EFFECTS OF DETRAINING ON CARDIORESPIRATORY AND METABOLIC RESPONSES AFTER SIX WEEKS HIGH-INTENSITY CYCLING

by

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(ABSTRACT)

This study evaluated novel submaximal indicators of cardiorespiratory fitness during high constant-load (HCL) exercise tests in response to detraining. A central variable was the slow component VO_2 (SC); SC is defined as the difference between end-exercise VO_2 and 3-min VO_2 (Gaesser et al. *ESSR*, 1996). Terminal heart rate (HR) and blood lactate (HLa) were taken at the end of HCL tests. Ten sedentary males (18-30 yr) were screened and gave informed consent. Subjects completed a maximal and HCL exercise test for baseline assessment. The maximal test variables, VO_2 peak and lactate threshold (LT), were used to set loads for the HCL tests and the training protocol. Cycle ergometer training was done ~30 min/day, 5 days/week for 6 weeks at .70(LT- VO_{2peak}). Subjects were tested at week six of training and then detrained for two weeks. HCL tests were repeated at one and two weeks of detraining and an additional maximal test was performed after week two. Significant differences ($p<0.001$) were found in terminal heart rate following one and two weeks of detraining compared to post-training values, with increases of 6.2% and 5%, respectively. No significant changes occurred for SC and HLa. While terminal heart rate is known to exhibit a rapid time course change in detraining, SC and HLa need to be studied for a longer detraining period.

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CHAPTER ONE

INTRODUCTION

Introduction

Exercise capacity can be significantly improved in previously sedentary individuals through endurance training. The development of peak exercise performance is determined by maximal oxygen uptake (VO_2max). VO_2max has traditionally been accepted as the gold standard of cardiorespiratory fitness and is used as the main criterion to demonstrate adaptation to training. However, recent studies suggest that VO_2max should not be used as the sole measure of training adaptation (24).

There are several maximal and submaximal cardiorespiratory responses that are associated with endurance performance. The importance of submaximal testing is frequently overlooked when measuring changes associated with exercise capacity. Cardiorespiratory and metabolic responses during constant-load exercise provides an alternative approach for evaluating training or detraining adaptation. Ventilatory kinetics (slow component) has emerged as a useful tool for evaluating submaximal exercise performance. The slow component can be defined as the continuous rise in VO_2 following the third minute of exercise (15). In most healthy individuals, a steady state response can be attained after approximately 2 to 3 minutes into the exercise bout. After three minutes this additional phase, defined as the slow component rise, may elevate VO_2 above values predicted from a linear-work relationship. Anything above these predicted values requires an additional oxygen cost. The magnitude of the slow component will increase with work and if not stabilized will drive VO_2 to its maximum and signal fatigue (15). For instance, if work was continuously added to a constant load exercise test, it would no longer be a constant load test, but rather an incremental test. If it became an incremental test it could no longer elicit a slow component response because the VO_2 would increase until exhaustion. Other physiological associated responses include respiratory exchange ratio (RER), ventilation (VE), and heart rate (HR). Heart rate is known to be a linear function of power output and is considered a valuable tool in assessment of fitness capacity (20). A metabolic change associated with training is lactic acid. The accumulation of lactic acid and the lactate threshold tends to decrease with training and increase with detraining. When the individual is at a higher fitness level the lactate-clearance rate becomes more efficient resulting in a decrease in lactate accumulation causing an increase in the lactate threshold. Weltman (24) concluded that the lactate threshold was not only a good indicator of training adaptation but could also play an integral role in the development of an affective training program. Weltman suggested that training intensity should be based on both VO_2 and the lactate threshold.

While a significant amount of research has been done on training and the associated physiological adaptations, very little has been investigated involving long and/or short periods of inactivity (detraining) and the possible reversal of these adaptations. When physical training is stopped, reduced, or interrupted the body tends to readjust in accordance with the diminished physiological demand and the benefits seen with exercise training may be lost (7). Detraining can serve as a methodological tool to study the limiting factors related to endurance exercise and the relative significant cardiorespiratory and metabolic factors.

Statement of the Problem

It is obvious that periods of inactivity are encountered by everyone at some point whether due to personal choice for a sedentary lifestyle, injury, sickness, business trips, vacations, emergency situations, etc. Countless studies have been done on the benefits of exercise and endurance training but very little has been done involving the effects of long and/or short periods of inactivity on the body. The importance of examining the consequences on fitness during these periods is meaningful to every aspect of the population. Previous physical fitness level and intensity of the training program are considered the two most influential aspects which play a role in time course involved in changes of training adaptations (18).

The time span under examination for individuals that are on a regular exercise program involves short periods of inactivity (detraining). Detraining is defined as continuing with normal daily routines without additional physical activity. This may be of particular importance to athletes that are not feeling well or have suffered a minor injury. In other instances, a moderately trained individual that must go on a business trip for a week, or the family wants to take a vacation and exercise is not in the plan, or the student who is in the middle of exam week and has no time to exercise. It is evident that every individual involved in a regular exercise program will be faced at some point with periods of inactivity and the consequences during this time need to be thoroughly investigated as to provide a tool in decisions regarding exercise. Therefore, the purpose of the present study was to determine the possible physiological adaptations related to short periods of inactivity following an intense exercise program of previously sedentary males.

Research Hypotheses

Ho_1: Following a two week period of inactivity there was no difference on ventilatory kinetics (VO_2SC) after six weeks of high-intensity cycle ergometer training at 70% of the difference between lactate threshold (LT) and VO_2peak.

Ho_2: Following a two week period of inactivity there was no difference on terminal heart rate after six weeks of high-intensity cycle ergometer training at 70% of the difference between LT and VO_2peak.

Ho_3: Following a two week period of inactivity there was no difference on end lactate after six weeks of high-intensity cycle ergometer training at 70% of the difference between LT and VO_2peak.

Significance of the Study

The objective of this study was to determine the possible adaptations related to short periods of inactivity (detraining) following an intense exercise program of previously sedentary males. There are times which arise in every individuals life when a period of inactivity may take place. Some of these times are controlled by the individual and other situations in which the decision is made without a choice. Therefore, it was important to document the potential reversal of training adaptations during this time period. This study focused on the physiological changes during fourteen days of detraining, the time period most likely to affect the majority of the exercising population. When investigating the potential changes in overall fitness it was important to look at several cardiorespiratory and metabolic factors which included: oxygen uptake (VO_2), slow component (SC), endurance capacity (EC), end lactate, lactate threshold (LT) and heart rate (HR).

