Using heart rate variability to evaluate training in adolescent swimmers: A series of case studies

Ann Somerville

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Using Heart Rate Variability to Evaluate
Training in Adolescent Swimmers, a Series of Case Studies

by

Ann Somerville

B.S. Michigan State University, 2003

presented in partial fulfillment of the requirements

for the degree of

Master of Science

The University of Montana

2005

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Date

5-24-05
USING HEART RATE VARIABILITY TO EVALUATE TRAINING IN ADOLESCENT SWIMMERS, A SERIES OF CASE STUDIES

Chairperson: Steven E. Gaskill

Monitoring the effectiveness of an aerobic training program has always been a difficult task for coaches and athletes. The purpose of this study was to use heart rate variability (HRV) and the fatigue index test (FIT) to identify patterns that appear related to overreaching (OR) and overtraining (OT).

Members (n=14) of the competitive Missoula Aquatic Club (MAC) served as subjects. Subjects were between 12 and 18 years of age at the initiation of the observation period. Resting HRV and FIT were tested weekly for 10 weeks using the Polar S810i heart rate monitor. Subjects completed weekly training logs recording illness, swim training duration, intensity, physical activities outside swimming, and daily perception of tiredness. HRV was analyzed using the Polar Precision Performance Software. A case study research design was utilized.

All athletes completed similar training under the same coach. Three basic patterns of stress response were observed and defined: 1) OT, 2) Effective training (ET), and 3) Under training (UT). Seven athletes were classified as OT showing low mean values for HF-HRV and high FIT values with a small range. Five athletes were classified as ET demonstrating a wide range in HF-HRV and FIT values. ET athletes also displayed moderately high FIT values. One athlete was classified as UT showing consistently high mean HF-HRV values with a small range. UT athlete also displayed moderately high FIT values.

Findings indicate significant individual variability in adaptation to training and overall tolerance of external and internal stressors. Athletes require individualized training programs in addition to frequent monitoring to prevent OT and promote ET.
ACKNOWLEDGEMENTS

Thank you to my committee members, Dr. Steven Gaskill, Dr. Merle Farrier, and Dr. Lew Curry. Your positive energy, insight, and knowledge made this project possible.

Thank you, Steve, for your constant support and guidance throughout this project. You made this project an enjoyable and rewarding experience. Thank you for your enthusiasm and always finding the time for me. Thank you for mentoring me throughout the past two years of graduate school and making the experience challenging, fulfilling, and a lot of fun. You’re an inspiration to us all.

Thank you to the Missoula Aquatic Club (MAC) for your willingness to take part in this project and your positive attitudes throughout the duration of the study. Thank you, Marion, your insight, eagerness, and enthusiasm made this project possible.

To my fellow graduate students: Thanks for your constant support!

To my family: Thanks for always being there for me and supporting me throughout my graduate experience. You inspire me. To my sister: Thanks for always being there. Thanks for your positive energy and motivation. To the MWTC: thanks for your constant support throughout the past two years both on and off the track.

To my fiancé: Thanks for always believing in me. Thanks for being there for me even when thousands of miles separated us. Thanks for your constant support of my goals and aspirations. I look forward to the next “M” we will climb together.
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CHAPTER ONE: INTRODUCTION

Introduction

The purpose of physical training for athletes is to stress physiological systems more than normal to elicit a positive response. This increased training load causes a brief period of decreased performance termed over-reaching. Over-reaching is an acute training stress that must be applied in order for the athlete to experience positive training effects and achieve peak performance with structural training overload causing over-reaching, followed by appropriate rest period the athlete will normally progress in training. Moreover, if proper recovery is frequently not allowed before a new training stress is applied overtraining may result (Kuipers and Keizer 1988; Uusitalo 2001).

Overtraining is a serious problem within the competitive athletic population (Uusitalo 2001). This debilitating condition may cause decreased performance in competition and training, loss of an entire competitive season, and pronounced decrement in overall health (Kuipers and Keizer 1988; Lehmann, et al. 1998; Uusitalo 2001). As stated by Lehmann et al “these are symptoms to be respected, not problems to overcome” (1998,1144). The overtraining syndrome or staleness results from a long-term imbalance between training and recovery and external and internal stressors.

The diagnosis of overtraining is a complicated process due to inexact diagnosis criteria, which makes detection by physicians, coaches, trainers and researchers very difficult (Hedelin, et al 2000a). Many other specifics concerning the pathophysiological mechanisms of overtraining are to this day still very unclear. Furthermore, overtraining in athletes is a challenging area of study since there are virtually no experimental models of the condition (Foster 1998; Sacknoff, et al. 1994).
Additionally, the vulnerability of overtraining in athletes' may be quite different under similar training stress factors, indicating significant individual variability in adaptation to training, exercise capacity, overall stress tolerance, and non-training stress factors (Lehmann, et al. 1993). This clearly suggests the importance of individual athlete evaluation by coaches, trainers, physicians, and researchers.

The simple, non-invasive technique of heart rate variability (HRV) is a promising new tool, which may aid in the prevention and early detection of overtraining. A dynamic window into the autonomic regulation of the cardiovascular system is provided through this measurement of instantaneous beat-to-beat (R-R interval length) variations. Heart rate variability distinguishes between SYM and PSYM nerve activity through analysis in the time and frequency domains thus allowing for evaluation of autonomic modulation. An optimal level of HRV is needed for proper physiological functioning. Heart rate variability is primarily a result of SYM and PSYM balance. Previous research has shown that profound autonomic imbalance is associated with increased mortality after a myocardial infarction (Kleiger, et al. 1987).

Previous research evaluating overtraining and its effects on HRV in the athletic population is inconsistent, mostly due to the small number of studies. Additional well-controlled studies are needed to further investigate the effects of a high training load on HRV before solid conclusions can be made. Furthermore, the pre-to post-test group means design dominates previous research. This design limits interpretation of individual differences. Individual athletes adaptation to training and non-training stressors vary greatly making it imperative that this population receive individual assessment.
Purpose

The purpose of this study is to investigate and identify individual patterns between HRV and training load and external and internal stressors in competitive high school swimmers and to explore the use of HRV as a promising tool to aid in the prevention and early diagnosis of overtraining. Specific HRV variables to be measured include: the standard deviation of the normal to normal R-R interval (SDNN) and the square root of the mean squared successive differences between adjacent R-R intervals (RMSSD) in the time domain. Additionally, high frequency (HF) power, low frequency (LF) power and the HF/LF ratio in the frequency domain will be evaluated.

Problem Statement

Athlete overtraining is a serious problem resulting in illness and long periods of lost training time and decreased performance. Identifying markers, which indicate over-reaching and overtraining, would be extremely valuable for coaches and athletes. If overtraining can be predicted from these markers, HRV is a promising marker of physiological stress within individuals. Overtraining believed to be extremely variable across individuals, but predictable within an individual. Unfortunately, reliable markers to predict overtraining before clinical symptoms appear have proven elusive.

Individual patterns may exist between specific HRV parameters and training load and non-training stressors in competitive high school swimmers, which then may aid in validating the use of HRV as a tool for prevention and early diagnosis of overtraining in the athletic population. This study will weekly observe the HRV parameters within each
subject for a 10 week period including periods of high intensity training, taper, and competition and evaluate training load and other stressors that effect HRV.

*Research Question*

Is HRV sensitive to changes in training loads or is there a training load threshold that causes expected changes in HRV suggesting over-reaching and possible overtraining? If this question can be answered, then further research can evaluate the use of HRV as a diagnostic tool for the early detection and prevention of overtraining in athletes.
Definition of Terms

**Autonomic Nervous System (ANS).** The visceral or involuntary nervous system is composed of three major components: 1.) The sympathetic 2.) parasympathetic and 3.) enteric nervous system. Heart rate variability (HRV) is associated with the sympathetic and parasympathetic divisions of the ANS which regulate the function of the organs involved in maintaining the consistency of the internal environment of the body. Is one of the primary effectors of homeostasis (Johnson, 2003).

**Frequency Domain.** The domain in which HRV is quantified by plotting the frequencies over which the R-R interval length changes.

**Heart Rate Variability (HRV).** The variation in time between normal R-R intervals (Achten and Jeukendrup, 2003).

**High Frequency Power (HF).** A HRV parameter in the frequency domain evaluated at 0.15-0.40Hz (frequency cycles taking 7 to 25 seconds to complete) which assesses parasympathetic modulation.

**Low Frequency Power (LF).** A HRV parameter in the frequency domain evaluated at 0.04-0.15Hz (frequency cycles taking 2.7 to 7 seconds to complete) which assesses sympathetic modulation.
**Over-reaching.** Mild, short-term overtraining due to overload by an increase in frequency, duration, and/or intensity of training. During over-reaching, recovery and adaptation does not take place within the anticipated time (Kuipers and Keizer, 1988).

**Overtraining syndrome.** Chronic overtraining resulting in the occurrence of physical, behavioral, and emotional symptoms that may require an extended recovery period (Kuipers and Keizer, 1988).

