO2 was measured in liters per minute, at the onset of exercise 30 sec. expired gas samples were continuously collected for the first
Fig. B-1: Graph of the VO2 vs time. The area below the curve and bounded by the vertical lines represents the volume of O2 consumed for that time period.
three minutes. So these 6 VO2 values were added together and divided by 2 giving the number of liters of O2 consumed for the 3 min. period. The next 7 minutes had one 30 sec. sample collected per minute and these 7 values were added together. The next sample was collected from 14:30 minutes to 15:00 minutes, this VO2 value was multiplied by 5 and so on right through the end of recovery. Each value was totalled for the one hour exercise period, the recovery period and these two values gave the total amount of O2 consumed for the test. The above process was completed by writing a Fortran programme for the University of Windsor's main frame computer (IBM 3031).

The data were analyzed using the one-way analysis of variance with repeated measures from the SPSS package on the University of Windsor's mainframe computer. The results were checked manually using the equations presented by Winer (1971) on pages 261-283.

The Pearson product–moment correlation coefficient (r) was calculated using the method of Remington and Schork (1970).
Glossary

Oxygen Deficit;

At the onset of exercise the oxygen uptake increases exponentially to a steady level, according to the energy demand of the activity. However at the onset of the activity the energy requirement is constant. So the difference between the O2 uptake lag and the required energy level is known as the O2-deficit.

Oxygen Debt.

This term refers to the elevated oxygen uptake one sees in recovery after exercise. Originally it was felt that this increased O2 was used to replace O2 stores and energy stores plus remove lactate from the blood. The context of its use in this paper is it denotes the excess O2 uptake after a very short exhaustive work bout.

Alactacid Debt

This is the part of the oxygen debt which is not accompanied by an increase of lactic acid in the blood, (Lamb 1978).

Lactacid Debt

This is the portion of the oxygen debt that is associated with a rise in blood lactic acid, (Lamb 1978).

Steady Level of Oxygen Uptake

The energy exchange during continued muscular exercise which in turn establishes the steady level of oxygen uptake is due to both the contractile activity and metabolite
turnover. The latter may not be steady with time and the depletion of substrate metabolites indicates a non-steady state, (Stainsby and Barclay, 1970). 

Recovery Oxygen

During recovery, oxygen is taken up to replace used oxygen stores, to provide ATP for the resynthesis of creatine phosphate used and to provide energy for metabolite turnover, which includes replacement of ionic gradients and depleted substrate stores, and removal of leftover metabolites such as lactate, (Stainsby and Barclay, 1970). 

Half time

This is the time it takes to reach 50% of the VO2 required at the steady level of work.
Table D-1: The liters of oxygen consumed during the exercise phase of each of the protocols. The values are for each individual subject.

<table>
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<tr>
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<th>SR</th>
<th>CR</th>
<th>IR</th>
</tr>
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<td>137.5</td>
<td>139.9</td>
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<td>3</td>
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<td>75.4</td>
<td>66.7</td>
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<tr>
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<td>127.2</td>
<td>128.0</td>
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<td>X</td>
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</tr>
<tr>
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<td>± 31.1</td>
<td>± 22.7</td>
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</table>
Table D-2: The liters of oxygen consumed during the active recovery for the three protocols.

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<th>IR</th>
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<td>18.2</td>
<td>17.9</td>
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<tr>
<td>$\bar{x}$</td>
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<td>± 4.5</td>
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</table>
Table D-3: The liters of oxygen consumed during the total test period.

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<th>CR</th>
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<td>$\bar{x}$</td>
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<td>124.5</td>
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<tr>
<td>SD</td>
<td>± 31.8</td>
<td>± 34.3</td>
<td>± 26.4</td>
</tr>
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</table>
Appendix E

INFORMED CONSENT FORM

This project is being undertaken to provide some information regarding the oxygen uptake requirements of a racing cyclist performing sprints during a simulated one hour ride. The information from the series of tests described below will provide some baseline data which seems to be lacking.

The tests will consist of a) a progressive continuous maximal oxygen uptake test, b) a steady load ride of one hour duration with an active recovery period, c) a steady load one hour ride with a two (2) minute continuous sprint at the midpoint of the ride, followed by an active recovery period, and d) a steady load ride of one hour duration with six (6) twenty (20) second sprints interspersed during the hour with an active recovery period.

The workload of the steady ride will be determined by using a load which will elicit 70% of the maximal heart rate attained during the maximal oxygen uptake test. The sprint will require the subject to increase the pedal cadence to a level of approximately 120 revolutions per minute. The total number of revolutions during the sprint phase will be recorded. Heart rate and the rectal temperature will be monitored throughout the test period, and expired gas
samples will be collected and analyzed.

If you have any questions we will be glad to try and answer them. This is experimental research, too much knowledge on your part may bias the data, so we may not be able to answer all your questions till after your tests are completed.

You being a volunteer subject have the right to withdraw at anytime during the testing period. This means you may quit before, during, or after a test without prejudice. All information collected concerning you will be kept confidential. Any material that is published the identity of the subjects will be masked, i.e., each subject will be referred to by a number or a letter known only to the researcher.

I have read and understood the above information and give my consent to participate in this study.

Date: ________________

Subject _________________________________________

Witness: __________________________
Bibliography


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