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# High-Intensity Interval Training in Well-trained Cyclists : Consecutive Days versus Alternating Days

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# HIGH-INTENSITY INTERVAL TRAINING IN WELL-TRAINED CYCLISTS: CONSECUTIVE DAYS VERSUS ALTERNATING DAYS

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Master of Science

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by

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CERTIFICATE OF APPROVAL

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MASTER OF SCIENCE THESIS

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This is to certify that the Thesis of

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submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

**Purpose**: This study compared the effects of 3 weeks of high-intensity interval training (HIT) on well-trained cyclists when three weekly HIT sessions were performed on either consecutive or non-consecutive days. **Methods**: Fifteen well-trained cyclists volunteered to participate in the study. They performed a 5-km time-trial ($TT_{5k}$) and an incremental test to assess peak oxygen consumption ($VO_{2peak}$) and peak aerobic power output ($PPO_a$), and were divided into two matched-pair groups based on $TT_{5k}$ performance. For 3 weeks, one group (N=9) performed three HIT sessions per week on consecutive days, while the other group (N=6) did so on non-consecutive days. Subjects trained lightly or not at all on the remaining 4 days. Sessions for both groups consisted of up to eight 2.5-minute intervals at 100% of $PPO_a$. Pre- and post-training $TT_{5k}$ performance, $VO_{2peak}$, and $PPO_a$ were compared using 2 × 2 (group × time) ANOVA with repeated measures on time. **Results**: Both groups significantly improved $TT_{5k}$ velocity ($0.9 \pm 0.8$ $km \cdot hr^{-1}$) and average power output ($17 \pm 19$ W), as well as $VO_{2peak}$ ($0.2 \pm 0.2$ $L \cdot min^{-1}$), and $PPO_a$ ($23 \pm 15$ W). Mean improvement (~7%) was similar for both groups, but varied widely among individuals. **Conclusion**: Neither the consecutive-day nor the non-consecutive day training design is definitively superior, although individual athletes may respond better to one design or the other.

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

Chapter Page

TABLE OF CONTENTS (continued)

Chapter | Page

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

# Chapter 1

# INTRODUCTION

A major physiological determinant of endurance performance is $VO_{2max}$, the maximum volume of oxygen that can be consumed per minute to produce energy used by the muscles to do work. Fueling work using oxygen (i.e., aerobically) is generally less fatiguing than other means, and so a higher $VO_{2max}$ allows greater sustainable work rates in training and in competition. Research has shown that low-intensity endurance training in previously untrained individuals will increase $VO_{2max}$ and aerobic performance within a relatively short period of time (Green, Jones, & Painter, 1990; Phillips, Green, MacDonald, & Hughson, 1995; Phillips, Green, Tarnopolsky, et al., 1996; Wood, Doyle, & Appenzeller, 1991). However, it has been argued that endurance performance in well-trained athletes ($VO_{2max} > 60$ ml·kg$^{-1}$·min$^{-1}$) is not necessarily improved by further increases in low-intensity training volume (Laursen & Jenkins, 2002). Although this claim is not fully substantiated in the current literature, one study did show that additional low-intensity training volume had no effect on endurance performance while decreasing sprint performance in collegiate swimmers (Costill et al., 1991). Such findings may have implications for athletes whose performance depends on both sustained submaximal efforts and sudden high-speed sprints.

Laursen and Jenkins (2002) suggest that high-intensity interval training (HIT) is a more effective way to improve $VO_{2max}$ and endurance performance in well-trained athletes. Indeed, interval training at the intensity associated with $VO_{2max}$ has repeatedly improved $VO_{2max}$ and peak aerobic work rate, capacities on which both endurance and sprint performance depend (Laursen, Shing, Peake, Coombes, & Jenkins, 2002; Smith, Coombes, & Geraghty, 2003; Smith, Dilger, & Coombes, 2000). Improvements in $VO_{2max}$ via interval training depend on instances of overload followed by periods of recovery and regeneration. Both work and rest must be sufficient, yet not excessive, to allow for the greatest improvement while avoiding overtraining (Hagerman, 1992; Jeukendrup, Hesselink, Snyder, Kuipers, & Keizer, 1992; Pichot et al., 2000). This principle applies on more than one scale—not only within an interval training session, but also within the training week, phase, or larger training cycle. Several HIT studies have shown the effectiveness of enhancing overload by focusing on a particular type of training interval during a multi-week training phase (Laursen, Blanchard, & Jenkins, 2002; Laursen, Shing, Peake, et al., 2002; Lindsay et al., 1996; Smith, Coombes, & Geraghty, 2003; Smith, Dilger, & Coombes, 2000; Stepto, Hawley, Dennis, & Hopkins, 1999; Westgarth-Taylor et al., 1997; Weston et al., 1997). However, there are differing philosophies on the optimal placement of work and rest within the weekly layout of a HIT phase. Many coaches recommend one or more days of recovery between HIT sessions (Carmichael & Rutberg, 2003). This method has been studied frequently (Laursen, Blanchard, & Jenkins, 2002; Laursen, Shing, Peake, et al., 2002; Lindsay et al., 1996; Smith, Coombes, & Geraghty, 2003; Smith, Dilger, & Coombes, 2000; Stepto et al., 1999; Westgarth-Taylor et al., 1997; Weston et al., 1997) and has consistently led to improved performance. Others advocate a more intense *training block* of several consecutive days of HIT followed by a longer multi-day recovery period (Ross, 2005;

Morris, 2003). This method, however, has not been studied. Further, no study has compared the effectiveness of these two contrasting philosophies.

## Statement of Purpose

The purpose of this study was to compare changes in peak oxygen consumption ($VO_{2peak}$), peak aerobic power output ($PPO_a$), and 5-km time trial ($TT_{5k}$) performance in well-trained cyclists after performing a high-intensity interval training (HIT) program on either 3 consecutive days per week or 3 non-consecutive days per week.

## Hypotheses

The null hypotheses in this study were

1. High-intensity interval training would have no effect on $VO_{2peak}$, $PPO_a$, or $TT_{5k}$ performance.
2. There would be no difference between the effects of the two training designs on $VO_{2peak}$, $PPO_a$, or $TT_{5k}$ performance.

The alternative hypotheses were

1. High-intensity interval training would improve $VO_{2peak}$, $PPO_a$, or $TT_{5k}$ performance.
2. One training design would lead to significantly greater improvements in $VO_{2peak}$, $PPO_a$, or $TT_{5k}$ performance compared to the other.

## Scope of the Problem

Endurance athletes commonly use high-intensity training intervals to mimic race speeds in training with the intent to improve performance. Those who plan multi-week training phases to focus on these intervals, such as in final pre-season preparation, may be uncertain of the optimal weekly training schedule to employ during that phase. Further, they may be unaware that non-traditional methods exist. This study made a novel, direct comparison of two conflicting philosophies regarding the layout of work and recovery within an interval-training week. Prescribing two groups of well-trained cyclist the same intervals three times per week for 3 weeks made it possible to determine any difference in effectiveness between placing the three weekly sessions on consecutive days versus placing them on non-consecutive days. Although the findings of this study are of particular interest to competitive cyclists, they should interest other endurance athletes and coaches as well.

## Assumptions of the Study

The following assumptions were made with regards to this study.

1. Subjects abided by performance test preparation instructions (Appendix A).
2. Subjects exerted maximal effort in both pre- and post-testing.
3. Subjects abided by recovery-day guidelines (Appendix B).
4. Subjects put forth their best effort during training sessions.
5. Five-km time-trial performance is relevant to the success of competitive cyclists.

## Definition of Terms

For the purposes of this study the following terms were defined operationally.

1. Endurance training base: a basic level of fitness established via regular ($\geq 2$ times$\cdot$week$^{-1}$) aerobic exercise performed continuously for periods of 30 minutes or longer.
2. High-intensity interval training (HIT): an exercise session coordinating alternating periods of strenuous effort ($\geq$ 80% of maximum intensity) and periods of active or passive rest. Each period usually lasts between 30 seconds and 5 minutes.

3. Low-intensity endurance training: long (≥30 minutes), sustained exercise bouts performed at 45-70% of maximum intensity.
4. Peak heart rate attainment ($Peak_{HR}$): reaching a heart rate (HR) within 5 beats·min$^{-1}$ of the highest HR seen during pre-testing.
5. Training block: a period of 3-5 consecutive intense training days designed to amplify the training stimulus. Training blocks are separated by multiple days of rest or recovery and are usually repeated weekly within a training phase.
6. Training phase: a multi-week period within the larger training plan with a specific goal, such as improving a skill or capacity.

## Delimitations

Subjects in this study were regular road or mountain bike riders with an endurance training base. They were considered well-trained, with a cycling $VO_{2peak}$ of at least 43 (females) or 54 (males) ml·kg$^{-1}$·min$^{-1}$ and a cycling relative $PPO_a$ of at least 3.7 (females) or 4.2 (males) W·kg$^{-1}$.

## Limitations

There are certain limitations on the extrapolation of this study's results. The exact training intervals used in this study will not lead to the same results in every athlete, or in every sport, since key variables such as interval duration are best calculated on the basis of individual capacities, and may also be sport-specific. In this study, these were calculated based on the mean values of well-trained cyclists in previous studies.

# Chapter 2

# REVIEW OF LITERATURE

## Introduction

A major physiological determinant of endurance performance is $VO_{2max}$, the maximum volume of oxygen that can be consumed per minute to produce energy used by the muscles to do work. Fueling work using oxygen (i.e., aerobically) is generally less fatiguing than other means, and so a higher $VO_{2max}$ allows greater sustainable work rates in training and in competition. Research has consistently shown that low-intensity endurance training in previously untrained individuals increases $VO_{2max}$ and aerobic performance within a relatively short period of time (Green et al., 1990; Phillips, Green, MacDonald, & Hughson, 1995; Phillips, Green, Tarnopolsky, et al., 1996; Wood et al., 1991). However, it has been argued that endurance performance in well-trained athletes ($VO_{2max} > 60$ ml·kg$^{-1}$·min$^{-1}$) is not necessarily improved by further increases in low-intensity training volume and that high-intensity interval training (HIT) is a more effective approach (Laursen & Jenkins, 2002). Although further research is needed to provide a better understanding of the first claim, the second claim is well-supported in the current scientific literature. Indeed, HIT provides a strong training stimulus and quickly improves physiological capacities that affect endurance performance in well-trained athletes (Laursen, Blanchard, & Jenkins, 2002; Laursen, Shing, Peake, et al., 2002; Lindsay et al., 1996; Smith, Coombes, & Geraghty, 2003; Smith, Dilger, & Coombes, 2000; Smith, McNaughton, & Marshall, 1999; Westgarth-Taylor et al., 1997; Weston et al., 1997). This review will present justification for the use of HIT in well-trained athletes, discuss several forms of training intervals and their effects as seen in previous research, summarize some prominent interval-training strategies, and introduce an aspect of interval training that has not yet been studied.

## Training

### Low-Intensity Endurance Training

Low-intensity endurance training in previously untrained individuals increases $VO_{2peak}$, $VO_2$ kinetics, oxidative enzyme capacity (Phillips, Green, MacDonald & Hughson, 1995), fat oxidation (Phillips, Green, Tarnopolsky, et al., 1996), plasma volume, stroke volume (Green et al., 1990), and blood viscosity (Wood et al., 1991) within a relatively short period of time. However, some argue that in athletes whose $VO_{2max}$ is over ~60 $ml \cdot kg \cdot min^{-1}$, aerobic performance is difficult to improve through further increases in low-intensity training volume (Laursen & Jenkins, 2002). Indeed, one study showed that 6 weeks of increased low-intensity training volume (two 1.5-hr $sessions \cdot day^{-1}$) caused no additional improvement in swimming endurance compared to normal training (1.5 $hr \cdot day^{-1}$); moreover, the additional training decreased sprint performance (Costill et al., 1991). Such findings could have implications for athletes whose performance depends on both sustained submaximal efforts, and sudden or sustained high-speed sprints. In the aforementioned study, however, sprint performance may have suffered only temporarily due to fatigue; moreover, training volume was only increased for 6 weeks, which could have been too short to produce observable benefits. Indeed, in a longitudinal study of elite rowers, Fiskerstrand and Seiler (2004) attributed the large performance and physiological improvements seen over three decades partly to increased low-intensity training volume. Clearly, the demands of endurance sports vary in terms of race intensity and the relative contributions from aerobic and anaerobic energy systems; thus ideal training distributions may not be generalizable. For example, swimming performance in Costill et al. (1991) was defined over one long (>30 minutes) and three short (~2 minutes or less) durations, whereas rowing performance in Fiskerstrand and Seiler (2004) was defined over ~7 minutes. Further, it may also be that what is considered increased low-intensity training volume for one sport is considered normal or reduced volume for another sport, since traditional training distributions differ among sports. Nonetheless, more research is needed to understand the amount of time athletes should devote to low-intensity endurance training, and the point beyond which such training begins to lose its effect.

## High-Intensity Interval Training

High-intensity interval training improves capacities on which both endurance and sustained sprint performance depend; hence, it is an especially effective training strategy for well-trained athletes. Indeed, HIT improves various physiological variables, such as $VO_{2max}$, ventilatory threshold, peak aerobic power output ($PPO_a$), running velocity at $VO_{2max}$ ($V_{max}$), time to exhaustion at $V_{max}$, and muscle-acid buffering capacity. Moreover, these changes have been credited for improved time-trial performance in well-trained runners (Smith, Coombes, & Geraghty, 2003; Smith, Dilger, & Coombes, 2000; Smith, McNaughton, & Marshall, 1999) and cyclists (Laursen, Shing, Peake, et al., 2002; Lindsay et al., 1996; Stepto et al., 1999; Westgarth-Taylor et al., 1997; Weston et al., 1997). Interval-training sessions consist of periods of intense effort (e.g., 80-175% of $PPO_a$) alternating with active or passive recovery. Work and rest durations generally depend on the chosen intensity and these variables can be combined in several ways to elicit different training effects.