**Parasympathetic (PSYM).** One of the main components of the ANS which aids in maintaining homeostasis within the body. The PSYM nerves serve a ‘housekeeping’ role. Their effects include resting bradycardia, dilation of blood vessels, and increase in gastrointestinal motility (Johnson, 2003).

**pNN50.** The percentage of adjacent R-R interval differing more than 50ms as evaluated in the time domain.

**Power Spectral Analysis.** Sinusoidal components formed through the decomposition of any steady, stationary, fluctuating time-dependent signal. (Aubert, 2003).

**R-MSSD.** The square root of the mean differences between adjacent R-R intervals as assessed in the time domain.
SDNN. The standard deviation of all normal to normal R-R intervals evaluated in the time domain.

Sympathetic (SYM). One of the main components of the ANS which aid in maintaining homeostasis within the body. The SYM nerves induce 'fight or flight' actions consisting of exciting the heart, constricting blood vessels, decreasing gastrointestinal motility, and constricting sphincters (Johnson, 2003).

Time Domain. The domain in which HRV is quantified by plotting the R-R intervals in milliseconds (ms) against time (Achten and Jeukendrup, 2003).

Training Load. Total training stress including frequency, duration, and intensity of training. In this study the terms are used as followed:

1. Training Frequency. The number of swim sessions per day.
2. Training Duration. The number of yards and minutes per swim session.
3. Training Intensity. The athlete's and coaches' subjective interpretation of swim sessions as a percentage of easy, moderate, and hard.
CHAPTER TWO: REVIEW OF LITERATURE

This review of literature examines prior research related to heart rate variability (HRV) in the athletic population. The literature review is organized into four sections: 1.) HRV related to overtraining, 2.) HRV in athletes with different training loads in cross-sectional and longitudinal studies, 3.) Influences of HRV parameters in athletes with varying training status, 4.) HRV sampling procedures.

Overtraining and Effect on HRV

Increasing intensity, frequency and/or duration more than the athlete is currently doing, is essential for the athlete to achieve peak performance. This concept is referred to as over-reaching or supercompensation (Kuipers and Keizer 1988). However, if adequate time for adaptation to increased training is not taken before a new stimulus is applied progressive physiological imbalance will occur (Uusitalo 2001). This process then leads to the condition of overtraining.

The ‘overtraining syndrome’ in athletes results from long term exhaustion due to an imbalance between training, external and internal stressors, and recovery (Aubert 2003; Kuipers and Keizer 1988; Lehmann, et al. 1993). If the athlete is not allowed proper recovery between stressors, disturbance of physiological homeostasis will persist resulting in decreased performance along with physiological and psychological symptoms (Kuipers and Keizer 1988; Lehmann, et al. 1993; Uusitalo 2001). Some clinical symptoms of overtraining include changes in mood state, long-term muscle soreness, sleeping disorders, depression, and hormonal imbalances. Furthermore, previous research has shown that in endurance athletes training volume and intensity of
the training stimulus can both improve and worsen moods of energy and fatigue (Morgan, et al. 1987; Raglin, et al. 1991).

Homeostatic imbalance results in a disturbance of the autonomic nervous system which may be caused by overtraining (Lehmann, et al. 1993, 1998; Uusitalo 2001). In 1976, two types of overtraining theories were defined by Israel 1.) sympathetic (SYM) and 2.) parasympathetic (PSYM) both resulting from an imbalance of the autonomic nervous system (Uusitalo 2001). However, conclusive results in support of Israel’s overtraining theories are limited.

It has been suggested that HRV indices, which are closely related to parasympathetic and sympathetic activity, could be used in prevention and early diagnosis of overtraining (Achten and Jeukendrup, 2003). However, the research is sparse and no conclusive results can be drawn. Previous studies conducted by Bosquet et al (2003) and Hedelin et al (2000c) show no changes in HRV parameters. Other overtraining studies have shown decreases (Pichot, et al. 2000; Uusitalo, et al. 1998, 2000) and increases (Hedelin, et al. 2000a) in HRV. Refer to figure 1 for a summary of these studies.

A case study was conducted on a highly trained adolescent cross country skier showing the athlete’s baseline HF power was initially high and following several months of intensive training continued to increase. After a two month recovery period the HF power returned to a lower value. The athlete was diagnosed with overtraining syndrome after experiencing decreased performance in competition and at standardized cycle work, breathlessness during training sessions, and increased depression and tension scores in the profile of mood states assessment (Hedelin, et al. 2000a). In another study
researchers observed the differences between a low intensity training group (n = 6) and a high intensity training group (n = 9) of female endurance trained athletes. Following the heavy training period, Low Frequency (LF) power significantly increased in the experimentally trained group (ETG) and 5 of the athletes were diagnosed as being overtrained. The criteria of overtraining included decreased maximal oxygen uptake by at least 2 ml·kg⁻¹·min⁻¹, decreased maximal treadmill performance, unwillingness to train and the feeling of inability to go on training (Uusitalo, et al. 1999).

Overall, the number of studies which have addressed the effects of highly intensive training on HRV in the athletic population is relatively small and the results are inconclusive. Additional well-controlled, longitudinal studies are needed before conclusions on HRV as an effective diagnostic tool of early overtraining can be made.

Longitudinal: Effect of Exercise Training on HRV in the Athletic Population

It has long been recognized, that highly trained endurance athletes may have profound resting bradycardia. One proposal for the significant decrease in resting heart rate (HR) is enhanced vagal tone to the sinus node (Stein et al, 2002). The role of the autonomic nervous system in reducing resting heart rates is still controversial. However, HRV has the potential to be a means for monitoring sympathetic and parasympathetic activity (Malik, et al. 1996). Several studies have undertaken the challenge to observe the effect of chronic and acute aerobic training sessions on HRV measurements in order to better understand sympathovagal modulation. Previous research is inconsistent showing increases (De meersman 1992; Hedelin, et al. 2000a; Hedelin, et al. 2000b), decreases (Hedelin, et al. 2000b; Pichot, et al. 2000; Uusitalo, et al. 1999) and no change.
(Bonaduce, et al. 1998; Bosquet, et al. 2003; Hedelin, et al. 2000c) in HRV following aerobic training in the athletic population. Figure 2 shows the expected results of HRV indices following positive training effects, over-reaching, SYM overtraining, and PSYM overtraining.

The autonomic nervous system (ANS) consists of two divisions: 1.) the sympathetic (SYM) branch and 2.) the parasympathetic (PSYM) branch (Kamath and Fallen 1993). The two branches are made up of efferent and afferent nerves which are concerned predominantly with regulation of bodily functions. Moreover, SYM and PSYM actions are complementary. In relation to the heart, the PSMP nerve fibers terminate at the sinoatrial and atrioventricular nodes, atrial and ventricular myocardium, and coronary vessels. The SYM nerves terminate at the sinus node pacemaker, atria, ventricles, coronary vessels, and conduction system (Aubert, et al. 2003; Kamath and Fallen 1993).

Since the action of the heart is modulated by the autonomic portion of the central nervous system, HRV serves as a revealing window into overall autonomic activity. The moment-to-moment variation of heart rate is dependent on sympathetic and parasympathetic balance (Kamath and Fallen 1993; Yamamoto, et al. 1991). When average heart rate is calculated these variations are easily overlooked and irregular at rest. For efficient physiological functioning, an optimal level of instability of inter-beat intervals is vital. However, too little or too much variation indicates autonomic imbalance (McCraty 2001). Previous research has shown decreased HRV is associated with increased mortality after myocardial infarction (Kleiger, et al. 1987). Furthermore, average heart rate measures the net effect of sympathetic and parasympathetic
innervation, while HRV differentiates sympathetic and parasympathetic contributions to cardiovascular control through the time and frequency domain (Aubert, et al. 2003; McCruty 2001).

**Time and Frequency Domain**

HRV is quantified in two domains: 1) time and 2) frequency. In the time domain, the R-R interval is plotted in milliseconds (ms) against time and the main disadvantage is the decreased discrepancy between PSYM and SYM activity. The most frequently used time domain parameters are the standard deviation of the normal to normal R-R intervals (SDNN), the square root of the mean squared successive differences between adjacent R-R intervals (RMSSD), and the percentage of adjacent R-R intervals differing more than 50ms (pNN50) (Aubert, et al. 2003; Achten and Jeukendrup 2003; Malik, et al. 1996). These parameters are adequate estimates of short-term (<5min) HRV, RMSSD, and pNN50 are highly correlated (Malik et al, 1996).

In contrast to the time domain, the frequency domain is plotted as the frequency over which the length of the R-R interval changes (Achten and Jeukendrup 2003). To determine parameters in the frequency domain, power spectral analysis is performed on the time domain (R-R) data and the time-dependent signal is decomposed into its sinusoidal components (Aubert et al, 2003). The main spectral components of short-term HRV recordings in the frequency domain are very low frequency (VLF) power (≤ 0.04Hz), low frequency (LF) power (0.04-0.15Hz), and high frequency (HF) power (0.15-0.4Hz) (Malik et al, 1996). These frequency domain parameters are usually expressed in absolute values of power (milliseconds squared). PSYM and SYM

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influences on HRV are reflected in the peaks at different frequencies (Achten and Jeukendrup 2003). The neural mechanisms responsible for spectral band fluctuations are PSYM and SYM activity. PSYM innervation is considered the main component for HF power, while SYM activity dominates LF power (Achten and Jeukendrup 2003).