Several factors may be assessed to determine if detraining had taken place. Researchers were able to conclude that detraining had taken place by a reversal of one or more training adaptations. Ideally, changes with inactivity would show a decrease in VO_2, an increase in SC, a decrease in EC, an increase in end lactate, a decrease in LT, and an increase in HR. However, it may be unrealistic to see these changes occur across all measurements, especially during such a short period of time.

Researchers have investigated these various responses to inactivity and have come to different conclusions. The traditionally measured adaptations (VO_2, HR) have even presented conflicting results. Previous tests were maximal in nature and did not examine all possible ventilatory kinetics (i.e. slow component). The present study addressed these limitations. The exercise tests were submaximal in nature and examined ventilatory kinetics in addition to other cardiorespiratory and metabolic factors.

Delimitations

The following delimitations were imposed by the researcher:

1. Subjects included 10 male volunteers attending Virginia Polytechnic Institute and State University between the ages of 18-30.
2. Subjects had not been involved in any cardiovascular physical activity for at least six months prior.
3. Subjects went through an aerobic training program for 5 days/week for six weeks on a cycle ergometer (Monark 818 E).
4. Training protocol was set at 70% of the difference between LT and $\dot{V}O_2$peak with a cadence of 60 rpm and each exercise session lasted ~30 minutes.
5. Following the sixth week of the training program the subjects detrained for a period of two weeks.
6. The dependent measures were ventilatory kinetics (VO_2SC) and terminal heart rate (HRterm), and end lactate.

Limitations

The following limitations may have effected the outcome of this investigation.

1. Due to the limited number of subjects (n=10) a non-random sampling procedure was used therefore possibly impacting the generalization of the results.

Basic Assumptions

1. Subjects exhibited a maximal performance during maximal and submaximal exercise tests.
2. Subjects were honest in reporting all activity outside of the study.
3. Subjects kept accurate activity logs during the two week period of detraining.
4. Subjects did not alter their diet throughout the study.
5. Subjects complied with pre-test instructions (i.e. no alcohol, no food, no tobacco products).
6. Testing and training cycles were accurately calibrated.
7. The MedGraphics CPX/D metabolic cart accurately measured oxygen consumption.

Definitions and Symbols

These definitions and symbols will assist with the understanding of the study.

1. Detrained: Significantly ($p<0.05$) meets the following criteria:

   -decrease in VO_2

   -decrease in power (watts)

2. Detrained -1 (DT-1): The subject had been "detraining" for a period of one week.
3. Detrained -2 (DT-2): The subject had been "detraining" for a period of two weeks.

4. High Constant Load Test (HCL): An exercise test in which a high constant power output (>70% V_{O2peak}) was required of the subject.

5. Incremental Test: An exercise test designed to provide a gradual increase in stress to the subject; work rate is usually increase over uniform periods of time.

6. Lactate Threshold (LT): Occurs when the accumulation of lactic acid greatly exceeds the removal and an increased amount of blood lactate is found in the body. The LT is used to set desirable training workloads.

7. METS: Metabolic equivalents defined as relative oxygen uptake divided by a constant, 3.5 ml/kg/min.

8. Pulmonary Gas Exchange: The process of inhaling and exhaling air through the lungs with exchange of oxygen and carbon dioxide.

9. Rate of Perceived Exertion (RPE): Subjective measure of exercise intensity whereby the subject assigns a rate on a numerical scale that corresponds to how the subject is "feeling".

10. Respiratory Exchange Ratio (RER): Ratio that expresses the relationship between carbon dioxide produced to oxygen consumed.

11. Slow Component (SC): The difference between end-exercise VO_2 and 3 minute VO_2 (27).

12. Slow Component of Oxygen Uptake (VO_2SC): The slow component is a delta score of oxygen uptake. This abbreviation is

frequently used in describing the ventilation of the slow component (it can be used interchangeably with SC).

13. Terminal Heart Rate (HRterm): The heart rate given at the end of the constant load exercise test.

14. Untrained: Subjects that have not participated in a structured endurance activity program (< 1 day/week) for at least 6 months prior to the study

15. VO_2peak: The highest value of oxygen consumption measured during the test and will be determined valid if meets two out of three criteria:

    -leveling off of VO_2 despite an increase in workload

    -RER of > 1.1

    -heart rate at 85% or greater of age predicted max

Summary

A time will arise in which every individual involved in an exercise program will be faced with a period of inactivity. This period may be due either to choice or other uncontrollable factors (i.e. injury, illness). Therefore, it is important to understand the potential losses following short periods of detraining. These possible changes can be measured through ventilatory kinetic responses, end lactate and terminal heart rate. Submaximal tests are most practical for this realistic situation and are appropriate for measuring these given response variables. Being aware of the possible physiological adaptations following short periods of inactivity can serve as a valuable tool in assessment of future conditions and choices regarding physical capacity.

CHAPTER II

LITERATURE REVIEW

Introduction

For several years physiological responses to periods of inactivity of highly trained individuals have been studied. However, no agreement has been reached in the literature regarding loss of training adaptations. Typically the investigators recruit previously trained subjects, in which a particular subset of athletes are used and termed "trained". The response variables frequently measured are VO_2, RER, and HR during maximal exercise testing.

This investigation was unique by using sedentary individuals and training the subjects for a period of six weeks followed by a two week period of detraining. During this time course the subjects performed three maximal exercise tests and four submaximal tests. The maximal tests recorded the traditional response variables of $\dot{V}O_2$, RER, LT, end lactate, HR, RPE and workload. These tests were used as markers to signify that training had in fact occurred since baseline and detraining had also occurred since peak training values. The four submaximal tests were high-intensity constant load exercise tests (HCL). These submaximal tests and associated measured physiological response variables contained the uniqueness of the study. The major response variables analyzed were the slow component of VO_2, end lactate and terminal heart rate. The slow component was determined by subtracting the VO_2 of the third minute of exercise from the last minute of exercise. This response variable has gained increasing recognition in the field of exercise assessment. Several potential mechanisms have been suggested to account for the slow component of VO_2 kinetics. These include: 1) the metabolic stimulatory effect of increasing levels of circulating catecholamines 2) increase VO_2 associated with the Q_{10} effect 3) increased ventilatory and cardiac work 4) progressive recruitment of less efficient fast twitch motor units 5) increased O_2 cost of lactate metabolism and 6) alteration in enzyme kinetics associated with reduction in O_2 cost (26). Davis et. al (11) investigated the reliability of VO_2SC during heavy exercise and found high test-retest reliability ($r = 0.91$).