Submaximal HIT (<100% of $PPO_a$)

Interval training performed at an intensity slightly below the maximum aerobic work rate aims not to increase $VO_{2max}$ *per se*, but to make higher percentages of $VO_{2max}$ sustainable. Common submaximal training intensities are between 80 and 95% of $PPO_a$. Generally, lower relative intensities have been paired with greater interval durations, and various time-intensity combinations have led to improved performance.

Intervals at 80% of $PPO_a$. Five-minute intervals at 80% of $PPO_a$ have been studied repeatedly in cyclists (Lindsay et al., 1996; Westgarth-Taylor et al., 1997; Weston et al., 1997). Subjects in these studies completed 6-12 training sessions consisting of 6-9 intervals over 4-6 weeks, and in each case both $PPO_a$ and 40-km time trial ($TT_{40k}$) performance improved. Additionally, improved sprint performance was measured in two of these studies (Lindsay et al., 1996; Weston et al., 1997). However, Stepto et al. (1999) found that 8-minute intervals at 80% of $PPO_a$ did not improve $PPO_a$ or $TT_{40k}$ performance. It may be that the training effect at this intensity occurs largely within the first 5 minutes, and that the ineffectiveness of 8-minute intervals is due to the fact that fewer intervals can be performed. This issue should be explored further.

Weston et al. (1997) suggest that the improved performance following 5-minute intervals at 80% of $PPO_a$ is not related to changes in $VO_{2max}$ or oxidative capacity (i.e., aerobic factors), and so other factors, such as anaerobic capacity, should be considered. The notion that improved aerobic performance may be due to improved anaerobic capacity is supported by the following findings: (1) Muscle oxidative enzyme capacity was not increased following HIT, nor was it correlated with either $TT_{40k}$ performance or $PPO_a$ (Weston et al., 1997); (2) Performance in $TT_{40k}$ was highly correlated with $PPO_a$

(Lindsay et al. 1996; Stepto et al., 1999; Westgarth-Taylor et al., 1997; Weston et al., 1997), but not with $VO_{2max}$ (Weston et al., 1997); (3) Muscle lactate-buffering capacity (βm) increased 16% after HIT, and was strongly correlated to $TT_{40k}$ performance (Weston et al., 1997); (4) Subjects relied more heavily on carbohydrates in post-HIT $TT_{40k}$ (Westgarth-Taylor et al., 1997).

Collectively, these data suggest that training at 80% of $PPO_a$ improves $PPO_a$ and time-trial performance partly by improving βm, thus allowing higher levels of anaerobic energy contribution to be sustained while at $VO_{2max}$, or at any submaximal $VO_2$. This increased anaerobic power augments total power output at $VO_{2max}$ (thus, higher $PPO_a$) and at the $VO_2$ sustained during a $TT_{40k}$. Typically, $TT_{40k}$ are performed at the maximal lactate steady state (MLSS), the highest exercise intensity where blood lactate concentration is elevated but stable (Harnish, Swensen, & Pate, 2001). With improved □m, greater lactate production can be tolerated; hence, MLSS occurs at a higher absolute work rate. This allows a higher sustainable absolute intensity during TT and thus, improved performance. Further evidence that the extra work accounting for the $PPO_a$ and performance increases in these studies was contributed anaerobically is the concurrent improvement in sprint performance (Lindsay et al., 1996; Stepto et al., 1999; Weston et al., 1997).

Intervals at 85% of $PPO_a$. Stepto et al. (1999) found greater improvement in $PPO_a$, $TT_{40k}$ performance, and sprint power following 4-minute intervals at 85% of $PPO_a$ compared to 8-minute intervals at 80% of $PPO_a$, 2-minute intervals at 90% of $PPO_a$, and 1-minute intervals at 100% of $PPO_a$, where total training volume was similar among all forms of HIT. The authors noted that these findings support the principle of specificity, as

$TT_{40k}$ are typically completed at approximately 80% of $PPO_a$. Since $TT_{40k}$ improvements following the 4-minute intervals at 85% of $PPO_a$ were significantly greater than those following the 8-minute intervals at 80% of $PPO_a$, 4 minutes may be a more appropriate duration for intervals in this intensity range. Indeed, improvements following the 4-minute intervals at 85% of $PPO_a$ were similar to those seen after the 5-minute intervals at 80% of $PPO_a$ discussed above.

Intervals at 90% of $PPO_a$. One training group in Stepto et al. (1999) performed HIT sessions consisting of 2-minute intervals at 90% of $PPO_a$. These were among the least-effective on all dependent variables, which suggests that 2 minutes is an insufficient duration for submaximal intervals, or conversely, that 90% is too low an intensity for 2-minute intervals. Thus, 4 or 5 minutes may be more appropriate durations for submaximal intervals, even if this requires reducing intensity from 90% to 80-85% of $PPO_a$.

Supramaximal HIT (>100% of $PPO_a$)

Intervals performed above the maximum aerobic intensity have also been shown to improve endurance performance in trained cyclists (Laursen, Shing, Peake, et al., 2002; Stepto et al., 1999). In both of these studies, subjects performed twelve 30-second intervals at 175% of $PPO_a$, separated by 4.5 minutes of recovery, twice per week. After 3 weeks, Stepto et al. (1999) noted significant improvements in $TT_{40k}$ and sprint performance, while Laursen, Shing, Peake, et al. (2002) saw significant improvements in $TT_{40k}$ and $PPO_a$ after 4 weeks. As well, $VO_{2peak}$ improved by 3% in the latter study, although this change was not significant. As noted by Stepto et al. (1999), it is paradoxical, considering the principle of training specificity, that intervals performed well beyond the maximum aerobic intensity, and thus heavily dependent on anaerobic energy sources, improve $TT_{40k}$ performance, which depends mainly on aerobic energy sources. However, in both studies, $TT_{40k}$ improvements after 30-second intervals at 175% of $PPO_a$ were similar to those seen after HIT performed at 80 or 85% of $PPO_a$, the approximate intensity sustained during $TT_{40k}$ (Lindsay et al., 1996; Stepto et al., 1999; Westgarth-Taylor et al., 1997; Weston et al., 1997). Since improved performance has been shown to occur independently of higher $VO_{2peak}$ (Acevedo & Goldfarb, 1989; Smith, Dilger, & Coombes, 2000), faster $TT_{40k}$ could be due to simultaneous increases in aerobic and anaerobic energy production (Laursen, Shing, Peake, et al., 2002). Possible mechanisms for improvement include increased muscle-fatigue resistance (Stepto et al., 1999) or increased lactate-buffering capacity (Laursen, Shing, Peake, et al., 2002). Such a two-dimensional training stimulus has been reported elsewhere in physically active subjects (Tabata, Nishimura, et al., 1996).

Maximal HIT (100% of $PPO_a$)

Submaximal and supramaximal interval training cause endurance performance improvements that are largely independent of changes aerobic capacity. Since they do not stress the $VO_2$ response maximally, they do not increase its capacity to move oxygen via blood circulation, and extract and use it for energy production in the working muscles. However, endurance performance depends most heavily on sustainable, aerobic energy production, and sustaining higher exercise intensities aerobically demands more oxygen. Maximum oxygen consumption is thus the principle determinant of aerobic ability, and training this capacity specifically may lead to the greatest overall performance improvement. Indeed, maximal HIT has repeatedly led to improved performance concurrent with increased $VO_{2max}$ (Laursen, Shing, Peake et al., 2002; Smith, Coombes, & Geraghty, 2003; Smith, Dilger, & Coombes, 2000).

Training at $VO_{2max}$. Further improvements in $VO_{2max}$ in well-trained athletes may only result from training at or above $VO_{2max}$ (Laursen & Jenkins, 2002). Since central cardiovascular improvements may be nearly maximized in well-trained athletes, additional peripheral adaptations may be needed to improve aerobic fitness; training at $VO_{2max}$ rather than at lower intensities may therefore be necessary to elicit such changes (Hill & Rowell, 1997). Further, training designs that maximize time spent at $VO_{2max}$ and elicit higher $VO_{2peak}$ values may cause the greatest increases $PPO_a$ and $VO_{2max}$ (Demarie, Koralsztein, & Billat, 2000). In addition, simply achieving $VO_{2max}$ repeatedly (as opposed to sustaining it) may be important for increasing the rate of response of the aerobic system (Hill & Rowell, 1997). To elicit $VO_{2max}$ in training, the intensity and duration of exercise bouts must be sufficient. Since duration is negatively related to intensity, there must be an ideal intersection of the two.

Eliciting $VO_{2max}$. The term $V_{max}$ is used to designate the running intensity at which $VO_{2max}$ is first attained during graded exercise testing (Hill & Rowell, 1997), that is, the minimum velocity which elicits $VO_{2max}$. In cycling, power output is preferred to velocity as a measurement of intensity; therefore, peak aerobic power output ($PPO_a$) in cyclists is analogous to $V_{max}$ in runners. The rationale for using these parameters in HIT prescription is that they represent the lowest intensity at which $VO_{2max}$ is elicited, and that it is necessary to achieve $VO_{2max}$ to improve $VO_{2max}$ (Hill & Rowell, 1997). However, it may be necessary to clarify that $V_{max}$ and $PPO_a$ actually represent the minimum intensity at which $VO_2$ climbs *directly* to $VO_{2max}$ (i.e., no plateau *en route*).

Indeed, Morton and Billat (2000) showed that $VO_{2max}$ can eventually be attained after ~7 minutes at only ~90% of $V_{max}$. Nonetheless, $V_{max}$ itself elicits $VO_{2max}$ directly in about 4 minutes or less (Hill and Rowell, 1997), and is therefore preferred over lower intensities, since maximum training time at or near $VO_{2max}$ is sought. Further, $V_{max}$ or $PPO_a$ is also preferred to higher (supramaximal) intensities, which reduce interval duration, and therefore, time spent at $VO_{2max}$. Thus, $V_{max}$ or $PPO_a$ appears to be the ideal training intensity for increasing $VO_{2max}$.

It is not the exercise intensity *per se* but the high oxygen uptake that is usually found during high-intensity intermittent training that results in improved $VO_{2max}$ (Tabata, Irisawa, et al., 1997). Thus, the optimal training intensity must nevertheless be coordinated with appropriate work and rest durations to facilitate high levels of oxygen uptake. Because there is a delay at the onset of exercise before $VO_2$ begins to approach the maximum (Tabata, Irisawa, et al., 1997), intervals must be of a certain minimum length for maximal or near-maximal $VO_2$ to be attained. For example, Stepto et al. (1999) showed that 1-minute intervals performed at $PPO_a$ had no effect on aerobic performance. Despite employing an appropriate training intensity, these intervals were far too short to facilitate $VO_{2max}$ (Billat, Renoux, Pinoteau, Petit, & Koralsztein, 1994; Hill & Rowell, 1997) and were therefore an ineffective means of stimulating aerobic adaptation.

The term $T_{max}$ is used to describe the maximum amount of time that $V_{max}$ or $PPO_a$ can be sustained, and previous training studies have used $T_{max}$ for determining interval duration (Laursen, Shing, Peake, et al., 2002; Smith, Coombes, & Geraghty, 2003; Smith, Dilger, & Coombes, 2000; Smith, McNaughton, & Marshall, 1999). Previously, Hill and Rowell (1997) evaluated the rationale for using percentages of $T_{max}$ in the prescription of

$V_{max}$-interval training. They tested highly-trained female runners to see how long $V_{max}$ training intervals needed to be to elicit $VO_{2max}$. By analyzing oxygen consumption during $T_{max}$ tests, they found that on average subjects attained 95% of $VO_{2max}$ within 149 seconds, or 50% of $T_{max}$, but that attainment of 100% of $VO_{2max}$ took an additional 85 seconds on average, or a total 80% of $T_{max}$.. Only one subject attained 100% of $VO_{2max}$ within the first 60% of $T_{max}$.

In contrast, other researchers have seen quicker attainment of $VO_{2max}$ in similar subjects, (Billat et al., 1994; Harling, Tong, & Mickleborough, 2003; Thomas, Hanon, Perrey, LeChevalier, & Vandewalle, 2005). Harling, Tong, and Mickleborough (2003), for example, saw recreational runners attain $VO_{2max}$ in 155 seconds at $V_{max}$, or about 65% of $T_{max}$. Furthermore, Billat et al. (1994) saw male sub-elite distance runners reach $VO_{2max}$ after only 97 seconds at $V_{max}$, or 25% of $T_{max}$. Although this estimate may be generous, it is nonetheless 52 seconds less than subjects in Hill and Rowell (1997) needed to reach 95% of $VO_{2max}$. One possible explanation for the quicker attainment of $VO_{2max}$ by subjects in Billat et al. (1994) is that they began the $V_{max}$ trial within 20 seconds of warming up. It has been shown that light activity prior to a maximal exercise bout increases initial $VO_2$ and allows faster $VO_2$ kinetics during the maximal bout compared to still rest (Dorado, Sanchis, & Calbet, 2004). Thus, residual excess post-exercise oxygen consumption (EPOC) associated with the preceding warm-up could have allowed subjects in Billat et al. (1994) to reach $VO_{2max}$ sooner than subjects in Hill and Rowell (1997).

The data of Billat et al. (1994) seem more relevant for determining optimal $V_{max}$-interval durations since the oxygen deficit encountered during high-intensity intervals leads to EPOC during the intermittent rest periods (Tabata, Irisawa, et al., 1997). Therefore, although reaching $VO_{2max}$ in the first interval of a HIT session may take up to 80% of $T_{max}$ as in Hill and Rowell (1997), EPOC at the onset of successive intervals could allow $VO_{2max}$ attainment in only 25% of $T_{max}$ as in Billat et al. (1994), assuming rest periods are not too long. Nonetheless, due to large inter-subject variance in the percentage of $T_{max}$ needed to achieve $VO_{2max}$, (Hill & Rowell, 1997; Harling, Tong, & Mickleborough, 2003), interval durations based simply on sample means for this parameter may not be the best way for all athletes to train at $VO_{2max}$. Although mean times at $V_{max}$ to attain $VO_{2max}$ may be 50% of $T_{max}$ or less, 60% seems to be a safer minimum cutoff point to encompass the amount of time needed by most athletes (Hill & Rowell, 1997).