De Meersmen (1992) found that parasympathetic tone was significantly augmented with a +23% change in the R-R variation (ms) along with a significant increase in maximum oxygen consumption in nine collegiate track runners following an 8 week, high intensity training program. Training sessions were held 7 days a wk, for 1.5-2 h per session. Training intensity was at 75% of maximum heart rate 4-5 sessions a week, along with 2 sessions a week at 85%-90% of predicted maximum heart rate. Similar parasympathetic alterations were also observed by Hedelin et al (2000b) in 17 national junior level cross-country skiers following 7 months of organized training. In the entire group, total HRV increased at rest following the training period. Researchers also observed decreased LF power for the entire group following a tilt. Furthermore, the athletes run time to exhaustion significantly increased along with a decrease in submaximal heart rate demonstrating a positive training effect.

In detrained athletes, Bonaduce et al (1998) observed increased cardiac parasympathetic modulation compared to untrained controls of similar age using a 24 h HRV analysis. However, following 5 months of vigorous training, consisting of 26 h · wk⁻¹ of cycling and 5 h · wk⁻¹ of aerobic training, 15 elite level cyclists showed no further increase in parasympathetic modulation even with an additional decrease in resting heart rate. Overall, both time and frequency measures of HRV remained unchanged after
intensive training, but left ventricular mass, dimensions, and aerobic capacity increased. It was concluded that the further decrease in heart rate be attributed to other mechanisms such as a decrease in intrinsic heart rate.

Additional studies with acute training duration have also produced conflicting results. Researchers observed no change in HRV parameters in 9 elite canoeists after 6 days of training with an overall training load increase of 50% consisting of 25% high-intensity, 65% endurance, and 10% strength training (Hedelin, et al. 2000c). Similarly, HRV was not affected in a study conducted by Bosquet, et al. (2003) on 9 endurance athletes after a 4 week training period with a total training load increase of 100%. Furthermore, Uusitalo et al (1999) observed an increase in LF power and a decrease in HF power indicating a withdrawal of parasympathetic activity in endurance training athletes after a 6-9 week overtraining protocol. Five out of nine endurance trained athletes were diagnosed as overtrained following the heavy training period. Pichot et al (2000) also noted a progressive decrease in HRV in 7 middle distance runners after a 3 week intensive training cycle, but a dramatic increase in HRV was observed following a one week recovery period. A diagnosis of overreaching or overtraining in the subjects was not made by the authors. The previous two studies indicate a significant shift in autonomic balance from the parasympathetic to sympathetic drive following highly intensive training. However, autonomic balance was shown to be restored with recovery.

Effect of Exercise Training on HRV in the Sedentary Population

The primary focus of this study is HRV in the athletic population. However, HRV in untrained individuals have also been investigated and the results are conflicting. Levy,
et al (1998) observed HRV in a group of untrained elderly (60-82 yrs.) and young men (24-32 yrs.) following a 6 month training program consisting of walking, jogging, and cycling for 105min, 4-5 times per wk beginning at 50% to 60% of heart rate reserve and then increased to 80%-85% by the fourth month. HRV significantly increased by 68% in the elderly and by 17% in the young men in the time domain. Levy and colleagues validated their time domain measurement through administering atropine and observing an 85% decrease in HRV indicating withdrawal of parasympathetic tone. Additional studies by Melanson and Freedson (2001) and Schuit et al (1999) have also observed increases in HRV parameters in the untrained population.

In contrast, a study conducted by Loimaala et al (2000) found no significant increase in HRV in 83 untrained middle-aged men (35-55 yrs.) after a training period of 5 months. HRV was measured in both the time and frequency domain. It was then concluded that "exercise training was not able to modify the cardiac parasympathetic activity in sedentary, middle-aged persons". Reports on HRV modulation following exercise training of sedentary subjects are inconsistent. Additional research within this population is needed.

Cross-Sectional: Comparison of Athletic and Sedentary Populations

When using heart rate variability it is important to consider the pre-trained status of the subjects. In highly trained endurance athletes, significant bradycardia resulting from enhanced vagal tone related to increased heart rate variability has been reported. In contrast, decreased heart rate variability has been shown in sedentary individuals.
However, previous studies have also reported similar heart rate variability measurements in trained endurance athletes and their sedentary controls.

Goldsmith et al (1997) observed a significant correlation between subject’s VO$_{2\text{max}}$ and HF power and HVR measurements ($r = 0.74$) indicating that physical fitness is a strong determinant of parasympathetic activity. Subjects ($n = 37$) were assigned into groups based on physical fitness status, as assessed by VO$_{2\text{max}}$ and exercise history. It was concluded that a withdrawal of vagal activity may be attributed to a decrease in physical fitness rather than age. Jensen-Urstad et al (1997) also found significantly increased HRV in both the time and frequency domain in 16 elite male middle-and long-distance runners in comparison to a control group of sedentary to moderately active individuals. Additional studies by Yataco et al (1997) and Puig et al (1993) coincide with the findings of Goldsmith et al (1997) and Jensen-Urstad et al (1997).

Buchheit et al (2004) found significantly increased HF power and LF power in measurements of HRV in moderately trained individuals compared to the highly trained subjects. Subjects were classified as moderately trained with 4 to 6 h of weekly aerobic activity and highly-trained with a minimum of 18 h of weekly intensive aerobic training. Interestingly, the absolute HRV indexes of the highly-trained subjects paralleled the sedentary controls. Furthermore, no signs of overtraining, as assessed by sleep quality and profile of mood states (POMS) questionnaires, were observed in the highly-trained subjects. Previous research by Reilings and Seals (1988), Maciel et al (1985), and Sacknoff et al (1994) report findings of similar HRV activity in highly-trained endurance athletes’ versus sedentary controls.
**Sampling Procedure**

The simple non-invasive technique of HRV analysis through the measurement of instantaneous beat-to-beat variations in R-R interval length evaluates overall autonomic modulation (Achten and Jeukendrup 2003; Aubert, et al. 2003). The frequency of this assessment will determine how often possible alterations of HRV, induced through varying training loads, can be observed. Training load capacity, recovery potential, stress tolerance and non-training stress variables cause significant individual variability among athletes under identical training loads (Lehmann, et al. 1993). Frequent sampling allows for observation of HRV adjustments among athletes'. However, standard statistics, using group means in a pre to post-test research design dominates previous studies, thereby limiting interpretation of individual differences.

HRV modulation in athletes is an almost unexplored domain. The current body of knowledge regarding HRV in the athletic population is inconclusive and firm results have yet to be drawn. However, previous research shows the potentially powerful method of HRV as a diagnostic tool and a potentially invaluable means for better understanding the regulation and control of the cardiovascular system.

This study will add to prior research by weekly investigating the patterns between HRV, training load and non-training stress factors in adolescent swimmers during a 10 week period including weeks of high intensity training, taper and competition.
CHAPTER THREE: METHODOLOGY

Research Hypothesis

Individual patterns between heart rate variability (HRV) parameters and training and non-training stressors will be observed in adolescent swimmers during a 10 week training period consisting of periods of high intensive training, taper, and competition.

Justification of Hypothesis

HRV is a window into autonomic function and balance. Previous research, although very limited, has shown that acute and chronic training in the athletic population alters HRV parameters. This suggests a relationship between training load and HRV parameters is present within the athletic population. HRV indices, which are closely related to parasympathetic and sympathetic activity, could then be used to aid in the prevention and early diagnosis of overtraining (Achten and Jeukendrup, 2003). Thus helping coaches, trainers, and physicians salvage athletes overall health and competitive seasons. Furthermore, standard statistics using group means in a pre-to post-test research design dominates previous studies, thereby limiting interpretation of individual differences. Additional studies are needed to evaluate these individual differences and relationships among athletes in relation to HRV and training loads.

Basic Assumptions

1. Subjects will adapt to the prescribed physical training implemented by the coach.

2. Subjects may experience symptoms of overtraining during swim training.

   However, direct diagnosis of overtraining in the subjects is beyond the scope of the study.
3. Pre-trained status of the subjects may influence HRV measurements.

**Limitations.**

1. Instrumentation. There is inherent error associated with all instrumentation.

2. Non-randomized samples. The sample of subjects used for this study was not randomly selected. Members of the local high school swim club were used for this study.

3. No control sample. There was no control group used for this project. Prior research has shown differing HRV parameters in sedentary controls versus trained individuals.

4. Differential loss of subject. An effect due to subjects dropping out of a study on a non-random basis.

5. Maturation. Processes and changes occurring within the subjects throughout the study.

**Delimitations.**

1. Population. Limited to members of the local high school swim club.

2. Gender. Gender was not controlled in this study. Comparison of data across gender will not be done in this study. It is possible that males and females will respond differently to the training program.

3. Sample size: Limited number of subjects.

**Significance of the study.**

Past research has failed to observe individual patterns between HRV parameters and training and non-training stress factors in athletes. With tremendous contrasting information from past investigations observing training load and HRV in the athletic
population as a whole, this study attempts to clarify the need for individual evaluation of an athletes' adaptation to training with possible prevention and detection of the overtraining syndrome as the main goal. Information gained from this study may help to further validate HRV as simple, non-invasive method for prevention and diagnosis of overtraining in athletes'.