Currently there is no data in the literature regarding detraining and the slow component, allowing its utility in evaluation of training/detraining effects to be studied. The role of the LT was essential in setting a desirable workload for maximizing changes associated with training/detraining and to obtain a slow component.

In organization of this particular study a great deal of research had to go into construction of an appropriate training protocol, an effective period of detraining, and measurement of appropriate and purposeful response variables. A considerable amount of information and support was gained from previous literature. However, the investigator's major area of concern dealt with submaximal exercise testing and the slow component response during detraining, an area new to the literature.

Maximal Exercise Testing

Maximal testing occurs when the subject puts forth their best effort in exercise capabilities on the cycle ergometer. This test enabled the investigators to determine several physiological parameters, the most important being the maximal amount of oxygen the subject was able to consume during the test. This response is referred to as VO_{2max} and has been traditionally accepted as the "gold standard" of cardiorespiratory fitness (2). The greater increase in oxygen uptake the greater the fitness level.

In conducting a maximal exercise test there are physiological characteristics that are defined for attainment of maximal exercise. A maximal test should last ideally between 8 to 12 minutes, implying that an appropriate testing protocol was essential (2). A maximum heart rate should reach greater than or equal to 85% of age-predicted maximum heart rate. A maximum rate of perceived exertion (RPE) should be at least 17 and the respiratory exchange ratio (RER) should be at least 1.10 (2).

Submaximal Exercise Testing

From the initial maximal exercise test a submaximal workload can be established. Researchers typically agree that if the purpose was to measure responses to a high intensity exercise domain that the workload should be set at 70% of the difference between LT and VO_2peak. Investigators that studied high-intensity exercise typically limited the subject to a period of 15 minutes or until volitional fatigue, whichever came first.

Slow Component

The slow component is defined as the continued rise in VO_2 following the third minute of exercise. It is at this third minute that the slow component appears to develop during a HCL exercise test. The slow component represents an "excess" in VO_2 above that predicted from the VO_2 work-rate relationship. Eliciting a VO_{2max} with submaximal work rates is not uncommon and can be a consequence of the additional oxygen uptake of the slow component (15). Typical slow component values range from 200 ml/min to 1000 ml/min (27). Untrained individuals tend to elicit a higher slow component in comparison to trained athletes. Following an intense endurance training program the magnitude of the slow component will stabilize and decrease the response values (15).

The first to examine the influence of endurance training on the slow component of VO_2 was Casaburi and colleagues (5). Ten subjects performed a series of constant-load exercise tests at 90% of pre-training VO_{2peak} values before and after 8 weeks of training. Following training the slow components of the subjects were reduced by ~150-200 ml/min. These values were significantly correlated with a reduction in ventilation. Womack (27) also found significant reductions in slow component of VO_2 but just after 2 weeks of training at a high intensity training protocol. The slow component enabled researchers to gain a better understanding of training adaptations and physiological responses concerning VO_2 kinetics.

Lactate [HLa]

Blood lactate concentrations have been studied in connection with setting proper workloads to elicit a slow component. Many investigators suggest that there is some type of link between the SC and blood lactate. Two aspects of lactate are important: the lactate threshold (LT) and end lactate. The LT occurs when the accumulation of lactic acid greatly exceeds the removal and an increased amount of blood lactate is found in the blood. With training this LT should increase (i.e. take longer to achieve) and the reversal should occur with detraining. As for end lactate, values should decrease with training and increase with detraining. However, researchers have seen variations from these expected results.

Determination of the LT is a valuable tool in setting desirable workloads for varying intensity domains of exercise. Heavy or high-intensity exercise is classified as being above the LT. When an individual exercises at a level greater than the LT there is an additional O_2 cost (SC) which elevates VO_2 above the predicted work-rate relationship (22). Barstow found that during heavy constant-load exercise that the rate of change of VO_2SC was correlated with blood lactate. Poole agreed, suggesting that the magnitude of the SC was highly correlated with the rise in lactate. However, Poole found no cause and effect relationship, and admits the mechanism between increases in blood lactate and the slow component may not be entirely clear.

In general, investigators agree that there is some link between blood lactate and the slow component. Some investigators focused on the importance of the LT while others studied the peak values. Casaburi (5) found that after 8 weeks of high-intensity training that VO_2SC and peak lactate concentrations were significantly correlated. However, Gaesser found evidence which suggested that the reduction in lactate following training is not a result of the decrease in VO_2SC. Gaesser states that the SC is evident only at work rates above the LT and that lactate is correlated with and not causal to VO_2SC.

Training Protocol

In establishing a training protocol several factors were taken into account. When setting up an effective protocol to maximize cardiorespiratory benefits the researcher had to establish with an appropriate duration, intensity, and mode of exercise that subjects would adhere and comply to throughout the duration of the study. Gaesser (14) organized a protocol in which his subjects cycled 6 days/week for 3 weeks. Each exercise session lasted ~30 minutes and the workload on the cycle was set at 70% of the difference between LT and VO_2peak with a cadence of 60 rpm. This intensity remained consistent throughout the duration of the study. All subjects had over a 90% attendance to the sessions. Following this three week training protocol Gaesser saw an 11% increase in VO_{2peak} and a decrease in heart rate.

More recently Womack (27) trained sedentary males for 4 days/week for 6 weeks. The training workload was set at >80% VO_{2peak} with a cadence of 60 rpm. This protocol was held constant throughout the study. All training took place on a cycle ergometer for ~30 minutes. Womack found significant changes in HR after just two weeks of training and VO_2 after six weeks. The present study used similar protocols. Both protocols were set at the same mode and intensity, >80% VO_{2peak} with a cadence of 60 rpm on a cycle ergometer, but varied considerably in duration of inactivity and results of the measured response variables.