Additional research suggests that 60% of $T_{max}$ may also be the optimal *maximum* cutoff point for $V_{max}$-interval duration (Smith, Coombes, & Geraghty, 2003). This study demonstrated that five intervals at 70% of $T_{max}$ are less effective than six intervals at 60% of $T_{max}$. Because the 70%-of-$T_{max}$ training group in this study had significantly higher blood lactate concentrations than the 60%-of-$T_{max}$ group after only the second interval, they were less able to complete the remaining three intervals. Thus, longer intervals allowed no more average time at $V_{max}$ per interval. Consequently, the 70%-of-$T_{max}$ group completed far less total time at $V_{max}$ (655 s) than the 60%-of-$T_{max}$ group (768 s) despite similar total prescribed training time. Given that 60%-of-$T_{max}$ intervals led to a greater decrease in 3000-m run time than 70%-of-$T_{max}$ intervals, the researchers concluded that the benefits of maximal HIT are related to the time for which the targeted high intensity is sustained, assuming that intervals are long enough to elicit $VO_{2max}$.

A final consideration for maximal-HIT prescription is that simply achieving maximal or near-maximal $VO_2$ repeatedly, as opposed to sustaining it, may increase the response rate of the aerobic system (Hill & Rowell, 1997). This response rate, also called $VO_2$ kinetics, refers to the rate of increase in $VO_2$ at the onset of exercise at a constant work rate. Until $VO_2$ begins to plateau, extra work must be contributed anaerobically; therefore, a faster increase in $VO_2$ and aerobic energy production reduces lactate production and may spare carbohydrate stores early in an exercise bout, thus delaying fatigue. Oxygen uptake kinetics increases with training (Yoshida et al., 1992) and is significantly faster in trained compared to untrained populations (Koppo, Bouckaert, & Jones, 2004). If repeatedly attaining $VO_{2max}$ improves $VO_2$ kinetics, HIT sessions should be structured not only to maximize time at $VO_{2max}$, but also to allow the most possible attainments of $VO_{2max}$.

Thus, three considerations are important regarding HIT prescribed to improve $VO_{2max}$. First, intensity should be that which first elicits $VO_{2max}$ during graded testing (i.e., $V_{max}$ or $PPO_a$) (Hill & Rowell, 1997). Second, intervals should be long enough to elicit $VO_{2max}$ yet of a duration that maximizes total training time spend near $VO_{2max}$ (i.e., ~60% of $T_{max}$) (Hill & Rowell, 1997; Smith, Coombes, & Geraghty, 2003). Third, interval repetitions and rest durations should maximize the number of $VO_{2max}$ attainments to improve $VO_2$ kinetics (Hill & Rowell, 1997). Thus, several intervals should be performed at maximal aerobic intensity for approximately 60% of $T_{max}$. For the runners in Hill and Rowell (1997), 60% of average $T_{max}$ was approximately 3 minutes. Cycling $T_{max}$ may be slightly shorter; for the cohort of cyclists in Laursen, Shing, Peake, et al. (2002), 60% of $T_{max}$ was about 2.5 minutes.

## Interval Training Design

A periodized training plan employing training cycles utilizes correct training loads and adequate regeneration periods to avoid excessive fatigue. It provides structure for controlling the stress and regeneration that are essential for training improvements (Smith, 2003). Periodization also aids the establishment of performance objectives and training emphases for each phase of training, thereby eliminating the random approach that may lead to excessive increases in volume or intensity and insufficient regeneration, that is, overtraining (Fry, Morton, & Keast, 1992). Incorporating HIT into a training regimen involves planning on multiple levels. One must consider how HIT best fits into the larger training plan, the numbers of sessions per week and intervals per session that are appropriate and tolerable, and how to arranged sessions and intervals to incorporate adequate recovery.

### Specialization Phases

Specialization phases involve concentrating on certain important workouts, such as maximal intervals, which are repeated several times during consecutive weeks to achieve a condensed, specialized training effect, leading to improvement in a particular skill or capacity. During HIT specialization phases, total training volume drops considerably, but the volume of high intensity work increases markedly (Morris, 2003). Carmichael and Rutberg (2003) recommend 4-week specialization training phases for goals such as peak power development. Morris (2003) suggests approximately 3-week phases of both supramaximal and maximal intervals during preseason preparation. Ross (2005) describes HIT phases as long as 6 weeks, but cautions against continuing HIT after reaching a plateau in improvement, which may occur after only 2-4 weeks.

Weekly Schedule

Even within intense multi-week specialization phases, intense training sessions have traditionally been separated by recovery days. Carmichael and Rutberg (2003) recommend at least 36 hours between maximal interval sessions, and suggests a plan placing HIT sessions on non-consecutive days. Likewise, in previous studies involving HIT, runners and cyclists have performed intervals on non-consecutive days (Laursen, Blanchard, & Jenkins, 2002; Laursen, Shing, Peake, et al., 2002; Lindsay et al., 1996; Smith, Coombes, & Geraghty, 2003; Smith, Dilger, & Coombes, 2000; Stepto et al., 1999; Westgarth-Taylor et al., 1997; Weston et al., 1997).

However, a relatively new training approach involves training very hard for several consecutive days, and then resting for several days to allow the body to recover and supercompensate (Morris, 2003). These *training blocks* essentially apply the concept of specialization training phases on a smaller scale; the theory behind block training is that overloading a single system to a greater degree and then allowing adequate rest will cause the system to supercompensate more than with other training designs (Morris, 2003). A multiple-day block of maximal HIT for example, would greatly overload the oxygen transport system, and a longer recovery period might allow greater adaptation. Morris (2003) recommended both pre-season and in-season training schedules involving 3 consecutive days of HIT per week. Each day, the interval length and intensity may change slightly, but HIT volume should stay approximately the same over the 3 days, that is, more repetitions as intervals become shorter. Similarly, Ross (2005) suggested a more compressed training stimulus followed by a longer recovery period, such as 3 consecutive days of HIT followed by 4 days of rest, or even 5 days of HIT followed by 2 days of rest in some cases. However, he cautioned against attempting more consecutive days than can be completed with reasonable success, and stressed the importance of adequate time for repair and recovery.

Block training is a relatively new idea based on theory and anecdotal evidence and has yet to be validated in research settings. In previous studies, HIT phases for runners and cyclists have typically spanned 3-4 weeks with 2 non-consecutive sessions per week. However, Acevedo and Goldfarb (1989) showed that three sessions per week can also effectively improve endurance performance. More research on the use of three sessions per week could provide a better understanding of related costs and benefits compared to two sessions per week. Moreover, only such programs could provide a means for comparison to a training block employing 3 consecutive days per week.

HIT Session Design

Carmichael and Rutberg (2003) proposed maximal HIT sessions involving 3-8 intervals of 3-5 minutes in length, and a work-to-rest ratio of 1:1 or 1:1.5. They recommended performing such intervals at a cadence of 110-120 RPM. Morris (2003) offered several options for HIT sessions, which were designed to work in conjunction as part of a 3-day training block. According to Morris (2003), interval length should decrease across the 3-day block (e.g., 4-min, 3-min, 1-min or 3-min, 2-min, 1-min) and intensity should increase accordingly. He divided sessions into 3-4 sets, which were separated by large (8-10 min) rest periods. Sets were then sub-divided into 3-6 intervals, which were separated by briefer rest periods, equal in length to the intervals. Depending on the interval length, sets and sub-sets were arranged so as to keep total HIT volume similar on each day. For example, three sets of three 3-minute intervals on the first day, and four sets of six 1-minute intervals on the third day. Ross (2005) suggested increasingly more-difficult intervals on each day of a weekly training block to develop muscular strength and endurance. He suggested 50, 60, and 70% of $T_{max}$ intervals at 100% of $PPO_a$ on days 1, 2, and 3, respectively, of an HIT block.

## Methods of Monitoring Performance

Ross (2005) believes power output or speed to be the best way to track HIT performance, since during intense but short bouts, heart rate (HR) might not rise to the desired level until after the interval is over. Morris (2003) agreed that power output is superior to HR as a means of gauging performance, and referred to instances of fatigue-related reductions of mean HR over the course of a HIT block, despite power output remaining constant. Carmichael and Rutberg (2003) added that power output is the most direct measure of actual work rate, whereas speed is subject to wind and terrain. As such, power output can be used to precisely identify ideal training intensities, as well as the point at which fatigue overcomes the ability to continue training effectively.

## Warm-Up

Most cycling training studies have incorporated warm-up routines prior to testing and training sessions (Laursen, Blanchard, & Jenkins, 2002; Laursen, Shing, Peake, et al., 2002; Lindsay et al., 1996; Stepto et al., 1999), but these have often been unstandardized (self-selected intensities) and shorter (~5 min) than many cyclists prefer. Carmichael and Rutberg (2003) recommended at least 10 minutes of warm-up, whereas Ross (2005) suggested 15-20 minutes.

Two studies have assessed warm-ups and their effects on cycling performance. Longer warm-ups have been shown to improve intense cycling performance compared to no warm-up, although the best protocol is not clear. Hajoglou et al. (2005) saw significant and similar improvements in 3-km time-trial performance following both easy (15 minutes below ventilatory threshold) and hard (an additional 3 minutes at ~90% of $VO_{2max}$) warm-up routines. Improvements were attributed to an accelerated $VO_2$ response, which allowed greater aerobic energy production during the first third of the time trial. Similarly, Burnley, Doust, and Jones (2005) saw improved performance following either moderate (10-12 min) or heavy (6 min) warm-up.

## Nutrition

Drinking a carbohydrate (CHO) sports drink has been shown to improve performance and delay fatigue during intense intermittent exercise, particularly sessions lasting an hour or more (Welsh & Davis, 2002). Sports drinks typically have lower carbohydrate concentrations (6%) than juice or soda (>10%) to optimize absorption; some drinks also contain protein (CHO-P), which is believed to enhance insulin release and glycogen repletion, and aid in the repair of damaged muscles (Millard-Stafford et al., 2005). In a study by Saunders, Kane, and Todd (2004), consuming a CHO-P beverage during and between two exhaustive exercise bouts significantly improved time to exhaustion (TTE) compared to a CHO beverage, as subjects rode 29% longer at 75% of $VO_{2max}$ in the first bout and 40% longer at 85% of $VO_{2max}$ 12 hours later. Further, the CHO-P group had 83% lower plasma CPK concentrations, indicating less muscle damage. However, in this study, the benefits of the CHO-P beverage could have been due simply to its greater total caloric content, rather than the presence of protein. Indeed, isocaloric CHO or CHO-P beverages increased insulin, blood glucose concentrations, and glycogen repletion rates equally (Roy & Tarnopolsky, 1998). Likewise, Millard-Stafford et al. saw no difference between the effects of isocaloric CHO and CHO-P beverages on running performance, although the CHO-P group reported significantly lower perceived muscle soreness.

## Laboratory Testing

Training studies typically use laboratory tests of physiological or performance capacities to look for the effects of training by comparing pre- and post-training results. However, to best detect true variance (that due to the treatment), tests must have a minimum degree of random error.

### Physiological Capacities

Measurements of submaximal and maximal $VO_2$ and HR, anaerobic and ventilatory thresholds, maximal lactate steady state, muscle lactate-buffering capacity, and muscle cellular and enzymatic activity all provide information about physical capacities and responses to exercise (Brittain, Rossiter, Kowalchuk, & Whipp, 2001; Harnish et al., 2001; Weston et al, 1997). Of these measures, $VO_{2max}$ is the most common; however, the random error when measuring $VO_{2max}$ is approximately 2%, which limits its value for tracking the smallest meaningful changes for competitive athletes (~1%) (Paton & Hopkins, 2001). Indeed, Laursen, Shing, Peake, et al. (2002) saw a 3% increase in $VO_{2peak}$ following 4 weeks of HIT, which was statistically nonsignificant but could nonetheless be very meaningful for competitive athletes. Therefore, although physiological data are helpful for explaining the mechanisms for improved performance, they are generally not used as criterion measures.

## Performance

Tests for performance variables such as mean or peak power output, velocity, time, or distance tend to have the smallest random errors (Paton & Hopkins, 2001). Maximum performance tests usually take one of three forms: (1) time-trials (TT) of fixed distance, (2) tests of fixed time, or (3) time-to-exhaustion (TTE) trials of fixed intensity, where subjects seek to maximize average velocity, distance, and duration, respectively. Because of their differing natures, these tests have different degrees of reproducibility in competitive cyclists. Jeukendrup, Saris, Brouns, and Kester (1996) and McLellan, Cheung, and Jacobs (1995) reported coefficients of variation (CV) for TTE of 26.6% and 31.4%, respectively. Reliability data for distance or work measurements in fixed-time tests are less extensive. However, CV have been reported at 2.7% for 1-hour (Bishop, 1997) and ~2.75% for 30-second bouts (Watt, Hopkins, & Snow, 2002). Compared to the TTE test where CV=26.6%, Jeukendrup, Saris et al. (1996) reported CV of only 3.49% and 3.35% for fixed-time and fixed-distance tests, respectively, where all three tests were of similar duration (~1 hour).

Fixed-distance TT are often believed to be the most reliable performance tests (Jeukendrup, Saris, et al., 1996; Paton & Hopkins, 2001). Schabort, Hawley, Hopkins, Mujika, and Noakes (1998) tested the reliability of a 100-km laboratory race-simulation and found a 1.7% CV within subjects and a high correlation (r=0.93) among all tests. Palmer, Dennis, Noakes, and Hawley (1996) found CV of 1.1% and 1.0% in 20-km and 40-km TT, respectively. Hickey, Costill, McConnell, and Tanaka (1992) observed a CV of only 0.95% across four 5-mile TT, and Laursen, Shing, and Jenkins (2002) showed a 0.9% CV in 40-km TT when subjects first performed a familiarization trial.