*Applied Research.*

If significant individual relationships are observed between HRV parameters and training and non-training stressors, then coaches, trainers, and physicians may be able to use the simple, non-invasive technique of HRV to individually assess an athletes' adaptation to training in association with his or her training load and non-training stress factors. Additionally, this research may help to predict the athletes' likelihood of developing the overtraining syndrome or showing the positive training adaptations which then lead to overall good health and successful competition results.

*Subjects*

Fourteen members (ten females and four males) of the competitive Missoula Aquatic Club (MAC) swim team in Missoula, Montana participated in the study. One athlete dropped out. Subjects were between 12 and 18 years of age at the start of the observation period and all participants participated in organized training under the same coach.

Subjects were informed about the aims and testing procedure of the study and signed an informed consent. Parental consent was also obtained for all subjects. Each subject was thoroughly instructed about their rights of consent, meaning they were free to
withdraw from the study at any time, and their rights to confidentiality before they were asked to sign an informed consent.

Instrumentation

The Polar S810i heart rate monitor was used to measure subject's resting heart rate, step test heart rate, and heart rate variability. Headsets were used to direct subject's through the study protocol as described by figure 3. 8 inch step was used for completion of the fatigue index test.

Procedures

Subjects reported their subjective training load weekly throughout the 10 wk duration of the study. The subjects recorded illness, swim training duration (min), swim training intensity (% easy, moderate, hard), duration and intensity of daily physical activities outside of swimming, and daily degree of evening tiredness. All subjects took part in organized training by the same coach. Each subject was tested once a week at the subjects practice facility (Grizzly Pool) throughout varied training periods.

Once a week, before the start of regular swim practices participants reported to the practice facility between 5:00 and 5:30 am. The subjects immediately put on a heart rate monitor transmitter then began listening to the instructional tape. See figure 3. While sitting quietly in a comfortable location at the swim center, the subjects filled out a validated questionnaire recording their hours of sleep and profile of mood states (POMS). After three minutes, of quite sitting, the subjects resting heart rate was recorded. The participants then performed a step test on an 8 inch step at 15 cycles per minute (1step·sec) for one minute. Immediately post exercise heart rate was recorded. The participants then sat down and recovery HR was recorded at 30 seconds and 60 seconds
past stepping. The subjects then laid in a supine position post exercise. After three minutes of supine rest, the subjects heart rates were then monitored continuously for four minutes per the instruction in the next section (HRV recording). Once the data was collected, subjects took off the heart rate monitor and began preparation for swim training.

**HRV Recordings**

Following 3 min rest in a supine position, HRV recording was performed during a 4 min period of controlled breathing (10 breaths·min). The Polar S810i uses a sampling rate of 1000 Hz. An automatic filtering process in the Polar Precision Performance software was used to identify and correct all measurement errors. Power spectral analysis (frequency domain) of all heart rate data was performed by the Polar Precision Performance software using an autoregressive model. The frequency limits used for low frequency power (LF) and high frequency power (HF) bands were 0.04-0.15 Hz and 0.15-0.40 Hz. Additionally, components of the time domain, the standard deviation of the NN intervals (SDNN) and the square root of the mean squared differences (RMSSD), were used in the assessment of short-term HRV.

**Research Design**

Individual patterns between the dependent variable (HRV), independent variables (training loads) and covariates (POMS, hours of sleep, other physical activity, and illness) were investigated using a case study design. This research project was designed as a descriptive report.
CHAPTER FOUR: MANUSCRIPT

Using Heart Rate Variability to Evaluate Training in Adolescent Swimmers, a Series of Case Studies

Key words: Heart rate variability, training load, overtraining, over-reaching

Introduction

Monitoring the effectiveness of an aerobic training program has always been a difficult task for coaches and athletes. Monitoring includes the evaluation of the physical and mental stress which can lead to either positive or negative results depending on the nature, the severity, and the duration of the stress. One of the main areas of concern for coaches is the problem of chronically overloading athletes with limited recovery resulting in what is termed overtraining. Overtraining is a serious problem within the competitive athletic population (Uusitalo 2001). This debilitating condition may cause decreased performance in competition and training, loss of an entire competitive season, and pronounced decrement in overall health (Kuipers and Keizer 1988; Lehmann, et al. 1998; Uusitalo 2001). As stated by Lehmann et al “these are symptoms to be respected, not problems to overcome” (1998, 1144). The overtraining syndrome or staleness results from a long-term imbalance between stress (both internal such as training and external such as poor sleep, social stress, etc.) and recovery.

The purpose of athletic physical training is to overload physiological systems beyond normal to elicit a positive physiological adaptation. This increased training overload causes a brief period of decreased performance termed over-reaching (Kuipers and Keizer 1988). Over-reaching refers to acute training stresses resulting in positive adaptation. Over-reaching is a principle that must be applied in order for the athlete to
experience positive training effects and achieve peak performance. In order to allow for recovery and adaptation to occur following periods of over-reaching (generally 1-2 days of increased load) the over-reaching must be followed by an appropriate rest period to enable the athlete to progress in training. When adequate recovery is frequently achieved before new training stresses are applied, the athlete will become fatigued, adaptations cease to occur, and attains what is termed overtraining (Kuipers and Keizer 1988; Uusitalo 2001).

Individual athletes may be quite different in their vulnerability to becoming over-trained, even under similar training stresses as may occur during team practices where all members do similar training. This varying risk of overtraining, and the differences in the stress needed to achieve over-reaching, indicate significant individual variability in adaptation to training, exercise capacity, overall stress tolerance, and non-training stress factors (Lehmann, et al. 1993). This individual response to overload has been a foundation of sport training for many years but is often ignored during the design of programs, especially in youth sports (Rushall and Pyke 1990). The importance of individual athlete evaluation by coaches, trainers, physicians, and researchers has been long recognized but remains difficult to assess. The simple, non-invasive technique of heart rate variability (HRV) is a promising new tool which may aid in the prevention and early detection of overtraining (Hedelin et al, 2000a; Pichot et al, 2000; Uusitalo et al; 1999). Heart rate variability offers a dynamic window into the autonomic regulation of the cardiovascular system provided through measurement of instantaneous beat-to-beat (R-R interval length) variations.
The study of HRV to help prevent overtraining in athletes, through the early
detection of abnormalities in the autonomic nervous system is still in its infancy. In order
to detect early signs of overtraining coaches and athletes require daily feedback on stress
and recovery. It is believed that HRV measurements may be able to monitor subtle
changes in stress and recovery. This feedback would allow athletes to push themselves
adequately to achieve maximal benefits provided by over-reaching, yet recover
adequately to avoid overtraining. Previous research evaluating overtraining and its
effects on HRV in the athletic population is inconsistent. This inconsistency may be due
to multiple factors and a small number of studies. All studies to date have evaluated
HRV only over extended periods of time as pre- to post-training studies. Additionally
these studies have only reported the change in group means and have not accounted for
the individual variation, fitness or ability to handle the stress. Heart rate variability has
also been used for clinical evaluation of heart status in patients with coronary artery
disease, congestive heart failure and diabetic neuropathy. In addition, HRV has been
found to be a reliable predictor of mortality post myocardial infarction (Wolf et al, 1978;

Hedelin et al (2000a) investigated HRV in 16 yr old male cross-country skier
before, during, and after several months of intense training peaking at 20 h • wk$^{-1}$.
According to the investigators criteria, the athlete was diagnosed as overtraining. During
the overtraining period high frequency HRV (HF-HRV) increased while low frequency
HRV (LF-HRV) decreased. This case study showed parasympathetic dominance in the
overtrained athlete concurring with Israel’s overtraining theory (Fry et al, 1991). In
another study by the same group of authors, nine elite canoists were observed following a
6 day increased training load. Conversely, no changes were found in HF-HRV or LF-HRV. However, the athletes were diagnosed as over-reaching. Bosquet et al. (2003) came to similar conclusions in nine endurance-trained athletes. Following 4 wks of increased training, no significant differences in HRV parameters were observed. However, three athletes were diagnosed as over-reaching while six athletes were overtraining. Pichot et al. (2000) observed decreased HF-HRV and increased LF-HRV in seven middle-distance runners following a 3 wk intensive training program concluding increased sympathetic drive. Finally, Uusitalo et al. (1999) observed no change in HF-HRV and an increase in LF-HRV in nine female athletes following an increased training load.

Additional well-controlled studies are needed to investigate the individual responses in HRV, on a daily or frequent basis, to a high stress training load. Before a major controlled study using a cross over design is developed, further preliminary evaluation may help to identify normal individualized HRV response patterns within athletes as well as establish normal HRV values expected over the course of a training period when reported on a frequent basis. Preliminary research to evaluate the sensitivity of HRV in detecting overtraining, under-training (failing to over-reach) and effective training would be helpful.