Detraining Protocol

Since the early 1960's there has been a variety of ways to define "detraining". In 1968, Saltin (23) and colleagues took 5 highly trained subjects and strictly confined them to bed rest. The subjects laid in a supine position for a period of 20 days. Saltin found decreases in VO_{2max} and increases in heart rate following the period of detraining. However, in 1986 an investigator named Cullinane (10) took 15 highly trained subjects and told them to detrain for a period of 10 days. Cullinane defined detraining as continuing to follow normal daily activities but to refrain from any physical training. Increases in heart rate were detected following this period, however no meaningful changes in VO_2. These two researchers provided direct contrasts in the definition of "detrained", yet they both find significant changes in detraining adaptations.

The number of subjects typically used as well as the duration of the detraining period needed review. The majority of researchers used between 7 and 15 subjects however the period of inactivity tended to differ in duration as well as the results of response variables. Coyle (8) studied 7 endurance athletes and saw a 8% decrease in VO_2, an increase in peak lactate, and an increase in heart rate. Cullinane (10) saw a significant decrease in heart rate but not VO_2 after 10 days of detraining with 15 athletes. Houmard (16) trained 10 athletes and saw significant decreases in VO_2 but not heart rate following 14 days of inactivity. Madsen (17) researched a 4 week period of inactivity using nine subjects and saw no changes in VO_2 and increases in heart rate. It was evident that results tended to differ in the literature for similar periods of detraining in addition to the variation in selected time spans of inactivity.

Summary

Over the past several years the major focus has been on the effects and physiological adaptations of endurance training. The research has been centered on establishing effective programs and the intensity, duration, and frequency of these protocols to assure significant increases in cardiorespiratory fitness levels while maintaining subject compliance. After spending many years investigating training adaptations researchers decided to look at what happened to the body's physiological responses following periods of inactivity. The research in this area was somewhat limited, in comparison to changes associated with training, but is rapidly continuing to grow.

When researchers reported their findings each investigator had to carefully define "detraining", the prior level of physical fitness, and the chosen time period of inactivity.

After reviewing previous literature it was obvious that investigators tended to agree on a proper initial level of physical fitness prior to detraining. The researchers uniformly focused on maximal exercise testing and associated parameters using similar guidelines. Very few performed any submaximal testing. The results of previous studies and the development of the detraining period seemed to vary amongst the investigators.

Due to the novelty of detraining adaptation analyses the research field is open for continued investigation in this area. An example of how this could be done was by manipulation of the protocols and/or use of different measured response variables. Areas of concern were physiological and metabolic adaptations to detraining during submaximal exercise testing and the analyses of end lactate, terminal heart rate and $\dot{V}O_2SC$ response variables. These measurements are currently gaining significance for assessment of exercise capacity. It is evident that further investigation is warranted to clarify contradictions and ambiguities regarding physiological adaptations to periods of inactivity.

CHAPTER III

JOURNAL MANUSCRIPT

EFFECTS OF DETRAINING ON CARDIORESPIRATORY AND METABOLIC RESPONSES AFTER SIX WEEKS HIGH-INTENSITY CYCLING

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This study evaluated novel submaximal indicators of cardiorespiratory fitness during high constant-load (HCL) exercise tests in response to detraining. A central variable was the slow component VO_2 (SC); SC is defined as the difference between end-exercise VO_2 and 3-min VO_2 (Gaesser et al. *ESSR*, 1996). Terminal heart rate (HR) and blood lactate (HLa) were taken at the end of HCL tests. Ten sedentary males (18-30 yr) were screened and gave informed consent. Subjects completed a maximal and HCL exercise test for baseline assessment. The maximal test variables, VO_2 peak and lactate threshold (LT), were used to set loads for the HCL tests and the training protocol. Cycle ergometer training was done ~30 min/day, 5 days/week for 6 weeks at .70(LT- VO_{2peak}). Subjects were tested at week six of training and then detrained for two weeks. HCL tests were repeated at one and two weeks of detraining and an additional maximal test was performed after week two. Significant differences ($p<0.001$) were found in terminal heart rate following one and two weeks of detraining compared to post-training values, with increases of 6.2% and 5%, respectively. No significant changes occurred for SC and HLa. While terminal heart rate is known to exhibit a rapid time course change in detraining, SC and HLa need to be studied for a longer detraining period.

Introduction

Sedentary individuals can significantly improve exercise capacity through endurance training. There are several physiological response variables that are associated with the assessment of cardiorespiratory fitness. These response variables can be measured by maximal and submaximal exercise testing. Maximal testing continuously measures pulmonary gas exchange, with particular attention to peak VO_2 and peak heart rate. Submaximal testing also examines continuous gas exchange, in addition to hemodynamics and metabolic responses. Submaximal high constant-load tests (HCL) are unique in that they can measure slow component. The slow component (SC) is defined as the difference between end-exercise VO_2 and 3-min VO_2 (Gaesser, 1996). The SC is becoming highly recognized as a valuable tool in exercise conditioning assessment. Several potential mechanisms have been suggested to account for the slow component of VO_2 kinetics. These include: 1) the metabolic stimulatory effect of levels of increasing circulating catecholamines 2) increase VO_2 associated with Q_{10} effect 3) increased ventilatory and cardiac work 4) progressive recruitment of less efficient fast twitch motor units 5) increased O_2 cost of lactate metabolism and 6) alteration in enzyme kinetics associated with reduction of O_2 cost (Whipp, Wasserman 1986). However, there is no agreement in the literature related to the predominant mechanism of O_2 cost. Davis et. al (1995) investigated the reliability of VO_2SC during heavy exercise and found high test-retest reliability (r=0.91). Currently there is no data in the literature regarding detraining and the slow component, allowing its utility in evaluation of training/detraining effects to be studied.

This study was unique because the focus was on response variables associated to high constant-load submaximal exercise testing. The majority of previous literature describes parameters associated with maximal exercise testing and/or the slow component in relation to training adaptations. For appropriate design of this study several investigations were reviewed in regards to training protocols, detraining periods, and associated response variables.

Womack et al. (1995) trained a group of sedentary males 4 days/wk for 6 weeks. The training workload was set at >80% VO_{2max} with a cadence of 60 rpm on a cycle ergometer for ~30 minutes. Womack found significant changes in HR and VO_2SC. SC attenuated by ~50% after the initial two weeks of training. Cullinane et al. (1986) detrained 15 highly trained subjects over 10 days. Cullinane defined "detraining" as continuing to follow normal daily activities but to refrain from any physical activities. Increases in heart rate were detected however no differences were seen in peak VO_2. Houmard et al. (1992) used 10 trained athletes and observed significant decreases in peak VO_2 but not heart rate following 14 days of inactivity.