Although laboratory TT distances ranging from 8 to 100 kilometers have been validated (Hickey et al., 1992; Schabort et al., 1998), training studies typically use 40-km tests ($TT_{40k}$) to track training gains (Laursen & Jenkins, 2002). This distance is similar to many competition TT, typically takes just under an hour for highly-trained cyclists, and is performed near the MLSS (Harnish et al., 2001). However, as noted by Padilla, Mujika, Orbañanos, and Angulo (2000), stage races typically also include a prologue TT, where distance is considerably less and intensity is higher. Therefore, shorter laboratory TT could be particularly useful to assess the effects of high-intensity training.

In summary, athletes may gain competitive advantage from performance improvements of 1% or less (Hopkins, Hawley, & Burke, 1999); however, such changes cannot be recognized by laboratory tests that have greater degrees of random error (Paton & Hopkins, 2001). Among laboratory performance tests, TTE trials seem to be the least reliable. Fixed-time tests are typically more reliable, but fixed-distance TT are best able to reveal small but meaningful performance increases. Other factors believed to improve test reproducibility include having subjects ride their own bicycles (Palmer et al., 1996; Paton & Hopkins, 2001; Schabort et al., 1998) and standardizing environmental conditions, time of day, food and fluid intake, activity leading up to testing, and warm-up procedures (Hickey et al., 1992; Jeukendrup, Saris, et al., 1996; Padilla et al., 2000; Palmer et al., 1996; Schabort et al., 1998).

## Summary

A review of current research and training literature reveals the following key points related to the current study. Peak aerobic work rate and $VO_{2max}$ are two important physiological variables for endurance performance, and training at a high intensity is the only way for well-trained athletes to significantly increase these capacities A high-intensity interval training format maximizes training time at a high intensity and at a high $VO_2$, and leads to the greatest overall improvements. Intervals of various durations and intensities will lead to improved endurance performance, through any of several mechanisms, including aerobic and anaerobic capacities. Intervals performed at the peak aerobic work rate and lasting long enough to elicit maximal or near-maximal $VO_2$ target aerobic capacity specifically.

Training should follow an organized, periodized plan, to optimize periods of work and recovery, thus maximizing training adaptations and avoiding overtraining. Specialization phases within periodized training facilitate specific training goals and adaptations. Multi-week training phases focusing on high-intensity training intervals quickly lead to significant improvements. Traditionally, endurance athletes have used high-intensity interval training conservatively, typically separating sessions by one or more recovery days. However, some theorists claim that more compressed training designs may be more effective, though these claims lack sufficient empirical evidence.

Power output is the best indicator of cycling performance during training, as well as laboratory testing, as it measures the work load more directly than heart rate or $VO_2$. Further, fixed-distance time trials are the most valid and reliable laboratory tests for tracking the smallest meaningful performance improvements in competitive athletes, especially when they require an intensity similar to that of both training and competition.

# Chapter 3

# METHODS

## Subjects

All testing protocols were approved by the Ithaca College Human Subjects Review Board. Seventeen (13 male, 4 female) well-trained cyclists associated with the collegiate teams at Cornell University and Ithaca College volunteered to participate in this study. During a preliminary subject-recruitment meeting, they were made aware of the study's procedures, risks, and benefits, and gave their written informed consent to participate (appendices C-E). They filled out medical history forms (Appendix F), and were in apparent good health. Subjects' training logs from the month preceding the study along with training history questionnaires indicated that all subjects had established a sufficient endurance training base via participation in various sports. All subjects currently trained regularly for cycling and were involved in the sport competitively (road or mountain bike, or both). Exclusion criteria for subjects were relative peak oxygen consumption ($VO_{2peak}$) and peak aerobic power output ($PPO_a$) values less than 54 $mL \cdot kg^{-1} \cdot min^{-1}$ and 4.25 $W \cdot kg^{-1}$, respectively, for males, and 43 $mL \cdot kg^{-1} \cdot min^{-1}$ and 3.7 $W \cdot kg^{-1}$, respectively, for females. Of the original 17 subjects, one dropped out during training due to chronic fatigue, and another failed to report to the lab for post-testing. Therefore, 15 subjects completed all elements of the study and were included in data analysis. Mean (± SD) were: age = 21 (± 3) yr; weight = 68.3 (± 9.4) kg; sum of seven skinfolds = 54.6 (± 24.9) mm; $VO_{2peak}$ = 62.1 (± 12.5) $mL \cdot kg^{-1} \cdot min^{-1}$.

## Research Design

This study employed a quantitative experimental design. Subjects were pre-tested, separated into two matched-pair groups, given one version of an experimental treatment, and then post-tested to assess changes within and between groups. Pre- and post-testing consisted of a 5-km time trial ($TT_{5k}$) and an incremental test to assess $VO_{2peak}$ and $PPO_a$. Reliability of all testing protocols and procedures was established using a sample from the subject cohort, and treatments were highly controlled.

## Equipment

Subjects completed all testing and training using their racing bicycles mounted on a CompuTrainer indoor trainer (Pro Model 8002, RacerMate, Seattle, WA), which was controlled by CompuTrainer Coaching Software 1.5 (CS) or MultiRider III Retail Version (RacerMate, Seattle, WA), installed on a Dell Optiplex GX260 computer. The CompuTrainer allows a bicycle's rear wheel to be suspended against a magnetically-braked roller. The resistance on the roller either reacts to wheel speed to maintain a constant workload in the Ergometer Mode, or is determined by rider weight and speed, so as to simulate outdoor cycling, in the General Exercise Mode. Software was used to create a user data file that included body weight for each subject, and to collect performance data during all tests. Heart rates (HR) during testing and training were measured using Polar heart rate monitors (S120 or F1, Polar Electro Oy, Kempele, Finland).

## Performance and Physiological Testing Protocols

Subjects completed all testing in the Exercise Physiology Laboratory at Ithaca College, at approximately the same time of day, under similar laboratory conditions (temperature, 20 C; relative humidity, 15-30%; barometric pressure, 735-745 mmHg). Subjects were asked to train lightly or not at all the day before testing and were instructed to eat similarly and at least 1.5 hours before arriving at the lab on testing days Additional pre-test guidelines are detailed in Appendix A. Upon their arrival for each test, subjects were weighed in their cycling shorts and shirt on a Detecto-Medic balance scale (Detecto Scales, Inc., Brooklyn, NY), and user data files were updated accordingly.

Following pre-calibration of the CompuTrainer according to the manufacturer's specifications (CompuTrainer, 2006), subjects performed a standardized 20-minute warm-up before each test. During the initial 15 minutes, the CompuTrainer operated in Ergometer Mode, and was controlled by CompuTrainer's MultiRider software (MultiRider III Retail Version). For males, the warm-up consisted of 8 minutes at 2.2 Watts (W) per kilogram (kg) body weight, 5 minutes at 2.6 $W \cdot kg^{-1}$, and 2 minutes at 3.3 $W \cdot kg^{-1}$. Ratios for females were 1.8, 2.2, and 2.6 $W \cdot kg^{-1}$. The CompuTrainer was then switched to General Exercise Mode, and subjects rode at a self-selected intensity for the final 5 minutes, whereupon they completed three short sprints (15-20 seconds) at a pedaling cadence of 100 $revolutions \cdot min^{-1}$ (RPM) or more. During one of the sprints, a researcher re-calibrated the CompuTrainer.

<u>$TT_{5k}$</u>

A flat 5-km TT course with a starting ramp was created using CS. During all $TT_{5k}$, the CompuTrainer operated in General Exercise Mode, where rolling resistance simulated outdoor riding and subjects were able to select their own intensity. Subjects were required to begin all $TT_{5k}$ in their preferred starting gear, which they established during practice runs prior to pre-testing. After the start, however, they were allowed unrestricted use of their gears. Subjects were instructed to complete the 5-km distance as fast as possible. No verbal motivation was provided.

During $TT_{5k}$, subjects monitored their HR using a Polar heart rate monitor, and saw their cadence on the CompuTrainer handlebar display. Researchers gave verbal updates of elapsed distance every 500 meters, as well as at 250 and 100 meters from the finish line. No other data were available to the subjects during the TT. Researchers recorded HR every 30 seconds and upon completion of the TT. Meanwhile, CS recorded total elapsed time ($t_{TT5k}$), and means for velocity ($v_{TT5k}$), power output ($P_{TT5k}$), and cadence. Mean HR was also calculated as the average of all 30-second readings. Finally, blood lactate concentration (BL) was measured 5 minutes after completion of the TT as described by Bassett, Merrill, Nagle, Agre, and Sampedro (1991), using an Acutrend Lactate analyzer (type 30112522, Roche, Mannheim, Germany).

Incremental Test

During all incremental tests, the CompuTrainer operated in Ergometer Mode, which allowed the workload to be fixed at a desired level, regardless of cadence. Coaching Software operated a pre-programmed graded protocol, which began at 2.5 $W \cdot kg^{-1}$ for men or 1.5 $W \cdot kg^{-1}$ for women. Thereafter, workload increased 10 W every 30 seconds. Subjects completed as many stages as possible before they reached exhaustion or could no longer maintain a wheel-speed of 24 $km \cdot hr^{-1}$, which is necessary to ensure the intended workload on the CompuTrainer. Exhaustion was verified if two of the following three criteria were met: (1) $VO_2$ reached a plateau or dropped slightly, the last two values agreeing within ± 2 $mL \cdot kg^{-1} \cdot min^{-1}$, (2) 90% of age-predicted $HR_{max}$ was attained, and (3) respiratory exchange ratio ($VCO_2$:$VO_2$) was greater than 1.10 (Laursen, Blanchard, & Jenkins, 2002).

Heart rate was recorded at the end of each 30-second stage using a Polar heart-rate monitor. Oxygen consumption ($VO_2$), expired carbon-dioxide ($VCO_2$), and ventilatory rate ($V_E$) were measured every 15 seconds using a TrueMax 2400 Metabolic Measurement System (Parvo Medics, Salt Lake City, UT). According to manufacturer's specifications, the flow-meter was calibrated using a 3-liter syringe (Hans Rudolph, Inc., Kansas City, MO) and the gas analyzer was calibrated using a standard mixture of 4% $CO_2$, 16% $O_2$, and 80% N. Peak oxygen consumption was defined as the highest average of any two consecutive $VO_2$ readings (Laursen, Shing, Peake, et al., 2002). Peak aerobic power output was defined as the average workload corresponding to those two readings.

Familiarization

The timeline for the 7-week experimental period is diagrammed in Figure 1. Subjects were instructed 6 weeks before the study to incorporate at least one $TT_{5k}$ into their training to gain familiarity with maximum effort at that distance. During weeks 1 and 2 of the study, subjects came to the lab to familiarize themselves with the testing procedures and to practice the $TT_{5k}$ performance test on the CompuTrainer. Each subject completed at least two $TT_{5k}$ following the exact research protocol, and rehearsed the initial stages of the incremental test used to assess $VO_{2peak}$ and $PPO_a$ to become familiar with riding while connected to the metabolic analysis equipment used during testing.

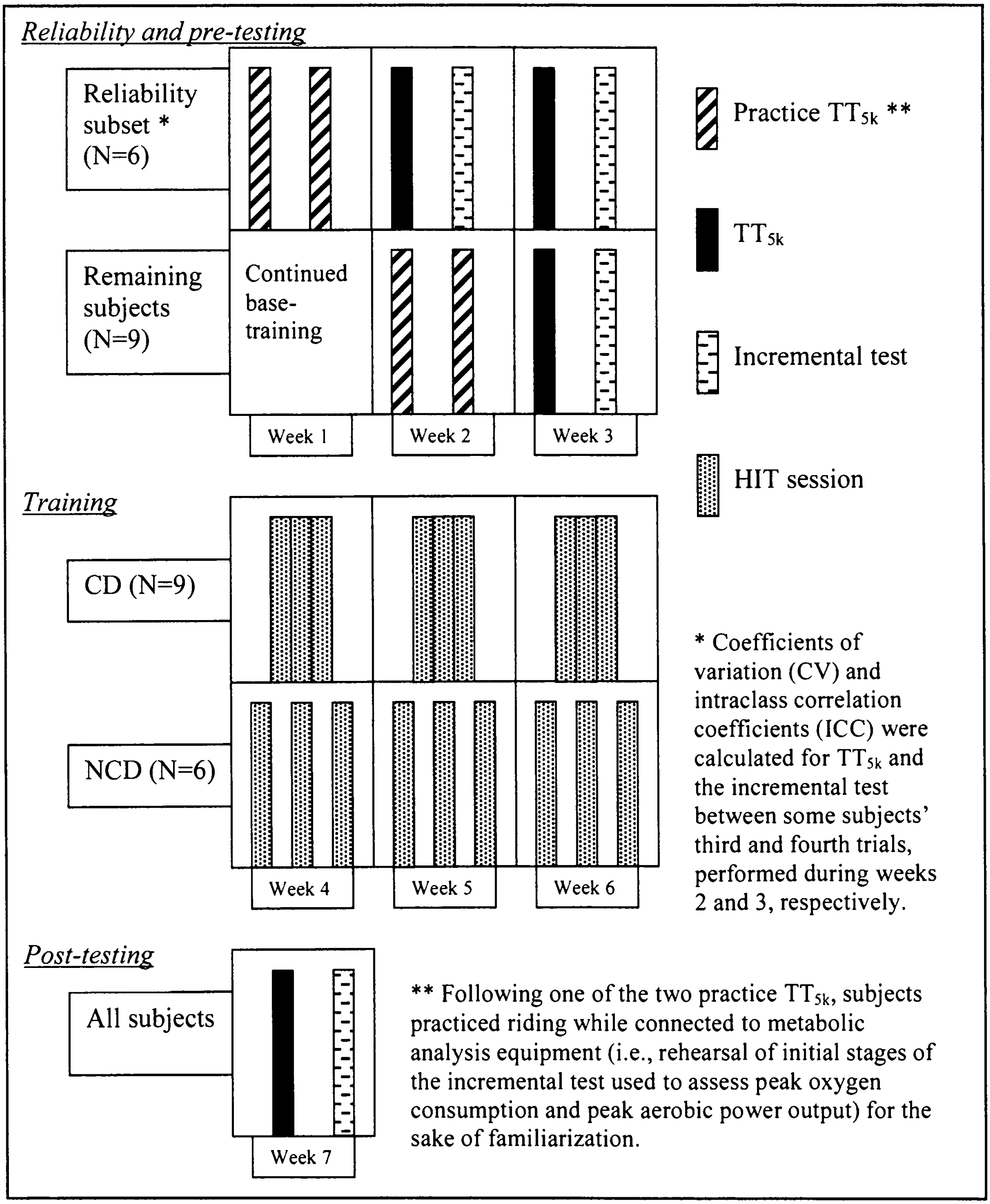


*Figure 1.* Diagram of the laboratory testing and training schedule during the 7-week experimental period. All pre- and post-test data were taken during weeks 3 and 7,

respectively. $TT_{5k}$ = 5-km cycle time trial; HIT = high-intensity interval training; CD = consecutive-day training group; NCD = non-consecutive day training group.