The purpose of this study was to provide additional information on the understanding of individual HRV responses across time within a group of adolescent swimmers of variable ability and training backgrounds who trained under the same coach and swam similar yardage and intensities. A primary goal was to investigate and identify patterns between HRV, training load, external and internal stressors in competitive high
school swimmers and to explore the use of HRV as a tool to aid in the prevention and early diagnosis of overtraining. This project was designed as a descriptive report using case study design.

Methodology

Subjects.

Fourteen members (ten females and four males) of the competitive Missoula Aquatic Club (MAC) team in Missoula, Montana started as participants in the study. One female dropped out. Subjects were between 12 and 18 years of age at the start of the observation period and all subjects participated in organized training under the same coach. Prior to participation, each subject completed an IRB approved informed consent. Parental permission was also obtained for all subjects.

Overview.

All testing was performed before morning swim practice at an indoor swim facility. Subjects were tested weekly for 10 weeks with weeks 2-10 reported in this manuscript. Week one was used to training the subjects in the test procedures. Subjects arrived at the pool between 5:00 and 5:30 am. Upon arrival, subjects immediately put on a heart rate monitor transmitter (Polar, Finland) and put on headphones to listen to an instructional tape (Figure 1), which provided verbal guidance for all the morning testing. The tests that were completed included a short questionnaire, resting heart rate, a sub-maximal step test to evaluate fatigue and recovery and finally a supine rest period during which HRV data was collected. The entire data collection required about 15 minutes.
Questionnaire.

The questionnaire included weekly inquiry of athlete’s state-of-mind and state-of-feeling perception. Prior nights sleep and step test heart rates (Resting HR, Exercise HR, 30 and 60 Second Recovery HR) were also recorded on the questionnaire.

Fatigue Index Test

At the completion of the questionnaire the subjects turned on their instructional tape, which led them through the remainder of tests. Subjects were instructed to turn on their heart rate monitors (Polar S810i, Polar Electro, Finland) and sit quietly for another two minutes after which resting HR was recorded. They then followed a stepping cadence of 120 steps • min\(^{-1}\) using a 20 cm (8 inch) step resulting in 30 complete cycles per minute. At the end of the two minutes they were instructed to record their exercise HR and to sit down. At 30 and 60 seconds post-exercise they recorded recovery HR values. The resting, exercise and recovery HR were later summed and used as the fatigue (step test) index. This and other similar sub-maximal exercise has been previously used by endurance athletes to monitor training (Boulay et al, 1997; Hill; Martin and Andersen 2000; Potteiger, J.A. and Evans, B.W. 1995)

HRV Recordings.

Following the fatigue index measurements, subjects were instructed to lie on a mat in the supine position for 3 min. They were then instructed to restart their HR monitor in the HRV recording mode (one push of a button). For the next four minutes their beat-to-beat HR intervals were recorded. During this period they were instructed
via the tape to control their breathing by following the cadence on the tape which was set at 10 full breathing cycles • min⁻¹. At the end of the four minutes the subjects were instructed to stop the HR monitor recording and prepare for their swimming practice.

The Polar S810i monitor samples at a rate of 1000 Hz. An automatic filtering process in the Polar Precision Performance software was used to identify and correct all measurement errors. Power spectral analysis (frequency domain) of all heart rate data was performed by the Polar Precision Performance software using an autoregressive model. The frequency limits used for low frequency power (LF) and high frequency power (HF) bands were 0.04-0.15 Hz and 0.15-0.40 Hz. Additionally, components of the time domain, the standard deviation of the NN intervals (SDNN) and the square root of the mean squared differences (RMSSD), were also recorded for short-term HRV.

Training.

Subjects completed weekly training logs to report their swim training and their other physical activities throughout the 11wk duration of the study. The subjects recorded illness, swim training duration (min), perceived swim training intensity (% easy, moderate, hard), duration and intensity of daily physical activities outside of swimming, and daily perception of evening tiredness. In addition to the individual training logs, the head coach reported the daily workouts including swim yardage and planned intensity (% easy, moderate, hard).
Competitive Results.

Competitive results were supplied by the coach for several competitions during the study period including a competition following the 10 week period for which the athletes reduced the training stress (taper) in preparation for this important competition.

Data Procedures.

The fatigue index and HRV variables were computed as noted above. The training data were manipulated to estimate total training load using a modified Training Impulse (TRIMP) Model (Banister 1992). For this data, modified TRIMPS, we multiplied the minutes of reported low intensity swimming by one, moderate intensity by two and high intensity by four. The coach data was dealt with similarly, but the units were in yards.

Individual data were plotted over time (daily for training and weekly for test data). Individual patterns between the dependent variables (HRV and Fatigue Test Index) and independent variables (training min, training yards, training TRIMPS) were evaluated by the investigators, coach, and athletes. In many instances the coach and the athletes were able to give reasons for changes in the HRV and fatigue index that were not accounted for by the independent variables. These included family stress, school, sleep, and an abscessed tooth that was not recorded. Data were also inspected to see if there were patterns in the training load, high frequency HRV (HF-HRV) and Fatigue Index Test-Heart Rate (FIT-HR) leading up to periods of reported illness.

In terms of training we were looking for three basic patterns suggested by coaches and prior overtraining research. 1) Overtraining (OT): Consistently low values for the
HF-HRV measures associated with high HR values in the fatigue test and poorer than expected competitive performances tend to be associated with overtraining, a state of poor or non-recovery. 2) Effective Training (ET): When training is associated with periods of overreaching we would expect the HF-HRV to be low after periods of high training loads and to be high (recovered) after periods of rest. Additionally, one would expect to see the fatigue index HR values to be high after high training loads and to be lower after recovery periods. An effective taper would result in decreased fatigue index and increased HF-HRV. Competitive performance during periods of recovery and taper should be improved and somewhat depressed during periods when the fatigue index is high and HF-HRV is low. This variability should also be reflected in an inverse relationship between HF-HRV and the fatigue index. 3) Under Training (UT): This pattern would show consistent moderately-high to high HF-HRV with lower or moderately-low fatigue index values than in the other two groups. The lack of variation would suggest that the training is not stimulating over-reaching and the athlete can handle additional training loads periodized with rest to optimally improve performance. A taper may or may not slightly improve the HF-HRV, fatigue index and swim performance.

Group means and standard deviations for the descriptive, independent and dependent variables for the subjects were calculated. Additionally, attempts were made with intra-individual multiple regression models to predict changes in HF-HRV from independent variables. Although there were significant individual regression models they were highly variable and are not reported here. Individual correlations between HF-HRV and the Fatigue Index were also completed as part of the hypothesis on how athletes might fit into one of the three predicted categories.
Results

Stress Response to Training.

All athletes completed similar training (yardage) under the same coach during the 11 week testing period. The daily TRIMPS, swim yards, swim time, high frequency heart rate variability, illness, daily day end-tiredness and fatigue index data of each athlete were graphed on the Y axis, against time on the X axis. The graphs were printed such that the different variables could be visually evaluated across time and compared to one another. Three basic patterns of stress response were observed and defined. 1) Overtraining (OT), 2) Effective training (ET) and 3) Under training (UT). Individual athlete assessment allowed for classification of all subjects into one of the three training conditions.

Seven athletes were classified as being in a state of poor recovery or non-recovery indicating OT, with all of the youngest athletes (12-13 yrs) included in this category. Five athletes displayed ET with good variation in their training stress, while one subject (18 yrs) displayed UT with values suggesting a moderately rested state and limited variation in stress markers.

Resting HRV Data.

Consistently low mean values for HF-HRV with a small range were observed in the seven OT athletes as shown in table 1. High frequency heart rate variability increased substantially in four OT athletes due to the prescribed taper, while taper elicited no response in two OT athletes (table 2). A wide range in HF-HRV between high training loads and periods of rest or decreased training were displayed by the five ET athletes.
Additionally, ET athletes had higher mean HF-HRV values than the OT group (+3,132) and generally exhibited favorable taper responses.

In contrast, consistently high HF-HRV values with a small range were demonstrated by the UT athlete as shown in table 3.

Fatigue Index Test (FIT)

The OT athletes regularly demonstrated high mean FIT-HR values with one chronically stressed athlete peaking at 470 as shown in table 1. The FIT-HR range was generally smaller than the ET group, especially during the training period, though during the taper some athletes rested and increased their range. The ET athletes displayed lower (-57 bpm) FTI-HR values (table 2) than did the OT group with generally greater weekly variations. Similar results (table 3) were also seen in the UT athlete for FIT-HR values peaking at 369 following a mild illness. However, excluding the brief period of illness, the UT athlete has consistent FTI values around 330 bpm.

An inverse relationship was observed between the FIT-HR values and HF-HRV within most athletes (r = -0.077 to r = -0.772, mean r = -0.298). The relationship was evident following the prescribed taper (Feb) and maximum training load (Dec 27-Dec 31) as shown in graphs {1, 2, 4}, {5, 6, 8}, {9, 10, 12} representing the OT athletes, ET athletes, and UT athlete.

Training Data

The daily yardage was similar for all athletes and positive individual relationships (r = 0.314 to r = 0.828, mean r = 0.574) was observed between daily yardage and total TRIMPS as shown by graphs 1, 5, 9. Total TRIMPS increased for all athletes during the
heaviest training week (Dec 27-Dec31), peaking at 15,300 yards. This increased training load elicited a maximum TRIMP value of 15.2 reported by two OT athletes.