It is apparent that the possibilities of future research are endless due to the novelty and controversy within this area. Brief periods of inactivity are frequently encountered by individuals that exercise on a regular basis. The purpose of this study was to determine the possible physiological adaptations related to short periods of inactivity following an intense exercise program of previously sedentary males.

Methodology

Subjects

Ten sedentary males (ages 18-30 yr) volunteered for this study. The subjects were screened for current activity level and were given a medical history questionnaire. Only those who indicated that they had not participated in cardiovascular training for at least 6 months and were free from physical limitations were accepted to the study.

Experimental Procedures

All subjects were given a full oral and written explanation of procedures and use of equipment during an orientation session. At this session subjects signed a written consent form and had the opportunity to ask questions.

Each subject completed a maximal and HCL exercise test for baseline assessment. The maximal test variables, VO_2peak and lactate threshold were used to set loads for the HCL tests and the training protocol. Cycle ergometer training was done ~30min/day, 5 days/week for 6 weeks at .70(LT-VO_2peak). Subjects performed submaximal and maximal tests at week six of training and then detrained for a period of two weeks. HCL tests were repeated at one and two weeks of detraining and a final maximal test was performed after week two. Immediately following the maximal test subjects were given specific directions concerning detraining procedures and maintenance of activity logs based on kilocalorie expenditure. After the first week of inactivity subjects performed a single HCL test to measure possible physiological changes after 7 days and following the second week subjects performed a final HCL and maximal test to measure total detraining adaptations.

Maximal Incremental Test

Three maximal tests were performed on the MedGraphics CardiO_2 cycle ergometer on separate occasions, as described above. All tests started with a 5 min rest period and ended with a 5 min recovery period. This allowed researchers to eliminate possible changes due to unfamiliarity of equipment and extreme fatigue, respectively. After the initial rest period subjects started at a power of 0 watts with a cadence of 60 rpm and increased by 20 watts every minute until subjects were unwilling to continue. Pulmonary gas exchange and ventilation were measured continuously using the MedGraphics CPX/D cart. The major test variables included peak VO_2, heart rate (HR), RER, RPE, and Power (watts).

Two blood samples (0.5-1.0ml) were collected at rest and at the end of every one minute stage through an indwelling venous catheter located in the forearm for determination of lactate. The first sample was drawn to clear the catheter and discarded as waste. The second sample was used for analysis. The exact time of the second sample was recorded. The samples were drawn into a vacutainer tube which contained potassium oxalate to prevent glycolysis and sodium fluoride as an anticoagulant to prevent clotting. Immediately after taking the sample it was placed into a slurry of ice for the duration of the test and sample analysis. When ready for analysis the sample was mixed thoroughly and placed into the YSI model 1500 Sport Lactate Analyzer. These samples were used for determination of the LT. The lactate threshold occurs when the accumulation of lactic acid greatly exceeds the removal and an increased amount of blood lactate is found in the body.

Submaximal High Constant-Load Exercise Test (HCL)

The workload for the HCL was derived from the initial maximal exercise test. It was set at 70% of the difference between LT and VO_{2peak}. This initial workload remained constant for each subject throughout the entire study, i.e. it was not altered to coincide with the subject's improved exercise capacity. Each exercise session started and ended with a 5 min rest/recovery period. Pulmonary gas exchange and ventilation were measured continuously during the test. Blood samples were collected after 3 min and at the termination of the test using the same procedures as maximal testing. The major response variables included VO_2SC, terminal heart rate, and end lactate. VO_2SC is a delta score of oxygen uptake and terminal heart rate and end lactate were taken during last minute of exercise.

Statistical Procedures

The subject sample was described using descriptive statistics. Means and standard errors of the means were recorded. One-way analyses of variance (ANOVA) with repeated measures were used to determine the effects of training and detraining upon the difference of the submaximal response variables: slow component, terminal heart rate and end lactate. One-way ANOVA's were used in analysis of maximal exercise testing for the variables: VO_2, Power (watts), RER, peak HR, and RPE. Bonferoni's comparisons were conducted for experiment wise error rates. The 1995 Jandel edition of SigmaSTAT (San Rafel, CA) statistical program was used for all statistical procedures.

It is important to clarify each of the four submaximal trials and the time frame that each represents. The first (PRE) trial was given prior to the 6 wk training protocol for baseline assessment . The second trial (POST) was taken immediately following the sixth week of training to measure training adaptations. The third trial (DT-1) was taken 7 days post-training during which the subjects remained physically inactive. The fourth and final trial (DT-2) was taken after 14 days of inactivity to measure final detraining adaptations. These trials remained consistent for all measured variables. In addition to the submaximal trials there were three maximal test trials that are referred to as PRE-training, POST-training, and DT-2.

Results

Descriptive statistics of subjects are provided in Table 1. Training compliance was 94% and all subjects were able to exercise for the duration of the session (see Table 1). All subjects met two out of the three criteria for maximal exercise testing (see Table 2). These criteria included: leveling off of VO_2 despite an increase in workload, RER of > 1.1, heart rate of ≥ 85% of age predicted maximum. One-way ANOVA with repeated measures on trials were conducted on all maximum response variables which included: VO_2 peak, Power (watts), HR peak, RER, and RPE. Table 3 contains descriptive statistics for these maximum variables. The Bonferoni's comparison analyses showed significant changes ($p<0.001$) for VO_2 peak between all three trials: 3.3 ± 0.2, 3.8 ± 0.2, 3.6 ± 0.2 L/min, pre-training, post-training, DT-2, respectively. The one-way ANOVA for power (watts) was also significant ($p < 0.001$) between PREpower and POSTpower, and PREpower and DT-1 (275 ± 19, 316 ± 19, 307 ± 22 watts, respectively). There was no significant change across trials ($p>0.05$) for HR peak, RER, or RPE.