## Reliability

Six subjects who had already performed two $TT_{5k}$ in the lab by the end of week 1 were selected to verify the reliability of testing protocols. During week 2, these six subjects performed a third $TT_{5k}$ followed at least 48 hours later by an incremental test; both tests followed exact research protocols. Data from these tests were compared to pre-test data from the following week for calculating coefficients of variation (CV) and intraclass correlation coefficients (ICC). One subject's data for the $TT_{5k}$ were excluded from reliability analysis due to an equipment error during the first trial. Both the $TT_{5k}$ and the incremental test were reliable measures. In the $TT_{5k}$ (N=5), CV for velocity ($v_{TT5k}$) and mean power output ($P_{TT5k}$) were 1.0% and 2.7%, respectively; ICC for these measures were 0.99 and 0.99, respectively. In the incremental test (N=6), CV for $VO_{2peak}$ and $PPO_a$ were 0.1% and 0.1%, respectively; ICC for these measures were 0.99 and 0.98, respectively.

## Pre-Testing

During week 3, all subjects came to the lab on two non-consecutive days. They performed a $TT_{5k}$ on the first day and an incremental test on the second. In both cases, complete testing protocols were followed, and all necessary data were gathered for comparison with post-testing data.

## Training

### Schedule

According to pre-test $TT_{5k}$ time, matched pairs of subjects were divided into consecutive-day (CD) and non-consecutive day (NCD) training groups. Independent t-tests confirmed that there were no significant differences ($\alpha$=0.05) between groups prior to training on any of the dependent variables (Table 1). Group characteristics are described in Table 2.

Training for both groups consisted of three sessions per week of high-intensity interval training (HIT) for 3 weeks (i.e., weeks 4, 5, and 6 of the experimental period). These sessions were assigned to either 3 consecutive days (CD) or 3 non-consecutive days (NCD) each week. On the 4 remaining days of each week, subjects from both groups trained lightly or rested completely. If subjects chose to ride on a non-HIT day, a low-intensity workout was prescribed to facilitate recovery. This workout consisted of 30-90 minutes of riding on flat terrain at 75-85 RPM and 65-70% of $HR_{peak}$ (Carmichael & Rutberg, 2003; Morris, 2003). Subjects were permitted one longer training ride per week, as long as it was at least 48 hours before the next HIT session. This ride was to be 2-4 hours at ~70 $PPO_a$ or 65-70% of $HR_{peak}$ (Morris, 2003; Ross, 2005). Subjects were advised to take one day of complete rest per week. Subjects were given training logs (Appendix G), in which they recorded details (e.g., mode, duration, intensity) of all training performed outside the lab during the training period, as well as other factors possibly affecting recovery and fatigue, for example, sleep patterns, and stress.

HIT Sessions

Subjects trained on CompuTrainers in groups of 2-4 in the Exercise Physiology Lab. All training sessions were monitored by at least one researcher. Individualized warm-ups and workouts based on subjects' $PPO_a$ were programmed into MultiRider software. The warm-up consisted of 8-, 5-, and 2-minute segments at 45, 60, and 75% of $PPO_a$, respectively, followed by 5 minutes at a self-selected intensity. Identical HIT workouts were prescribed to both CD and NCD, and consisted of 2.5 minutes at

Table 1

*Summary Statistics from Paired-Sample T-Tests Comparing Groups on Pre-Training Performance and Physiological Variables*

| | df | t-value | p |
|---|---|---|---|
| $v_{TT5k}$ | 13 | 0.214 | 0.834 |
| $P_{TT5k}$ | 13 | 0.069 | 0.946 |
| $VO_{2peak}$ | 13 | -0.137 | 0.893 |
| $PPO_a$ | 13 | -0.0601 | 0.953 |

Note: variables are mean velocity ($v_{TT5k}$) and mean power output ($P_{TT5k}$) during a 5-km time trial and peak oxygen consumption ($VO_{2peak}$) and peak aerobic power output ($PPO_a$) during an incremental cycle ergometer test.

Table 2

*Descriptive Characteristics of Subjects by Group and Gender*

| | | Age (yr) | Wt (kg) | $SSF_7$ (mm) | $VO_{2peak}$ ($mL \cdot kg^{-1} \cdot min^{-1}$) | $PPO_a$ ($W \cdot kg^{-1}$) | $HR_{peak}$ ($b \cdot min^{-1}$) |
|---|---|---|---|---|---|---|---|
| CD | All (N=9) | 21.9 ±3.4 | 67.9 ± 9.1 | 49.6 ±18.8 | 62.1 ±12.2 | 4.76 ±0.79 | 191 ±11 |
| | M (N=7) | 21.7 ±3.9 | 70.4 ± 8.8 | 41.8 ±12.2 | 67.0 ± 8.4 | 5.04 ±0.63 | 194 ± 9 |
| | F (N=2) | 22.5 ±2.1 | 59.1 ± 1.3 | 77.0 ± 0.0 | 44.8 ± 1.7 | 3.76 ±0.10 | 182 ±13 |
| NCD | All (N=6) | 20.5 ±1.9 | 68.9 ±10.7 | 62.0 ±32.6 | 62.1 ±14.2 | 4.74 ±0.78 | 192 ± 4 |
| | M (N=4) | 20.5 ±2.4 | 73.1 ± 7.7 | 42.5 ±14.5 | 70.4 ± 7.6 | 5.15 ±0.61 | 193 ± 5 |
| | F (N=2) | 20.5 ±0.7 | 60.5 ±13.5 | 101.0 ±11.3 | 45.5 ± 2.9 | 3.94 ±0.12 | 191 ± 4 |

Note: data (mean ± standard deviation) are age, weight (Wt), sum of seven skinfolds ($SSF_7$), and peak oxygen consumption ($VO_{2peak}$), peak heart rate ($HR_{peak}$), and peak aerobic power output ($PPO_a$) during an incremental cycle ergometer test. CD = consecutive-day training group; NCD = non-consecutive day training group.

100% of $PPO_a$, followed by 4 minutes at 25% of $PPO_a$, repeated eight times. To ensure the intended workload on the CompuTrainer, wheel speed must be at last 24 $km \cdot hr^{-1}$ (CompuTrainer, 2006). Thus, if wheel speed fell below 24 $km \cdot hr^{-1}$ or actual power output remained 30 W below the prescribed load for 10 seconds, the interval was terminated and considered incomplete. A session ended when the subject either failed twice in a row to complete an interval, or had attempted eight intervals. If a subject successfully completed all eight intervals at the prescribed power output, his load was increased by ~10 W for the next session. Subjects were advised to maintain 110-120 RPM while at 100% of $PPO_a$ (Carmichael & Rutberg, 2003); however, they were ultimately free to choose their preferred cadence. A computer screen showed time progress through both work and recovery periods while handlebar-mounted display monitors showed pedaling cadence and Polar heart rate monitors measured heart rate. Data collected during training sessions were: number of attempted ($I_{att}$) and completed ($I_{com}$) intervals, $HR_{peak}$ for each attempted interval, total time ($t_{train}$) and total work ($W_{train}$) completed at $PPO_a$, number of intervals in which subjects came within 5 $b \cdot m^{-1}$ of the $HR_{peak}$ from the incremental test ($Peak_{HR}$), as well as BL 5 minutes after the final attempted interval.

Nutritional Supplementation

Subjects drank water and Accelerade sports drink (PacificHealth Laboratories, Inc., Matawan, NJ) *ad libitum* during HIT sessions. All subjects were directed to drink a serving of Endurox R4 recovery drink (PacificHealth Laboratories, Inc.) within 30 minutes of completing each session. Accelerade and Endurox were distributed to them at no cost by the researchers. This was done to control and optimize glycogen replenishment and muscle recovery between HIT sessions (Saunders, Kane, & Todd, 2004).

## Post-Testing

During week 7, after completion of nine training sessions, all subjects visited the lab twice on non-consecutive days for post-testing. The first post-test session ($TT_{5k}$) was scheduled so as to continue the pattern of training, such that CD had at least 4 recovery days and NCD had at least two days following HIT session 9. Post-test procedures for the $TT_{5k}$ and the incremental test were the same as in pre-testing.

## Statistical Analysis

A 2 × 2 (group × time) analysis of variance (ANOVA) with repeated measures on time was run to compare CD to NCD both pre- and post-training, and to compare pre-training to post-training in both CD and NCD. Mean velocity ($v_{TT5k}$) and mean power output ($P_{TT5k}$) during the $TT_{5k}$, $VO_{2peak}$, and $PPO_a$ were analyzed. For training-session data, independent t-tests were run to compare $t_{train}$, $W_{train}$, $Peak_{HR}$, $I_{att}$, $I_{com}$, and post-session BL between groups. Correlations were explored for both groups individually and for the subject sample as a whole between the above training data and degree of improvement on dependent variables. All statistics were performed on SPSS 13.0 for Windows, and alpha was set at 0.05. All data are expressed as mean (± standard deviation).

# Chapter 4

# RESULTS

## Results of HIT

Interval training significantly improved $TT_{5k}$ performance, $VO_{2peak}$, and $PPO_a$ in CD and NCD; there were no differences between training groups (Figure 2). Absolute improvements in $v_{TT5k}$ and $P_{TT5k}$ were 0.9 (± 0.8) km·h$^{-1}$ and 17 (± 19 W), respectively. Absolute improvements in $VO_{2peak}$ and $PPO_a$ were 0.2 (± 0.2) L·m$^{-1}$, and 23 (± 15) W, respectively. Pre- and post-test data, along with percent changes are displayed in Table 3. Additional 2×2 ANOVA (group × time with repeated measures on time) revealed no difference between groups or change across time in the relative intensity maintained during $TT_{5k}$ as percentages of either $HR_{peak}$ [95.9 (± 2.5)%] or $PPO_a$ [83.8 (± 7.2)%]. Moreover, although three data points were missing, a paired t-test on 12 subjects' data showed no significant change [$t(12) = -0.503$; $p=0.624$] in BL after $TT_{5k}$ completion. Summary statistics for performance and physiological data are displayed in Table 4.

## Training Session Data

Both groups increased training load ($P_{train}$) significantly across the 3-week training phase (Figure 3). Independent t-tests revealed no differences between groups in $P_{train}$, $W_{train}$, $t_{train}$, (Figure 4), $I_{att}$, $I_{com}$, $Peak_{HR}$, or post-session BL during training. Training session summary data are displayed in Table 5. Subjects were able to complete 66.5 (± 8.5)% and 70.3 (± 6.4)% of all prescribed training in CD and NCD, respectively ($p=0.375$). Further, training group did not affect subjects' ability to complete intervals late in the week, as the progression of $W_{train}$ from the first to the third session of the week was not related to training group (Figure 5).

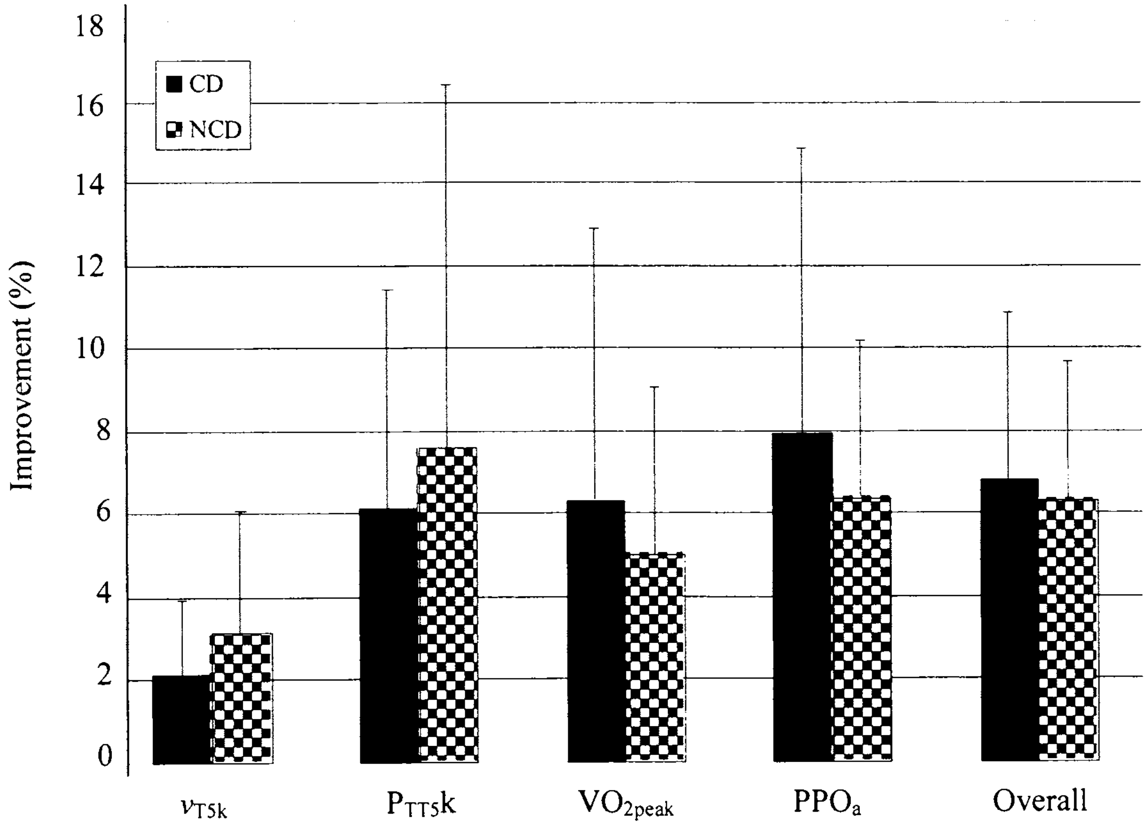


*Figure 2.* Bar chart showing similar improvement after high-intensity interval training on consecutive (CD) or non-consecutive days (NCD). Data are mean velocity ($v_{TT5k}$) and mean power output ($P_{TT5k}$) during a 5-km time trial, peak oxygen consumption ($VO_{2peak}$) and peak aerobic power output ($PPO_a$) during an incremental cycle ergometer test, and a mean improvement across these four variables (Overall). Both groups improved significantly in all areas, and there were no significant differences ($\alpha$=0.05) between groups.