Reported Illness and Perception of Tiredness.

Ten athletes reported increased illness and tiredness ratings following: 1) 5 days (Dec 27-Dec 31) of a continuously high training load with poor or no recovery and 2) four microcycles consisting of a moderate to high training load as shown in graphs {1,3}, {5,7}, {9,11}. Three athletes consistently reported mild to moderate illness in addition to a moderate to high perception of tiredness. Leading up to reported illness, we observed decreases in HF-HRV and increases in FIT-HR values in 5 athletes. However, this pattern was not evident in all athletes reporting an increased illness rating.

Discussion

The case study research design utilized in the present study enabled investigation of individual adaptation to training load in adolescent swimmers and identification of patterns between HRV, training load, external and internal stressors. This design also allowed for further insight into individual HRV responses across time in the athletic population.

The major finding of this study was the observation of three stress response patterns, which were identified by the magnitude of effect on high frequency-heart rate variability (HF-HRV) and fatigue index test-heat rate (FIT-HR) in response to the training load across time. These finding were observed in adolescent swimmers over the course of 10 weeks. The three stress response patterns were distinguished by the following criteria: 1) Overtraining (OT): Consistently low HF-HRV values, high FIT-HR...
values and poor variation of the stress markers, 2) Effective training (ET): Good variation of HF-HRV and FIT-HR values and 3) Under training (UT): Consistently moderate to high HF-HRV values and limited variation of the stress markers. Further, we noticed individual interactions between HF-HRV, FIT-HR, training load and reported illness. The identification of these diverse patterns in athletes, all receiving similar training, clearly indicates significant individual variability in adaptation to training and overall tolerance of external and internal stressors. These findings also suggest that the stress required to achieve over-reaching is quite individual. Furthermore, the data suggests that vulnerability to becoming over trained was different for each athlete. Interestingly, the youngest athletes were in the OT group while the oldest athlete was in the UT group. This result suggests the significant impact training experience has on one’s ability to adapt and tolerate a given training load in addition to other external and internal stressors. These data also consider the importance of knowing the athlete’s training and competition history before interpreting the HF-HRV and FTI results.

Since the action of the heart is modulated by the autonomic portion of the central nervous system, HRV serves as a revealing window into overall autonomic activity. The moment-to-moment variation of heart rate is dependent on sympathetic and parasympathetic balance (Kamath and Fallen 1993; Yamamoto, et al. 1991). The OT athletes demonstrated low HF-HRV, a measure of parasympathetic activity as shown by Uusitalo et al. (1996), indicating decreased vagal activity. Conversely, the UT athlete showed consistently higher HF-HRV values suggesting increased parasympathetic activity. However, both groups demonstrated autonomic imbalance as shown by too little or too much sympathovagal modulation. It has been suggested that for efficient...
physiological functioning, an optimal level of instability of inter-beat intervals is vital (McCraty 2001). The ET athletes showed large variability in HF-HRV suggesting periods of autonomic imbalance (over-reaching) and autonomic balance during recovery. Uusitalo et al (1999) came to similar findings showing increased HF-HRV in effective trained athletes (5600 ± 3200) while the overtrained athletes displayed decreased variability (2900 ± 700). However, Hedelin et al (2000c) showed no significant changes in mean HRV parameters in athletes when comparing pre- and post-overtraining condition.

It has long been recognized that highly trained endurance athletes have a lower resting heart rate than do sedentary controls (Fagard 1992; Pichot et al, 2000). One proposal for the significant decrease in resting heart rate (HR) is enhanced vagal tone to the sinus node (Stein et al, 2002). Due to this sympathovagal shift, slower increases in heart rate at any submaximal oxygen uptake may also be observed (Uusitalo et al, 1996) However, the role of the autonomic nervous system in reducing resting heart rates is still controversial. In spite of the controversies we consistently observed that FIT-HR values in the OT athletes were consistently high suggesting a withdrawal of parasympathetic control, while lower FIT-HR values in the ET and UT athletes indicate better parasympathetic restraint during rest and submaximal exercise.

Individual inverse relationships (r = -0.077 to r = -0.772, mean r = -0.298) between HF-HRV and FIT-HR values were displayed by 10 athletes. The probable overall cause of these relationships is decreased parasympathetic stimulation at rest and during light exercise. The FIT stress measurement may aid in the validation of HRV as a tool for prevention of overtraining. However, 3 athletes demonstrated a positive
relationship suggesting a lack of, or decreased sensitivity by the HRV parameters in
measuring training stress of individual athletes. Additionally, only 5 athletes
demonstrated this negative relationship during periods leading up to reported illness.

Another lesson that can be learned from these data was the positive individual
relationships ($r = 0.314$ to $r = 0.828$, mean $r = 0.574$) between training load (yds) and
TRIMPS. The value of calculating TRIMPS was evident in all athletes during the
heaviest training cycle and allowed us to validate that the coach in this program was
varying the training load. The TRIMP model is yet another means by which coaches are
able to monitor athletes training on an individual basis, providing valuable information
regarding the athletes perception of training intensity (% easy, moderate, hard) which
may or may not be similar to other athlete's or to that of the coach. Additionally, an
increased illness rating was observed in 10 athletes following two periods of increased
training suggesting lack of recovery by the majority of individuals on the team.
Furthermore, no conclusions can be made from the psychological data due to the
prescribed methodology protocol. Overall, the major observations of this study should
help to lay the foundation for establishing better methods for monitoring athletes and
ultimately preventing the overtraining syndrome.

Limitations

Limitations of this study include the use of weekly measurements instead of daily
monitoring, which might have helped to identify daily variations. Additional limitations
include, lack of overtraining diagnostic criteria before initiation of research and limited
exercise data to describe and understand each athlete. Additional independent variables
such as school and family stress, were not recorded. These additional stressors may have
influenced the HF-HRV and FIT-HR values. Furthermore, the population was limited to adolescent swimmers.

Recommendations

The aim of this study was to further investigate individual HRV responses in competitive adolescent swimmers. Further research should focus on daily or frequent monitoring of HRV parameters in the athletic population across sustained periods of time. It is also imperative that overtraining diagnostic criteria are clearly established prior to initiation of research. More attention also needs to be directed towards power athletes and team sports. In addition, psychological parameters may also be further investigated. This preliminary research will help to further identify and establish HRV response patterns in athletes possibly providing a valid means of preventing overtraining.

Conclusion

The primary aim of this research study was accomplished by identification of three stress patterns: 1) Overtraining (OT), 2) Effective training (ET), and 3) Under training (UT) suggesting individual variability of adaptation to training and non-training stressors in a group of athletes doing similar training. Despite the limitations of a case study design, our data gives support to the importance of individualized training and monitoring for the prevention of overtraining and promotion of effective training. Further research is necessary for development of an overtraining model for use by coaches, physicians, trainers, and researchers to predict, prevent and diagnose debilitating overtraining and promote effective monitoring of training in the athletic population.
We believe, based on the individual data in this study, that athletes require individualized training programs in addition to frequent monitoring to prevent overtraining and promote effective training.
References


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### Overtraining and HRV in the athletic population

<table>
<thead>
<tr>
<th>Study</th>
<th>N</th>
<th>Age (yr)</th>
<th>HF</th>
<th>LF</th>
<th>Comments</th>
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</thead>
<tbody>
<tr>
<td>Hedelin et al. 2000c</td>
<td>9</td>
<td>18-23</td>
<td>⇐</td>
<td>⇐</td>
<td>Competitive Background 6-14 yr. Overreaching</td>
</tr>
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<td>Hedelin et al. 2000a</td>
<td>1</td>
<td>16</td>
<td>↑</td>
<td>↓</td>
<td>Overtraining syndrome</td>
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<td>Uusitalo et al. 1999</td>
<td>9 (ETG)</td>
<td>19-27</td>
<td>⇐</td>
<td>↑</td>
<td>Prior training: 8 yr. Overtraining 5 athletes</td>
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<tr>
<td></td>
<td>6 (CG)</td>
<td></td>
<td>⇐</td>
<td>⇐</td>
<td></td>
</tr>
<tr>
<td>Bosquet et al. 2003</td>
<td>9</td>
<td>27+/-5</td>
<td>⇐</td>
<td>LF/HF</td>
<td>Prior training: 7 yr. Night recording; Overtraining: 6; Overreaching: 3</td>
</tr>
<tr>
<td>Pichot et al. 2000</td>
<td>7</td>
<td>24.6 +/- 4.8</td>
<td>↓</td>
<td>↑</td>
<td>Prior training: 3 yr. Night recording</td>
</tr>
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</table>