One-way ANOVA with repeated measures for trials were used for analyses of all submaximal response variables. Table 4 contains descriptive statistics for submaximal variables. Physical activity logs maintained by the subjects showed a 53% decrease in kcals of energy expenditure during the detraining period. The analysis for SC revealed statistical significance ($p<0.001$) between PREsc and POSTsc (536 ± 203, 274 ± 133 ml/min). Following one week of detraining (DT-1) SC increased to 365 ± 103 ml/min. After 2 wk, 308 ± 152 ml/min (DT-2), these changes were not significant ($p>0.05$). See Figure 1 for the SC pattern across all four trials. The subject sample size for all trials was N=10 with the exception of trial four with N=9 subjects.

Terminal heart rate showed statistical significant changes ($p>0.001$) between PREhr and POSThr, PREhr and DT-1, PREhr and DT-2, and POSThr and DT-1, and POSThr and DT-2. The trials of greatest interest due to the detraining time frame were: POSThr and DT-1, and POSThr and DT-2. Respectively, these trials showed response values of 161± 8.9, 171 ± 7.9, 169 ± 7.7 bpm, respectively. The subject sample size for all trials was N=10.

End lactate values did show statistical significance ($p<0.001$) between PREHLa and POSTHLa (11.2 ± 2.8, 7.6 ± 2.3 mMol/L). No statistical significant changes ($p>0.05$) were found between any other trials. However, the trials were associated with increasing lactate through detraining: PREHLa 11.2 ± 2.8, POSTHLa 7.6 ± 2.3, DT-1 8.1 ± 1.9, DT-2 8.6 ± 1.1 mMol/L. See Figure 2 for end lactate pattern across all four trials and the sample subject size was reduced to N=6. It is important to note that the subject sample size did not remain consistent for all trials in computing statistical analyses (Table 5). An analysis was run on RPE which showed statistical significance ($p<0.001$) between PRErpe and POSTrpe, PRErpe and DT-1, and PRErpe and DT-2. Statistical significance ($p>0.05$) was not found between any other trials.

Discussion

The purpose of this study was to determine possible physiological adaptations related to brief periods of inactivity following vigorous aerobic training. The measured maximal response variables were useful in determining if training and detraining had taken place. The results of the analyses showed that both adaptations had taken place because of the statistical significance found in VO_2peak and in Power (watts) as measured in the maximal tests of this study. The fact that RER, peak HR, and RPE did not change significantly showed that all test were consistent and maximal in nature.

The measured submaximal response variables VO_2SC, terminal heart rate, and end lactate were of central importance in this study. Eighty percent of the subjects obtained VO_2 values in these submaximal tests that equaled or exceeded their measured VO_2peak values. Gaesser (1996) states that "eliciting a VO_2max with submaximal work rates is a common consequence of VO_2SC". Significant physiological changes occurred with detraining and the results indicate that just one week of inactivity can impact exercise capacity.

The findings of these analyses agree with some investigators and contradict others. The mean values of the SC variable in this study were similar to other investigators in regards to SC and training. Womack (1995) had a similar training cycling protocol and saw SC rapidly and significantly respond to training after 2 wk. The magnitude of reduction was ~ 220 ml/min. The results of this study showed a reduction of ~260 ml/min with a range of 93 to 837 ml/min. Gaesser (1996) reported that it was not uncommon to observe a SC range of 500 ml/min to >1000 ml/min. Due to the limited research with the SC, no current published data exists on SC that may occur with detraining. The majority of the previous investigations have concentrated on use of maximal VO_2 uptake to define rates of aerobic fitness decline with detraining. This study did reveal statistical significance in regards to maximal oxygen uptake between all three trials. This was similar to other researchers with comparable protocols (Houmard 1992, Coyle 1985) yet contradicted others (Cullinane 1986, Madsen 1993, Moore 1987) because they did not find significance.

The results of this study for terminal HR were similar to the findings of Houmard (1992). Houmard found significance ($p<0.05$) in terminal heart rate (173 to 184 bpm) of trained individuals following 14 days of detraining. Few researchers actually examined submaximal testing so the majority of comparisons were in regards to maximal HR response following periods of detraining. When comparing the maximal trials of the present study the results agreed with Cullinane's (1986) 10 days of detraining investigation. Cullinane found statistical significance ($p<0.05$) in maximum heart rate (183 bpm to 192 bpm) following this period of inactivity. Coyle in 1985 conducted a detraining study in which the subjects ceased physical activity for 12 days and found a significant increase (158 to 170 bpm) in maximum heart rate response. However, 1987 Moore's results contradicted Coyle's findings because Moore found no difference in maximal heart rate following 21 days of detraining.

The statistical analyses of the end exercise lactate response revealed a difference ($p<0.01$) between training and detraining but minimal changes ($p>0.05$) were observed during detraining. These findings are similar to those of SC in that significance was found between the first two trials and not between the last 3 detraining trials. This shows a response consistency that supports a possible link between aerobic and anaerobic mechanisms. According to previous literature attention has been given to the relationship between SC and HLa. Casaburi et al. (1987) demonstrated that after 8 wk of training the reduction in VO_2SC was significantly correlated with reductions in end exercise lactate during high constant-load exercise bouts. Evidence both for and against HLa concentrations as a mediator of the VO_2SC have been addressed in literature (Gaesser 1994).

It is evident that terminal heart rate is affected with acute periods of detraining but the time course remains unclear for SC and end HLa. A longer detraining period would be needed to determine when those major components of fitness would be significantly affected: thereby giving a more accurate assessment of the time course for detraining adaptations. In regards to practical implications these findings do suggest that if given a choice of whether to continue or cease activity for a brief duration (i.e. greater than 7 days) the decision should be to continue with exercise to avoid possible reductions in cardiovascular responses.