Table 3

*Pre- and Post-Test Data (Mean ± SD) for Consecutive-Day (CD) and Non-Consecutive Day (NCD) Interval Training Groups with Percent Improvements*

| | | CD (N=9) | NCD (N=6) |
|---|---|---|---|
| $v_{TT5k}$ ($km \cdot h^{-1}$) | pre-test | 37.5 ± 3.5 | 37.0 ± 5.2 |
| | post-test | 38.3 ± 3.4 | 38.1 ± 4.9 |
| | % change | 2.2 ± 1.8 | 3.1 ± 3.0 |
| $P_{TT5k}$ (W) | pre-test | 278.6 ± 74.3 | 275.5 ± 97.4 |
| | post-test | 295.1 ± 76.4 | 294.2 ± 98.9 |
| | % change | 6.1 ± 5.3 | 7.6 ± 8.9 |
| $VO_{2peak}$ ($L \cdot min^{-1}$) | pre-test | 4.25 ± 1.15 | 4.34 ± 1.34 |
| | post-test | 4.48 ± 1.09 | 4.54 ± 1.34 |
| | % change | 6.3 ± 6.6 | 5.0 ± 4.0 |
| $PPO_a$ (W) | pre-test | 325 ± 78 | 328 ± 81 |
| | post-test | 348 ± 74 | 351 ± 96 |
| | % change | 7.9 ± 6.9 | 6.4 ± 3.8 |

Note: data (mean ± standard deviation) are mean velocity ($v_{TT5k}$) and mean power output ($P_{TT5k}$) during a 5-km time trial and peak oxygen consumption ($VO_{2peak}$) and peak aerobic power output ($PPO_a$) during an incremental cycle ergometer test. There were no significant differences between groups, either pre- or post-training. However, both groups improved significantly ($p<0.05$) on all test variables.

Table 4

*Summary Statistics from 2×2 Repeated Measures ANOVA (Group×Time with Repeated Measures on Time) on Performance and Physiological Variables from Pre- and Post-Testing*

| | | $v_{TT5k}$ | $P_{TT5k}$ | $TT_{5k}$ $\%HR_{peak}$ | $TT_{5k}$ $\%PPO_a$ | $VO_{2peak}$ | $PPO_a$ |
|---|---|---|---|---|---|---|---|
| Group | F(1, 13) | 0.022 | 0.002 | 0.020 | 0.593 | 0.013 | 0.004 |
| | p | 0.884 | 0.965 | 0.890 | 0.455 | 0.910 | 0.949 |
| Time | F(1, 13) | 17.709 | 12.107 | 0.878 | 0.076 | 13.892 | 33.293 |
| | p | 0.001 | 0.004 | 0.336 | 0.787 | 0.003 | 0.000 |
| Group × Time | F(1, 13) | 0.480 | 0.043 | 0.615 | 0.195 | 0.075 | 0.005 |
| | p | 0.500 | 0.838 | 0.447 | 0.666 | 0.789 | 0.946 |

Note: variables are mean velocity ($v_{TT5k}$), mean power output ($P_{TT5k}$), and percentages of peak heart rate ($TT_{5k}$ $\%HR_{peak}$) and peak aerobic power output ($TT_{5k}$ $\%PPO_a$) during a 5-km time trial and peak oxygen consumption ($VO_{2peak}$) and peak aerobic power output ($PPO_a$) during an incremental cycle ergometer test.

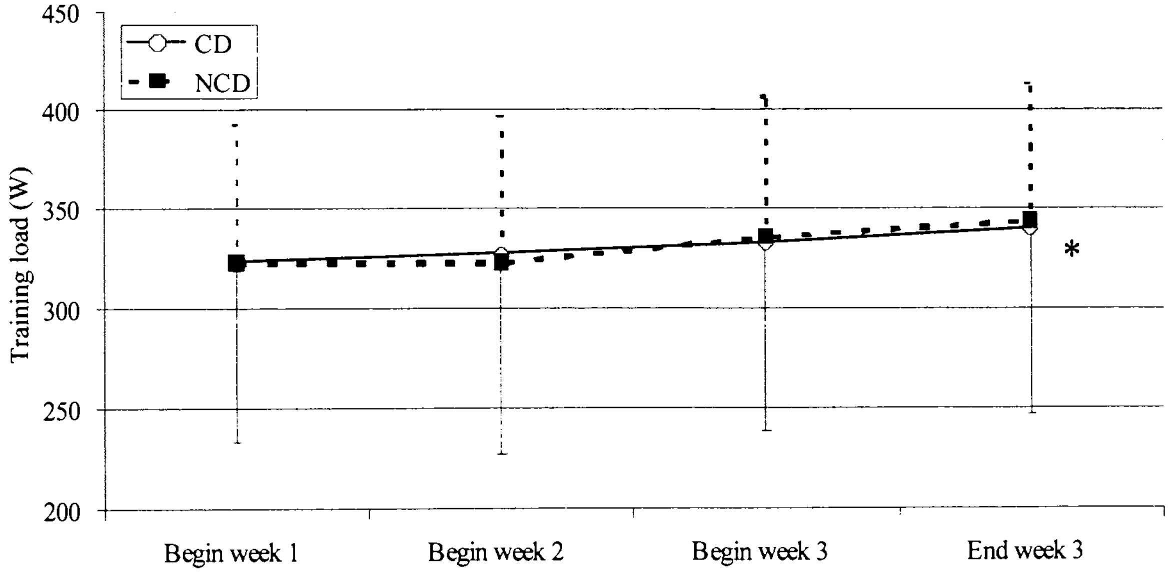


*Figure 3.* Line graph showing progression of training load ($P_{train}$) across the 3-week interval-training phase by group. Subjects increased $P_{train}$ each time they successfully completed eight intervals in a session. There were no significant differences ($\alpha$=0.05) at any point between consecutive-day (CD) and non-consecutive day (NCD) training groups, although the total increases over the 3 weeks of 4.5% and 6.4% for CD and NCD, respectively, were significant (*) [$F(1, 13)=28.4$; $p=0.000$].

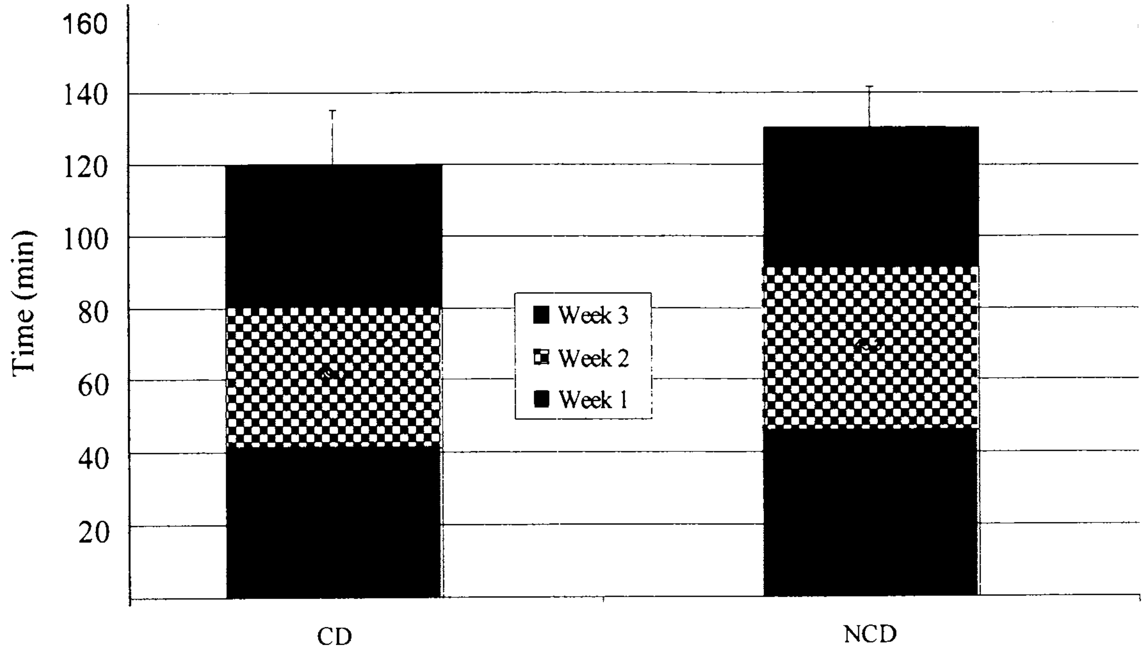


*Figure 4.* Bar graph showing total training time completed at 100% of peak aerobic power output ($t_{train}$) for consecutive-day (CD) and non-consecutive day (NCD) training groups cumulatively and by week. There were no significant differences between groups [$F(1, 13)=0.784$; $p=0.392$] or weeks [$F(2, 13)=0.364$; $p=0.698$]. Error bars indicate standard deviations for total $t_{train}$.

Table 5

*Summary Data (Mean ± SD) from Interval Training Sessions for Consecutive-Day (CD) and Non-Consecutive Day (NCD) Training Groups*

| | $P_{train}$ (W) | $t_{train}$ (s) | $W_{train}$ (kJ) | $I_{att}$ | $I_{com}$ | $Peak_{HR}$ | BL (mM/L) |
|---|---|---|---|---|---|---|---|
| CD (N=9) | 325 ±75 | 807 ±97 | 261 ±81 | 6.1 ±0.6 | 4.2 ±0.7 | 3.2 ±1.9 | 10.4 ±2.2 |
| NCD (N=6) | 330 ±95 | 843 ±76 | 279 ±91 | 6.3 ±0.6 | 4.2 ±0.5 | 3.9 ±1.4 | 11.5 ±1.4 |

Note: training sessions were up to eight 2.5-minute intervals at 100% of peak aerobic power output ($PPO_a$) separated by 4 minutes at 25% of $PPO_a$. Data are training workload ($P_{train}$), total time ($t_{train}$) and total work ($W_{train}$) at $P_{train}$, numbers of attempted ($I_{att}$) and completed ($I_{com}$) intervals, and number of times subjects came within 5 beats·min$^{-1}$ of their peak HR ($Peak_{HR}$) in the training session, and blood lactate concentration (BL) 5 minutes after completing the session.

Significant correlations between dependent variables are displayed in Table 6. Attempted intervals, $I_{com}$, $W_{train}$, $t_{train}$, and $Peak_{HR}$ were not significantly correlated with changes in performance or physiological parameters. However, improved $VO_{2peak}$ was negatively correlated with initial relative values for $PPO_a$ ($r=-0.518$; $p=0.048$) and $VO_{2peak}$ ($r=-0.638$; $p=0.010$). Improved $TT_{5k}$ performance was also negatively correlated with pre-test $P_{TT5k}$ ($r=-0.583$; $p=0.032$).

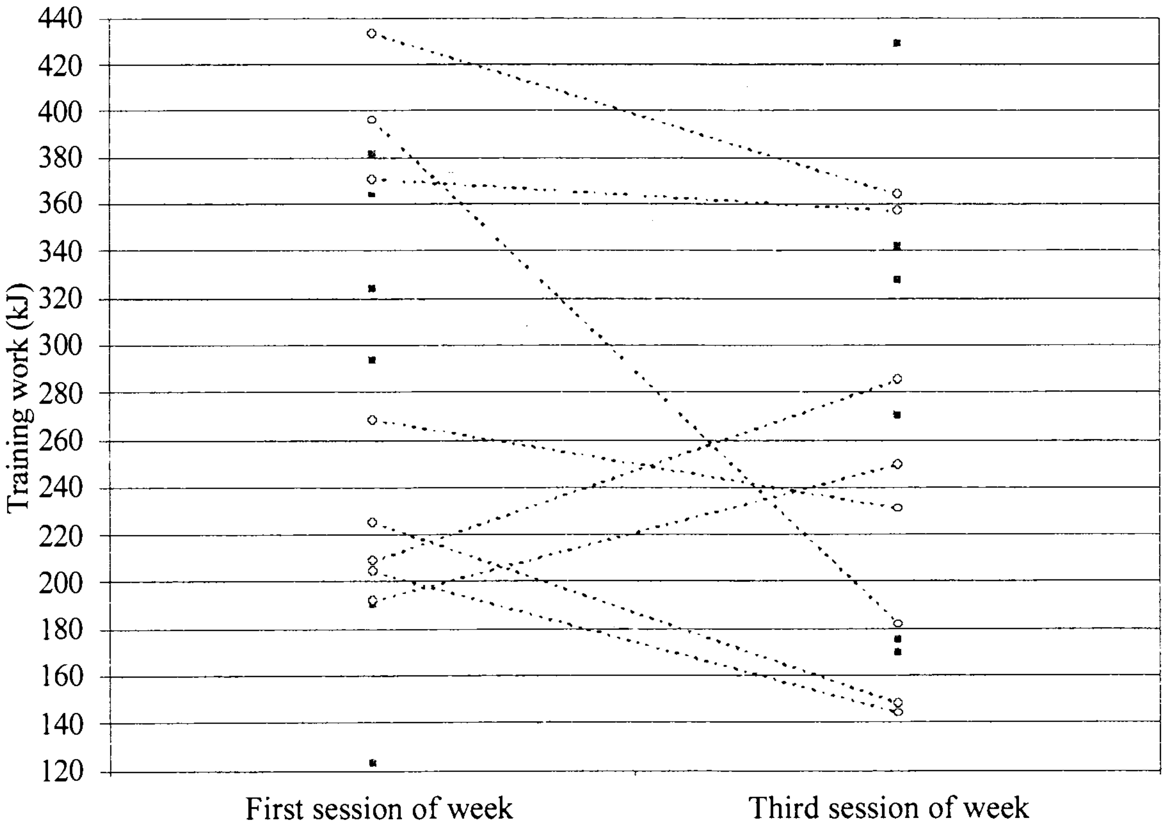


*Figure 5.* Line graph displaying high inter-subject variation in the progression between the first and third interval-training sessions of a training week in terms of work completed during the session ($W_{train}$). Black segmented lines represent subjects who trained on 3 consecutive days, while grey solid lines represent subjects who trained on 3 non-consecutive days per week. Regardless of training group, there was no consistent trend for increase or decrease of $W_{train}$ across the training week.