Fig. 1. HF = High Frequency Power; LF = Low Frequency Power; ⇐ indicates no change; ↑ indicates increases; ↓ indicates decreases
<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Instruction</th>
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<td>Sit Quietly and fill out questionnaire</td>
</tr>
<tr>
<td>0:01:00</td>
<td>Sit Quietly and relax</td>
</tr>
<tr>
<td>0:02:00</td>
<td>Continue to relax</td>
</tr>
<tr>
<td>0:02:30</td>
<td>Record resting HR</td>
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<tr>
<td>0:03:00</td>
<td>Step Test Stepping (following metronome cadence)</td>
</tr>
<tr>
<td>0:04:00</td>
<td>Record exercise HR immediately</td>
</tr>
<tr>
<td>0:04:30</td>
<td>Record 30 second recovery HR</td>
</tr>
<tr>
<td>0:05:00</td>
<td>Record 60 second recovery HR</td>
</tr>
<tr>
<td>0:05:30</td>
<td>Lay quietly on mat</td>
</tr>
<tr>
<td>0:06:00</td>
<td>Focus on breathing and staying relaxed</td>
</tr>
<tr>
<td>0:07:00</td>
<td>Continue to focus on staying relaxed</td>
</tr>
<tr>
<td>0:08:00</td>
<td>Prepare to begin HR monitor recording and controlled breathing</td>
</tr>
<tr>
<td>0:08:30</td>
<td></td>
</tr>
<tr>
<td>0:09:00</td>
<td>Begin HR monitor-recording HR during controlled breathing (10 breaths·min)</td>
</tr>
<tr>
<td></td>
<td>Inspire and expire every 3 seconds by following the command “breathe”.</td>
</tr>
<tr>
<td>0:10:00</td>
<td>“Breathe” (every 3 seconds)</td>
</tr>
<tr>
<td>0:11:00</td>
<td>Continue to follow the command “breathe” (every 3 seconds)</td>
</tr>
<tr>
<td>0:12:00</td>
<td>“Breathe”</td>
</tr>
<tr>
<td>0:13:00</td>
<td>Completed. Begin preparation for swim practice</td>
</tr>
</tbody>
</table>

Fig. 2
How many hours of sleep did you get last night?

STATE-OF-MIND SCALE
Read each item carefully. Using the scale shown below, please select the number that best describes how you think about yourself right now and put that number in the blank before each sentence. Please take a few moments to focus on yourself and what is going on in your life at this moment. Once you have this “here and now” set, go ahead and answer each item according to the scale below:

1. If I should find myself in a jam, I could think of many ways to get out of it.
2. At the present time, I am energetically pursuing my goals.
3. There are lots of ways around any problem that I am facing right now.
4. Right now, I see myself as being pretty successful.
5. I can think of many ways to reach my current goals.
6. At this time, I am meeting the goals that I have set for myself.

STATE FEELING SCALE
Read each item and then mark the appropriate answer in the space provided. Right now, to what extent are you experiencing the following feelings? PLEASE BE HONEST!

1. not at all
2. a little
3. moderately
4. quite a bit
5. extremely

energized
stressed
tired
determined
strong
irritable
inspired
focused
frustrated
upset

STEP TEST HEART RATES
Resting HR
30 second Recovery HR
Exercise HR
60 Second Recovery HR

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<table>
<thead>
<tr>
<th>DATE</th>
<th>ILLNESS</th>
<th>TUESDAY GROUP</th>
<th>Week #</th>
<th>TIRENESS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Do you feel like you are getting a cold or other illness? Please list symptoms.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>How long did your swim practices last?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>What percentage of your swimming practice was: (The total should add up to 100%)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Please list any other physical activities that you did today and fill in how long you went (minutes) how hard (overall) the activity was (darken the most appropriate choice).</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>How tired did you feel at the end of the day today compared to a normal day?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Darken the most appropriate.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tuesday</td>
<td>am:</td>
<td>Easy Mod Hard</td>
<td>ACTIVITY Minutes</td>
<td>HOW HARD</td>
</tr>
<tr>
<td>01/11/05</td>
<td></td>
<td></td>
<td>easy mod hard</td>
<td></td>
</tr>
<tr>
<td>Wednesday</td>
<td>pm:</td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/12/05</td>
<td></td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thursday</td>
<td>pm:</td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/13/05</td>
<td></td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Friday</td>
<td>am:</td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/14/05</td>
<td></td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Saturday</td>
<td>pm:</td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/15/05</td>
<td></td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sunday</td>
<td>am:</td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/16/05</td>
<td></td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monday</td>
<td>pm:</td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/17/05</td>
<td></td>
<td>easy mod hard</td>
<td></td>
<td></td>
</tr>
<tr>
<td>OT Subjects</td>
<td>HF-HRV Low - High</td>
<td>HF-HRV Range</td>
<td>HF-HRV Ind. Mean</td>
<td>FIT-HR Low - High</td>
</tr>
<tr>
<td>-------------</td>
<td>-------------------</td>
<td>--------------</td>
<td>------------------</td>
<td>------------------</td>
</tr>
<tr>
<td>01</td>
<td>198 - 2546</td>
<td>2,348</td>
<td>831</td>
<td>397 - 470</td>
</tr>
<tr>
<td>03</td>
<td>778 - 9040</td>
<td>8,262</td>
<td>3886</td>
<td>304 - 366</td>
</tr>
<tr>
<td>06</td>
<td>742 - 5055</td>
<td>4,313</td>
<td>1717</td>
<td>316 - 353</td>
</tr>
<tr>
<td>13</td>
<td>266 - 4763</td>
<td>4,497</td>
<td>1421</td>
<td>383 - 466</td>
</tr>
<tr>
<td>15</td>
<td>53 - 518</td>
<td>465</td>
<td>241</td>
<td>351 - 402</td>
</tr>
<tr>
<td>16</td>
<td>139 - 3377</td>
<td>3,238</td>
<td>1455</td>
<td>339 - 420</td>
</tr>
<tr>
<td>18</td>
<td>60 - 1182</td>
<td>1,122</td>
<td>406</td>
<td>380 - 439</td>
</tr>
<tr>
<td>Group Mean</td>
<td>282 ± 3,783</td>
<td>3,463 ± 2,601</td>
<td>1422 ± 1220</td>
<td>353 - 416</td>
</tr>
</tbody>
</table>

OT: overtraining; HF-HRV: high frequency-heart rate variability; FIT-HR: fatigue index test-heart rate; Mean ± standard deviation.
<table>
<thead>
<tr>
<th>ET Subjects</th>
<th>HF-HRV Low - High</th>
<th>HR-HRV Range</th>
<th>HF-HRV Ind. Mean</th>
<th>FIT-HR Low - High</th>
<th>FIT-HR Range</th>
<th>FIT-HR Ind. Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>04</td>
<td>179 - 11,683</td>
<td>11,504</td>
<td>5022</td>
<td>297 - 384</td>
<td>87</td>
<td>336</td>
</tr>
<tr>
<td>05</td>
<td>433 - 6,206</td>
<td>5,773</td>
<td>3276</td>
<td>239 - 295</td>
<td>56</td>
<td>277</td>
</tr>
<tr>
<td>11</td>
<td>1,393 - 8,117</td>
<td>6,724</td>
<td>5652</td>
<td>310 - 375</td>
<td>65</td>
<td>337</td>
</tr>
<tr>
<td>12</td>
<td>4,075 - 8,615</td>
<td>4,540</td>
<td>5949</td>
<td>275 - 355</td>
<td>80</td>
<td>301</td>
</tr>
<tr>
<td>17</td>
<td>714 - 6,124</td>
<td>5,410</td>
<td>3868</td>
<td>343 - 406</td>
<td>63</td>
<td>375</td>
</tr>
<tr>
<td>Group Mean</td>
<td>1,359 - 8,149</td>
<td>6,790 ± 2,748</td>
<td>4554 ± 1142</td>
<td>293 - 363</td>
<td>70.2 ± 12.8</td>
<td>325.2 ± 37.6</td>
</tr>
</tbody>
</table>

ET: Effective training; HF-HRV: high frequency-heart rate variability; FIT-HR: fatigue index test-heart rate; Mean ± standard deviation.
Table 3-Heart Rate Variability and Fatigue Index Test for UT Athlete

<table>
<thead>
<tr>
<th>UT Subject</th>
<th>HF-HRV Low - High</th>
<th>HF-HRV Range</th>
<th>HF-HRV Ind. Mean</th>
<th>FIT-HR Low - High</th>
<th>FIT-HR Range</th>
<th>FIT-HR Ind. Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>02</td>
<td>5765 - 9171</td>
<td>3,406</td>
<td>6,617</td>
<td>285-369</td>
<td>84</td>
<td>333</td>
</tr>
</tbody>
</table>

UT: under training; HF-HRV: high frequency-heart rate variability; FIT-HR: fatigue index test-heart rate; Mean ± standard deviation.
OT Athlete Rep:

**Graph 1**

Total Daily TRMPS vs Total Daily Swim Minutes

**Graph 2**

HF-HRV

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OT Athlete Rep:

**Graph 3**

![Illness Rating vs Perception of Tiredness](image)

**Graph 4**

![Fatigue Index Test](image)
ET Athlete Rep:

**Graph 5**

Total Daily TRIMPS vs Total Daily Swim Minutes

**Graph 6**

HVR-HF

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ET Athlete Rep:

**Graph 7**

*Illness Rating vs Perception of Tiredness*

**Graph 8**

*Fatigue Index Test*
UT Athlete Rep:

**Graph 9**

*Total Daily TRIMPS vs Total Daily Swim Minutes*

**Graph 10**

*HVR-HF*
UT Athlete Rep:

**Graph 11**

*Illness Rating vs Perception of Tiredness*

**Graph 12**

*Step Test Stress Index*
APPENDIX 1

Informed Consent
IRB Approval
November 15, 2004

Dear parents of Missoula Swim Team members,

We have talked to your son or daughter’s coach, Marion, about swim team members participating in a simple research project. She feels that it would be a useful project and has approved our moving forward. The information about the project is outlined in the attached Parent Information and Consent Form. In brief summary, we hope to be able to evaluate a simple test which might enable us to identify optimal training loads that help a swimmer improve but not cause symptoms of overtraining. Marion has agreed to allow each swimmer one morning a week where they would show up at the normal practice time, but spend the first 15 minutes with us for resting heart rate measures, a very easy 1-minute step test, and a short questionnaire about how you are feeling.