Table 1. Descriptive Characteristics of the Subjects (n=10)

Subject (Males)	Age (years)	Height (cm)	Weight (kg)	Training Compliance (%)
1	25	174	83	93
2	23	177	92	93
3	27	171	99	90
4	26	183	78	97
5	22	184	85	100
6	23	182	82	90
7	24	183	96	97
8	30	174	76	100
9	26	178	79	93
10	30	181	80	90
Mean ± SE	26 ± 1	179 ± 2	85 ± 3	94 ± 1

Table 2. Peak Test Summary Data for Maximal Test Variables

Subject	Trial	VO_2 (L/min)	HR (bpm)	RER	RPE	Power (Watts)
1	1	3.39	190	1.27	19	300
	2	3.99	185	1.20	17	351
	3	3.67	188	1.22	15	341
2	1	3.38	178	1.23	17	294
	2	3.93	170	1.15	16	327
	3	3.58	169	1.14	20	288
3	1	3.30	182	1.14	16	254
	2	3.97	182	1.16	17	326
	3	3.85	175	1.13	20	309
4	1	2.99	188	1.19	16	268
	2	3.78	186	1.17	17	314
	3	3.63	197	1.18	20	312
5	1	3.38	198	1.21	13	265
	2	3.69	196	1.27	16	310
	3	3.72	196	1.26	20	331
6	1	3.39	181	1.16	17	275
	2	3.69	186	1.28	19	315
	3	3.49	178	1.14	18	300
7	1	3.43	174	1.23	19	279
	2	3.63	162	1.17	19	300
	3	3.55	171	1.18	19	280
8	1	2.73	188	1.32	20	238
	2	3.38	190	1.22	19	280
	3	3.12	188	1.22	19	280
9	1	3.23	187	1.19	20	292
	2	3.68	180	1.22	19	320
	3	3.66	179	1.21	20	330
10	1	3.25	187	1.23	15	280
	2	3.72	185	1.16	17	320
	3	3.68	176	1.10	17	300
Mean ± SEM	1	3.25 ± 0.07	185 ± 2.15	1.22 ± 0.02	17 ± 0.7	275 ± 6.0
	2	3.75 ± 0.06	182 ± 3.09	1.20 ± 0.01	18 ± 0.4	316 ± 5.8
	3	3.60 ± 0.06	181 ± 3.15	1.17 ± 0.02	19± 0.5	306 ± 7.0

Table 3. Descriptive Statistics for Maximal Test Variables

Variables	Trials	Mean	Std. Dev.
VO_2 peak	1	3.3	0.2
	2	3.8	0.2
	3	3.6	0.2
Power(watts)	1	275	19
	2	316	19
	3	307	22
HR peak	1	185	7
	2	182	10
	3	182	10
RER	1	1.2	0.1
	2	1.2	0.1
	3	1.2	0.1
RPE	1	17	2
	2	18	1
	3	19	2

N=10 (subject sample size)

Table 4. Descriptive Statistics on Submaximal Response Variables

Variables	Trial	Subjects (n)	Mean	Std Dev
SC	1	10	536	203
	2	10	274	133
	3	10	365	103
	4	9*	308	152
HR	1	10	186	9
	2	10	161	9
	3	10	171	8
	4	10	169	8
HLa	1	7*	11.2	2.8
	2	8*	7.6	2.3
	3	7*	8.1	1.9
	4	6*	8.6	1.1
RPE	1	10	17	3
	2	10	12	3
	3	10	13	2
	4	10	14	1

*Denotes a subject sample size <10.

Table 5. Submaximal Test Summary Data

Subject	Trials	SC (ml/min)	VO_2 term (L/min)	HLa term (mMol/L)	HR term (bpm)	RPE
1	1	402	3.27		186	19
	2	184	3.15		159	8
	3	281	3.27		172	10
	4	245	3.19	7.3	169	12
2	1	529	3.64		182	15
	2	174	3.39		147	11
	3	389	3.53	8.9	164	13
	4	422	3.52	9.0	177	14
3	1	504	3.53	8.4	180	18
	2	093	3.07	3.6	155	13
	3	235	3.09	4.3	162	13
	4	247	3.24		162	16
4	1	779	3.15	13.2	197	17
	2	380	2.93	9.1	171	12
	3	349	2.90	9.1	176	13
	4	322	3.00	9.3	178	13
5	1	770	3.47	14.3	205	20
	2	240	3.00	7.9	175	10
	3	380	3.12	7.7	178	10
	4	480	3.20	10.3	181	12
6	1	415	3.31	10.3	186	16
	2	250	3.25	4.8	162	10
	3	400	3.12	9.6	178	13
	4				170	14
7	1	837	3.74		179	18
	2	342	3.45	9.4	163	16
	3	590	3.59		169	15
	4	570	3.51		160	13
8	1	555	2.89	13.0	190	17
	2	239	2.56	7.4	164	16
	3	446	2.73		175	17
	4	156	2.61		167	16
9	1	329	3.32	12.4	183	20
	2	267	3.15	8.3	150	15
	3	270	3.24	7.3	155	15
	4	143	3.06	7.6	159	14
10	1	235	2.98	6.7	176	11
	2	571	3.27	10.3	168	13
	3	312	3.15	9.8	177	14
	4	189	3.02	8.3	167	13

Trial 1: Pre - train submaximal test
Trial 2: Post - six weeks training submaximal test
Trial 3: Post- detrain one week submaximal test
Trial 4: Post - detrain two weeks submaximal test