Table 6

*Significant Correlations ($p<0.05$) Between Dependent Variables*

| | $v_{TT5k}$ | $P_{TT5k}$ | $VO_{2peak}$ |
|---|---|---|---|
| $P_{TT5k}$ | 0.99 | — | — |
| $VO_{2peak}$ | 0.96 | 0.96 | — |
| $PPO_a$ | 0.97 | 0.98 | 0.98 |

Note: variables are mean velocity ($v_{TT5k}$) and mean power output ($P_{TT5k}$) during a 5-km time trial and peak oxygen consumption ($VO_{2peak}$) and peak aerobic power output ($PPO_a$) during an incremental cycle ergometer test.

## Chapter 5

## DISCUSSION

The purpose of this study was to compare changes in peak oxygen consumption ($VO_{2peak}$), peak aerobic power output ($PPO_a$), and 5-km time trial ($TT_{5k}$) performance in well-trained cyclists after performing a high-intensity interval training (HIT) program on either 3 consecutive days per week or 3 non-consecutive days per week. The principle findings were (1) HIT at 100% of $PPO_a$ improves $VO_{2peak}$, $PPO_a$, and $TT_{5k}$ performance, and (2) HIT is equally effective whether performed on consecutive or non-consecutive days.

### Training Effects

#### On Groups Collectively

The results of HIT at 100% of $PPO_a$ in the present study are comparable to those seen elsewhere (Laursen, Shing, Peake, et al., 2002; Smith, Coombes, & Geraghty, 2003; Smith, Dilger, & Coombes, 2000; Smith, McNaughton, & Marshall, 1999); namely, subjects improved $VO_{2peak}$, peak aerobic work rate, and time-trial performance by about 7%. Training led to increased absolute intensity in the time-trial, but there was no change in relative intensity or lactate accumulation, which suggests training-induced adaptations were largely aerobic. This finding is consistent with Laursen, Shing, Peake, et al. (2002).

In contrast to the above studies, however, the present study used a slightly more intense training program; instead of training twice per week for 4 weeks, the present subjects trained three times per week for 3 weeks. Thus, a slightly greater training load was fit within a 25% briefer time period. A possible confounding factor in this approach could be excessive fatigue limiting training effectiveness. However, Acevedo and

Goldfarb (1989) showed that three HIT sessions per week can lead to improved performance. Moreover, the present subjects did not display unusual amounts of fatigue compared to other training designs. Laursen, Shing, Peake, et al. (2002) noted that their subjects, who performed HIT sessions nearly identical to those in the present study but only twice per week, were able to complete 64% of prescribed training. Single-sample t-tests show that the present subjects did not differ significantly from that, completing 66.5 (± 8.5)% [$t(8)=0.525$; $p=0.614$] and 70.3 (± 6.4)% of prescribed training [$t(5)=2.019$; $p=0.100$] in CD and NCD, respectively.

Since previous studies had all looked at non-consecutive-day training designs, the improvement seen in the present study in NCD was not surprising. The most novel finding was that a condensed HIT block, placing intervals on 3 consecutive days per week, separated by 4 days of recovery, can be equally as effective compared to the more traditional non-consecutive day method. It has been theorized that training blocks provide a greater training stimulus and a more effective recovery period, promoting greater supercompensation (Morris, 2003). However, the present data suggest that, on average, adaptation and supercompensation are similar whether the breakdown-recovery cycles are large (i.e., block training) or briefer but more frequent (i.e., HIT on non-consecutive days).

## On Individual Athletes

In contrast to the generally similar effects of the two training designs, there was a large degree of variability in response to training. All subjects improved indeed, although many did so by a large amount in some areas but by less or hardly at all in other areas. Moreover, the area of greatest improvement was not consistent across subjects, such that standard deviations on percent improvement are rather large, sometimes as large as the mean. This was true as well in the cohort of runners in Smith, McNaughton, and Marshall (1999). In that study, authors noted that the interval sessions were very fatiguing and, like in the present study, led to a wide range of improvement (relatively large standard deviations) in 3-km running velocity [3.87 (± 3.24)%], $VO_{2peak}$ [5.32 (± 7.07)%], and $V_{max}$ [5.00 (± 3.76)%]. Likewise, in a later study, Smith, Coombes, and Geraghty (2003) saw inconsistent improvement across one group of runners on a similar training program.

In contrast to the large individual variation in the present study, the changes seen by Laursen, Shing, Peake, et al. (2002), which were similar on average to the ones in the present study, were more uniform (standard deviations ~1%). Subjects in Laursen, Shing, Peake, et al. (2002), however, were more homogeneous in terms of fitness level (i.e., smaller standard deviation for initial $VO_{2peak}$ and $PPO_a$) compared to subjects in the present study. Therefore, it is possible that initial fitness-level played a roll in the inter-subject variability in the present study. Indeed, significant negative correlations existed between $VO_{2peak}$ improvement and initial relative values for $PPO_a$ (r=-0.518) and $VO_{2peak}$ (r=-0.638). The present study may have lacked the statistical power to capture this trend among the other variables. Nevertheless, it is logical to assume that better-trained athletes would improve less from training than less-trained athletes. Thus, a more homogenous subject cohort may have yielded more consistent reactions to training.

Another factor that may have accounted for the difference in variability between the present study and Laursen, Shing, Peake, et al. (2002) is that the latter study used interval durations that were individualized based on each subject's time to exhaustion at $PPO_a$ ($T_{max}$), whereas the present study used a fixed interval duration based on an estimated population mean for this parameter. Interval duration is an important factor for eliciting $VO_{2max}$, which was the main objective of the intervals in both studies. However, since there is a large amount of inter-athlete variability in $T_{max}$ (Hill & Rowell, 1997; Harling, Tong, & Mickleborough, 2003), it is possible that the interval durations used in the present study were poorly suited for this purpose for some subjects.

Ultimately, individual athletes may be better-suited physiologically and psychologically for either consecutive or non-consecutive HIT days depending on their day-to-day stamina, resistance to breakdown, ability to recover, and mental approach to training. If this is true, choosing the appropriate design becomes crucial for maximizing training adaptations. Thus, varied responses in the present study may have been due in part to some athletes training with their individually-optimal design and others training with their individually-less optimal design. Figure 5, for example, showed how fatigue vastly decreased training performance by week's end in some athletes but had little effect on others, regardless of group. A cross-over study with consecutive-day and non-consecutive day HIT designs is warranted to see if individual athletes respond better to one design or the other.

Nonetheless, despite a wide range of responses, mean improvement in the present study was greater than 6% in both groups. Thus, HIT sessions on consecutive and non-consecutive days, when accompanied by appropriate recovery time, can be very effective in certain individual cases. Athletes interested in optimizing training should experiment with both designs used in the present study to learn how they respond individually. Unfortunately, the lack of correlation in the present study between success during training sessions and improvement make it hard to recommend indicators to look for during training. Thus, performance enhancement should be the primary determinant of training effectiveness.

## Subject Experience

Almost exclusively, subjects found training to be challenging but tolerable, and they seemed to approach all training sessions with enthusiasm and determination. Subjects appeared to be highly motivated to improve and embraced the challenge posed by the HIT. Only one subject complained of feeling overworked, and dropped out of the study after the second week. However, of all the subjects, he began the study having done the least amount of base endurance training. This along with his vigorous approach to training led to a physiological stress his body may not have been prepared to handle.

Several subjects came down with common cold-like symptom during the training period, and some training sessions were therefore rescheduled within the same week to facilitate maximum productivity from the training. Nonetheless, subjects always followed their respective training prescriptions, with properly oriented training and rest days. Sickness is of course a common challenge faced by athletes in training, and in the present study it was not considered a confounding factor, *per se*, as no training sessions were lost.

## Additional Findings

An auxiliary finding in the present study was the utility of the 5-km time trial ($TT_{5k}$) as a performance measure compared to $TT_{40k}$ used elsewhere. In the present study, $TT_{5k}$ performance improvements were due to increased absolute intensity with no change in relative intensity. This was the case as well for $TT_{40k}$ improvements seen by Laursen, Shing, Peake, et al. (2002) after similar training. Similar degrees and causes of improvement over these two distances is remarkable considering the difference between them. Although further comparison of the two TT is warranted, this cursory analysis suggests that the $TT_{5k}$ is an equally viable measure of training adaptations as the $TT_{40k}$, and may be preferred by both subjects and researchers in future studies given the difference in test duration.

## Summary

This study has increased athlete-awareness of a novel and lesser-known approach to high-intensity interval-training phases and for the first time subjected it to scientific analysis. The results show that 3 consecutive days of HIT (i.e., block training) is an equally effective means for improvement compared to a more-traditional alternating-day design, although not clearly superior. This study presents two possibilities for HIT phase design, and warrants exploration by individual athletes to find which one may be optimal. If any recommendation is to be given to coaches who are responsible for several athletes training together, non-consecutive HIT days may be slightly safer since, in the present study, the three smallest values for overall percent improvement all came from the block-training group. As well, this study suggests that 5-km time trial performance is and equally useful indicator of adaptation compared to 40-km.

# Chapter 6

## SUMMARY, CONCLUSIONS, & RECOMMENDATIONS

### Summary

This study compared two 3-week training designs employing high-intensity interval training (HIT) at 100% of peak aerobic power output ($PPO_a$). Two groups, CD and NCD, performed up to eight 2.5-minute intervals three times per week, on consecutive or non-consecutive days, respectively, and trained minimally on non-HIT days. Subjects were tested before and after training for performance in a 5-km time trial ($TT_{5k}$), peak oxygen consumption ($VO_{2peak}$), and $PPO_a$. These tests were validated beforehand and reliability was high (ICC>0.98). Nine and six subjects completed all procedures in CD and NCD, respectively.

Success during training was adequate and similar for both groups. Improvement in all dependent variables was significant following training and equal between groups. There was fairly large inter-athlete variability in the magnitude and distribution of improvement, which was not clearly correlated to degree of success during training. Further research comparing HIT designs using consecutive and non-consecutive days is warranted.

### Conclusions

The findings of this study yield the following conclusions.

1. High-intensity interval training at 100% of $PPO_a$ improves short (<10 minutes) TT performance, in addition to $VO_{2peak}$, and $PPO_a$.

2. On average, performing HIT on 3 consecutive days per week followed by 4 days of recovery elicits a similar training adaptation compared to alternating days of HIT and recovery.
3. Athletes do not react uniformly to rigorous HIT phases, some improving greatly and some very little. Thus, training optimization may not be generalizable.
4. Performing nine HIT sessions over 3 weeks yields similar improvements in TT performance, $VO_{2peak}$ and $PPO_a$ compared to eight sessions over 4 weeks (Laursen, Shing, Peake, et al., 2002).

Recommendations

This study reveals the following areas of opportunity for further research on the topic of interval training and training phase design in particular.

1. The relative effectiveness of block training compared to non-consecutive day HIT in well-trained athletes should be explored further.
2. A cross-over study comparing consecutive-day and non-consecutive day HIT should explore whether differences between these two designs exist within individual athletes.
3. Block training's effects on well-trained populations should be compared to its effects on less-fit populations
4. Physiological factors observable during training that are indicative of optimal degrees of breakdown and recovery, leading to greatest possible improvement, should be sought.

5. Possible correlations between physiological characteristics and degree of improvement following block training should be explored.

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# APPENDIX A

## Performance Test Preparation

You are scheduled to complete a maximum effort exercise test; your performance depends upon adherence to these instructions:

1. Do not perform heavy exercise in the 24 hours preceding your test.
2. Do not drink alcohol for 12 hours preceding your test.
3. Do not use caffeine (e.g., coffee) or nicotine (e.g., cigarettes) for 3 hours preceding your test.
4. Do not eat within 1.5 hours of arriving at the lab for the test.
5. Do not eat any food that may cause you discomfort the day of the test.
6. Avoid over-the-counter medications for the 12 hours preceding the test. (However, cancel appointment if you are ill and treat yourself accordingly; we can always reschedule).
7. Bring your cycling gear and bicycle, preferably with a 21-11 cassette.
8. Bring a change of clothes and food and sport drink for after the test.
9. Bring your own HR monitor if you prefer and a towel to dry off with.

Thank you for your cooperation.

## APPENDIX B

### Recovery Day Guidelines

When you are not in the lab doing interval training, your primary occupation is recovery, so as to afford maximal performance during the next interval session. These guidelines apply both to recovery days and training days outside the training session. Most of them are common sense, but are worth a reminder.