In addition to the weekly heart rate monitoring, we would ask the swimmers to keep a very simple log book of training that they do outside of swim practice, and record if they are feeling sick or overly tired on any day. In the log book we also ask them to rate how hard the practices were and how tired they were at the end of the day. A copy of a page of the log book is attached. The study will last for 12 weeks.

We hope to be able to give each individual swimmer feedback at the end of the 12 week study concerning how they respond to the training that they are doing. We hope to be able to give the swimmers and their coach information that will be helpful to their future training. We cannot guarantee that we will be able to give useful feedback, but there is good evidence from prior studies, in older athletes, that these measures are useful and may help to monitor training.

Please read through the attached information. This has been approved by the University of Montana institutional review board. If you have any questions or reservations do not hesitate to call Steven Gaskill, Ph.D. at 243-4268 (office) or 829-8978 (home). Both the parent and the participant will be asked to sign separate forms. All data and information are confidential. You may also sign to have us share the information with your son or daughter’s coach.

Sincerely,

Steven Gaskill, Ph.D
Ann Somerville, Graduate Student
PARENT INFORMATION AND PERMISSION FORM

Effects of varying training loads on heart rate variability in competitive swimmers

HUMAN PERFORMANCE LABORATORY
Dept of Health and Human Performance
THE UNIVERSITY OF MONTANA

(Athlete's (child's) Name) ID#_________ Today's Date: _____/_____/______ Participant

STUDY DIRECTOR(S): Steven Gaskill, Ph.D. (406) 243-4268 University of Montana
Ann Somerville (406) 721-4228 University of Montana

This form may contain words that are new to you. If you read any words that are not clear to you, please ask the person who gave you this form to explain them to you.

PURPOSE OF THE RESEARCH

Your son or daughter is being asked to take part in research evaluating how their swim training effect heart rate variability (changes in the duration of time between heart beats) and morning heart rates at rest and during light activity. These measurements are non-invasive and are used to evaluate stress.

- Your son or daughter are being asked to participate in this project as they are a member of the Missoula Swim Team.
- This research is observing two factors that may enable coaches to better determine when young athletes are training adequately or too much and increasing their risk of overtraining and illness.

PROCEDURES

> Read and sign this permission form (Your son or daughter will be asked to sign a separate assent form).
> We will measure their height and weight during one of their practice sessions.
> Once a week, at the start of their regular swim practices starting at 5:30am, they will be asked to do the following procedures taking about 15 minutes:
  - They will put a heart rate transmitter on their chest.
  - In a quiet and comfortable location at the swim center, they will rest lying down for 3 minutes.
  - At the end of three minutes their resting heart rate will be recorded.
  - They will then perform a step test on an 8-inch step for 1 minute (1 step/sec)*. This is very easy.
  - At the end of the stepping they will sit down quietly for 1 minute. Heart rates immediately after the stepping, at 30 seconds and 60 seconds will be recorded.
  - They will then sit quietly for three minutes to allow their heart rate to get back to complete rest. During this time they will be asked to evaluate how they are feeling on a simple questionnaire.
  - After the three minutes of rest and completing the questionnaire, they will continue to sit quietly for four additional minutes during which time their HR will be monitored continuously. Their breathing rate will be controlled during this period by following a recording that leads them in controlled deep breathing at a slightly slower than normal rate **.
• After the data collection (about 12 minutes) they will then take off the heart rate transmitter and begin preparation for swim training.

• The step test is used to evaluate how their heart rate responds to light activity and how quickly it recovers from the activity.

• The four minutes of continuous heart rate monitoring is to evaluate "heart rate variability," a measure of how their heart rate varies with breathing and other factors. Heart rate variability is believed to change as athletes become stressed.

➢ Other information that your son or daughter will be asked to record and hand in weekly (copy of the form is attached) includes:
  • Their daily physical activity outside of swimming.
  • How healthy your son or daughter is feeling each day.
  • How hard (tiring) they rate the swim practice each day.
  • Their competitive results (technique, distance, times)

➢ The study will continue weekly for 3 months.

LOCATION AND LENGTH OF TIME REQUIRED
The study will take place at the University of Montana Swimming Center on the University of Montana campus and requires one data collection period each week at the start of practice for 12 weeks. Each of the 12 sessions will last for approximately 15 minutes. In addition, each athlete will probably spend about 15 minutes a week completing the supplemental data form.

PAYMENT
There is no payment for participation.

RISKS/DISCOMFORTS
• Mild discomfort may result during and after the swim training exercises that the athletes are already participating in and which will not be changed because of this research.
• There are no known risks or discomforts from wearing a heart rate monitor.
• The light physical activity required for the step test is much less than these athletes do on a regular basis and is easier than walking up stairs at a normal rate. No risks or discomforts are anticipated from this activity.

BENEFITS OF PARTICIPATING IN THIS STUDY
• There is no promise that your son or daughter will receive any benefit from taking part in this study.
• The information from these tests may provide your son or daughter and their coach (if you agree to share the information with their coach) about their training status. The information may also help the athletes learn the optimal loads of training necessary to push themselves physically as well as an understanding of the training load that may put them at risk for "overtraining," a state where performance actually decreases and your son or daughter is more likely to become ill.
• At the end of the study, one of the researchers will spend time with you and your son or daughter (and their coach if you wish) to discuss the results and what they might mean for their training.
• There are no other direct benefits to the participants in the study.
CONFIDENTIALITY
- Their records will be kept private and will not be released without their consent except as required by law.
- Only the researcher and the faculty supervisor will have access to the files.
- Their identity will be kept confidential.
- If the results of this study are written in a scientific journal or presented at a scientific meeting, their name will not be used.
- All data, identified only by an ID #, will be stored in our laboratory.
- The signed consent form and information sheet will be stored in a locked office separate from the data.

COMPENSATION FOR INJURY
Although we believe that the risk of taking part in this study is minimal, the following liability statement is required in all University of Montana consent forms. "In the event that your son or daughter is injured as a result of this research you should individually seek appropriate medical treatment. If the injury is caused by negligence of the University or any of its employees, you may be entitled to reimbursement pursuant to the Comprehensive State Insurance Plan established by the Department of Administration under the authority of M.C.A., Title 2, Chapter 9. In the event of a claim for such injury, further information may be obtained from the University's Claim representative or University Legal Counsel."

VOLUNTARY PARTICIPATION/WITHDRAWAL
- Your son or daughter's decision to take part in this research study is entirely voluntary.
- Your son or daughter has the right to request that a test be stopped at any time.
- Your son or daughter may refuse to take part in or withdraw from the study at any time without penalty or loss of benefits to which your son or daughter is normally entitled.
- They have the right to leave the study for any reason.
Your son or daughter may be asked to leave the study for any of the following reasons:
- Failure to follow the study investigator's instructions.
- The study director/investigator thinks it is in the best interest of their health and welfare
- The study is terminated.

QUESTIONS
- You may wish to discuss this with others before you agree to allow your son or daughter to take part in this study.
- If you have any questions about the research now or during the study contact:
  Steven Gaskill Ph.D. - (406) 243-4268 or Annie Sommerville - (406) 721-4228
- If you have any questions regarding their rights as a research subject, you may contact the Chairman of the Institutional Review Board through the Research Office at the University of Montana at (406) 243-6670.
PARENT'S STATEMENT OF CONSENT
I have read the above description of this research study. I have been informed of the risks and benefits involved, and all my questions have been answered to my satisfaction. Furthermore, I have been assured that a member of the research team will also answer any future questions I or my son or daughter may have. I voluntarily agree to allow my son or daughter to take part. I understand I will receive a copy of this consent form.

________________________________________
Printed Name of Participant

________________________________________
Parent or Guardian’s Signature

________________________________________
Date

I agree that the researchers may share my son or daughter’s individual results of this study with the swimmer’s coach. (The researchers believe that the individual swimmer data from this research will be beneficial to the swimmer’s coach and will help in the planning of training.) If you choose not to sign below no data will be shared with the swimmer’s coach.

________________________________________
Parent or Guardian’s Signature (if participant is 18 or under)

________________________________________
Date

Approval Expires On 11/13/05

Date Approved by UM IRB 12/19/04

IRB Chair