**Nutrition and hydration**

1. These workouts are intense but short. That means you will be burning less energy than you would during a 4-hour steady-state ride, yet most of the energy will be carbohydrate, namely muscle glycogen. Be aware of energy needs and be sure to replenish glycogen stores by eating ample carbohydrates (~70% of calories). Remember that glycogen is most effectively restored during the first 30 minutes following exercise, and the process occurs more slowly as time goes on. This is particularly important for athletes performing high-intensity intervals on the following day as well.
2. Protein is also important for recovery but need not be overdone (15-20% of calories).
3. Vitamins are important to defend against sickness. This is particularly true if the interval training program presents an unusually high fatigue and stress on your body.
4. Adequate iron intake is also worth thinking about. This mineral plays an important role in oxygen transport through the blood to the working muscle.
5. If you find you are sweating a lot, electrolyte replenishment may merit attention, since these are lost in sweat.
6. Drink plenty at meals and throughout the day. Your urine should be clear and copious.
7. This training block is not a good time to try to lose weight.

**Activity and exercise**

1. During this 3-week phase, the intervals must be your primary training focus. Other means of making training gains should not also occupy this phase. Rather, during any training sessions other than the prescribed intervals, bear in mind that the most important thing is to become fresh and ready again for the next interval session.
2. Auxiliary training should be low-intensity and not fatiguing.
3. Rest days will not hurt and may be most beneficial at times.

**Sleep and rest**

Adequate sleep is important during any training period and this block is no different. One full night's sleep is usually more effective than a short night and an afternoon nap. You want to wake up in the morning excited to begin another day.

## APPENDIX C

### Practice Testing and Pre-Testing: What to Expect

For this study, we will be measuring the effects of high-intensity interval training (HIT) using two cycling tests. The first is a 5-km time trial ($TT_{5k}$), the second, an incremental test for peak oxygen consumption ($VO_{2peak}$) and peak aerobic power output ($PPO_a$). Both should require one hour in the lab, including warm-up and other standard procedures. Tests are performed with your own bike. Bring it and any related things you need to ride. Since one athlete can warm up while another is testing, sign-ups are for one-hour blocks, on the half-hour. Please read and abide by the guidelines on the hand-out titled "Performance Test Preparation." If you're coming from off campus, you will be allowed to park in front of the Center for Health Sciences (CHS) building in the spots labeled for PT, OT, and speech clinics (safely, as long as I have your car make/model and license plate number). Once you enter the lab, the procedure will be as follows.

**Both tests:**

Give your bike to a lab technician to mount onto a CompuTrainer.
Change into cycling shorts (you may also do this ahead of time of course).
Have your weight taken.
Fill out 24-hour history questionnaire.
Put on shoes, heart-rate monitor, jersey, etc.
Warm up, as follows:

| | |
|---|---|
| 8 mins @ 1.0 $W \cdot lb^{-1}$ (men) | 0.8 $W \cdot lb^{-1}$ (women) |
| 5 mins @ 2.0 $W \cdot lb^{-1}$ | 1.0 $W \cdot lb^{-1}$ |
| 2 mins @ 3.0 $W \cdot lb^{-1}$ | 1.2 $W \cdot lb^{-1}$ |

5 mins self-selected intensity, including three ~20-second sprints at 100+ RPM. During the third, the CompuTrainer's roller will be re-calibrated.

**$TT_{5k}$:**

Select starting gear (the computer-simulated course has a starting ramp)
Begin on start command.
Ride as fast as you can.
Note: during the TT, you will be verbally updated on your elapsed distance approximately every 500 as well as the final 250 and 100 meters. You will be expected to regulate your intensity using your heart rate (a TT of this distance should be ridden above ~90 of $HR_{max}$) and cadence.
You will not be aware of your speed or elapsed time.

**PPO:**

Be fitted with the metabolic analysis equipment. This consists of head gear designed to support a plastic hose running between a mouthpiece and the analyzing chamber, and a nose-clip to make sure that all expired air goes into the hose.
Begin test when ready.
Test protocol is as follows:

Beginning workload is 2.5 W per kg of your body weight (1.5 $W \cdot kg^{-1}$ for women)
After 30 seconds, load increases 10 W. Spin up cadence to prepare.
Every 30 seconds, load increases another 10 W, until completion of test.
The tests ends when you absolutely cannot go any further, which is usually after 10-12 minutes.

When you think you've reached the limit of your ability, try to complete the 30-second stage you're in before you quit.

**Both tests:**

Have blood-lactate tested, 5 minutes after completing test.
Towel off and cool down, as you so desire. Nab some free Accelerade or Endurox.

# APPENDIX D

## Training Period: What to Expect

Training will consist of three interval sessions per week. Each will involve, following warm-up, up to eight 2.5-minute intervals at your peak aerobic power ($PPO_a$), separated by 4 minutes at ~25% of $PPO_a$. Depending on which group you get assigned to, you will perform these sessions on either 3 consecutive days or 3 non-consecutive days.

The lab can be available for training at many different times of day (early morning, mid morning, afternoon, evening). We want to accommodate everyone's schedule if possible. You should however always train at approximately the same time of day. Training sessions will be offered in 2-hour blocks (e.g., 6-8, 10-12, 12-2, 2-4, 4-6, 6-8 as necessary), and should not take longer than that. However, if time requires and space allows, you may come off the hour.

The intervals will be intense and taxing, albeit short. As this should be your only ride of the day, and riding on off-days should mostly be light, your training volume will be fairly low during this specialization period. However, this is no cause for alarm, as the volume of high-intensity training will be great, and performance improvements are practically guaranteed.

Training on non-interval days should basically be light, geared toward recovering or staying fresh for the next interval session. The intervals are your central focus. You will be instructed to limit training to 30-90 minutes on flat terrain, at 75-85 RPM and 65-70% of peak HR. However, you will be permitted one longer, more taxing ride per week, as long as it is no less than 48 hours before your next interval session. This ride should be 2-4 hours at ~70 $PPO_a$ or 65-70% of peak HR, and we will try to organize these as group rides for as many of you as possible. One day of rest per week is recommended.

## APPENDIX E

## Informed Consent Form

**Effects of high intensity interval training on aerobic performance**

1. **Purpose of the Study:** Current training theory informs athletes to complete blocks of similar intervals; each block lasts about 3 weeks. Current training theory also informs athletes to complete about 3 interval sessions per week or about 9 sessions each block. There is no consensus, however, on when in the week the intervals should be performed to optimize results. Some coaches suggest that each interval session should be separated by at least one recovery day, i.e., each week's intervals should be completed on alternating days; other coaches suggest that the intervals should be grouped, i.e., each weeks' intervals should by completed on consecutive days. The purpose of this project is to see which training method works best.

2. **Benefits:** You will benefit from participating in the study because you will learn what your $VO_2max$ is. You will also get very fit, learn which type of interval training maximizes performance, and receive professional coaching during the project.

3. **Your Participation** requires you to be at least 18 years old, actively racing, and currently trained. Prior to beginning training, you will report to the lab on two days: on one day you will complete a $VO_2max$ test and the other a 5 km TT. Two days will separate each test. You will be given written instructions on how to come prepared for them. Prior to each test, you will be fitted with a chest strap so that HR can be monitored telemetrically. After the chest strap is fitted, you will warm-up as directed for approximately 15 min on your bicycle, which will be attached to a CompuTrainer. During the warm-up and the test, a fan will cool you. At the end of the warm-up on the $VO_2max$ day, you will be fitted with a headgear, which will hold a mouth piece that is attached to a hose from which expired ventilatory gases will be measured. You will also wear a nose clip. During the $VO_2max$ test, the initial load will be 2.5 watts per kg of body mass for men and 1.6 watts per kg of body mass for women at your freely chosen cadence. During the time trial, you will pedal the 5 km as fast as you can in whatever gear and cadence you prefer. After each test is over, which is when you reach volitional exhaustion or have pedaled 5 km, respectively, you will cool-down at an easy pace for 5 min. At the end of the cool-down, one of your fingertips will be sterilized with an alcohol prep pad. Afterwards, a sterile lancet will be used to make a small puncture in the fingertip so that a 25 μl blood sample can be obtained for blood lactate analysis. After training, you will complete both tests again. Each testing day will take about 1 hr.

After the pre-training testing, you will be separated into two groups, which will be balanced based on 5 km time trial scores. Both groups will then complete 3 interval training sessions per week for 3 weeks. In each session, you will complete 5 to 8 intervals at 100% of peak power, as measured during the max test. The intervals will last 2.5 min and will be separated by an active rest period or approximately 5 min. One group will complete the intervals on alternating days, whereas the other group will complete them on consecutive days. You will wear a heart rate monitor during training, which will take place in the lab. You will ride your bike for the interval sessions; the bike will be attached to a wind trainer. The lab will be cooled during the training sessions; you will be encouraged to drink during training and will receive nutritional counseling as well. When you are not training in the lab, you can ride your bike as prescribed by me based on the your needs and experience level. Each lab training session will last about 2 hr. Total participation time for the project is 22 hr. You must be at least 18 years old, actively racing, and currently trained to participate.

**Initials:**_________________________________________________

**4. Risks of Participation:** The risks involved in this project are no greater than the risks you freely assume when you train or race. These risks include skeletal muscle injury and possibly a cardiac event, which could be fatal. The chances of a cardiac event are low in your age group. You may also have sore muscles 24 to 48 hours after the tests or training; the fingertip that is lanced may also be tender for a few days. To minimize the risks, you will warm-up and cool-down before and after each test and training session. If you feel poorly during the test or training session, you may terminate it at any time. In the event that there is an injury or cardiac event, standard first aid procedures will be promptly administered by me. I will call 911 to seek additional assistance if warranted.

**5. Compensation for Injury:** If you suffer an injury that requires any treatment or hospitalization as a direct result of this study, the cost of such care is your responsibility. If you have insurance, you may bill your insurance company. Ithaca College and the investigator will not pay for any care, lost wages, or provide other compensation.

**6. If you would like more information** about this study at anytime prior to, during, or following the data collection, you may contact Micah Gross at mgross1@ithaca.edu or 262-6280. You also can contact Tom Swensen at tswensen@ithaca.edu or 274.3114.

**7. Withdrawal from the study:** Participation in this study is voluntary and you may withdraw at any time if you so choose. You will not be penalized for withdrawing.

**8. Confidentiality:** Information gathered during this study will be maintained in complete confidence. Only the I will have access to this information, which will be stored in a locked cabinet in room 320 in the Center for Health Sciences at Ithaca College or on password protected computer. You and your name will never be associated with this information in any future disclosures.

I have read and understood the above document. I agree to participate in this study and realize that I can withdraw at anytime. I also understand that I can and should address questions related to this study at any time to Micah Gross or Tom Swensen. I also verify that I am at least 18 years of age.

________________________________

Your Name (please print)

________________________________

Your Signature Date

## APPENDIX F

## Medical History and Health Habit and 24-Hour Recall Questionnaire

**Name:**__________________________________

**Age:**__________

**Weight:**_______

**Sex:**__________

1. **Medical/Health History: Check if you ever had?**

| | |
|---|---|
| Heart disease/ Stroke | |
| Heart Murmur | |
| Skipped, rapid beats, or irregular heart rhythms | |
| High blood Pressure | |
| High Cholesterol | |
| Rheumatic Fever | |
| Lung Disease | |
| Diabetes | |
| Epilepsy | |
| Injuries to back, hips, knees, ankles, or feet | |

**Other conditions/comments:**

**Present Symptoms: Check within the box if you have you had these symptoms within the last 6 months?**

| | |
|---|---|
| Chest Pain | |
| Shortness of Breath | |
| Lightheadedness | |
| Heart Palpitations | |
| Loss of Consciousness | |
| Illness, surgery, or hospitalization | |
| Ankle/Leg swelling | |
| Joint/muscle injury requiring medical treatment | |
| Allergies (if yes please list under comments) | |

**Other conditions/comments:**

**List all medications presently taking:**

2. **Training habits:**

Do you presently train on your bike? Yes No

How many times a day do your work out?

How many days a week do you work out?

Describe your typical training week:

Did you ever have or you do you currently have discomfort, shortness of breath, or pain when exercising? (circle one)

**Yes** **No**

3. **Have you consumed alcohol in the last 12 hours? (circle one)**

   **Yes** **No**

4. **Have you used caffeine (e.g., coffee) or nicotine (e.g., cigarettes) in the last 3 hours? (circle one)**

   **Yes** **No**

5. **Did you eat any food in the last 3 hours? (circle one)**

   **Yes** **No**

6. **Did you exercise in the last 24 h ours? (circle one)**

   **Yes** **No**

# APPENDIX G

Appendix G: Training Log

| | |
|---|---|
| **Monday** (d/m/y) | **Wednesday** (d/m/y) |
| HR upon waking: Weight: | HR upon waking: Weight: |
| *Workout 1*: | *Workout 1*: |
| | |
| | |
| | |
| Total time (min): | Total time (min): |
| Distance: | Distance: |
| | |
| *Workout 2* | *Workout 2* |
| | |
| | |
| | |
| Total time (min): | Total time (min): |
| Distance: | Distance: |
| | |
| | |
| **Tuesday** (d/m/y) | **Thursday** (d/m/y) |
| HR upon waking: Weight: | HR upon waking: Weight: |
| *Workout 1*: | *Workout 1*: |
| | |
| | |
| | |
| Total time (min): | Total time (min): |
| Distance: | Distance: |
| | |
| *Workout 2* | *Workout 2* |
| | |
| | |
| | |
| Total time (min): | Total time (min): |
| Distance: | Distance: |

| | |
|---|---|
| **Friday** (d/m/y) | **Sunday** (d/m/y) |
| HR upon waking: Weight: | HR upon waking: Weight: |
| *Workout 1*: | *Workout 1*: |
| | |
| | |
| | |
| Total time (min): | Total time (min): |
| Distance: | Distance: |
| | |
| *Workout 2* | *Workout 2* |
| | |
| | |
| | |
| Total time (min): | Total time (min): |
| Distance: | Distance: |
| | |
| | |
| **Saturday** (d/m/y) | **Weekly Summary** |
| HR upon waking: Weight: | Total bike time (min): |
| *Workout 1*: | Total bike miles: |
| | On bike strength time (min): |
| | Weight lifting time (min): |
| | Other work out time (min): |
| Total time (min): | Total time working out (min): |
| Distance: | |
| | |
| *Workout 2* | ***Notes:*** |
| | |
| | |
| | |
| Total time (min): | |
| Distance: | |