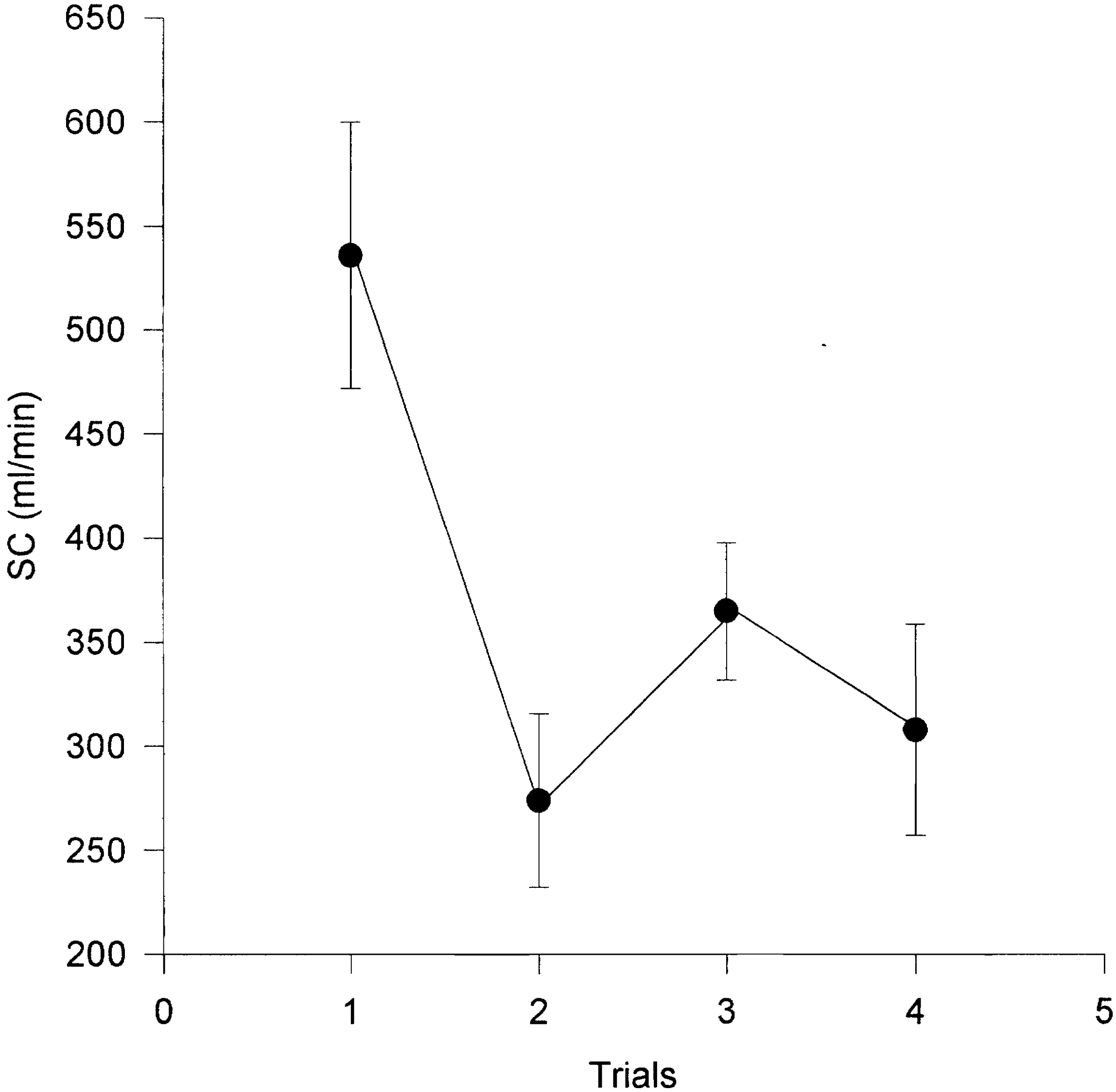

Figure 1. Slow Component Response During Submaximal Exercise

Vertical bars represent standard error of the mean

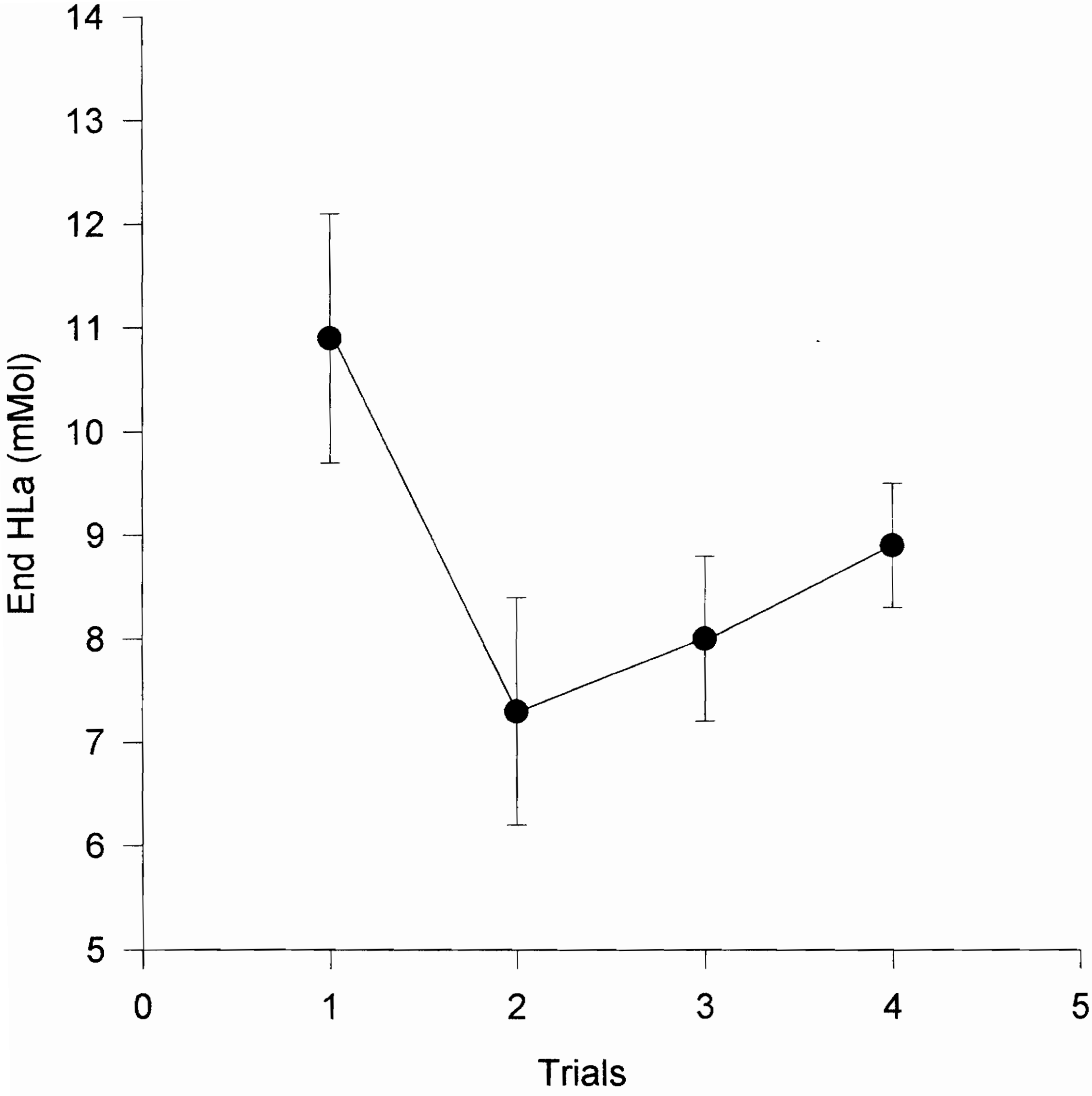

Figure 2. End Lactate Response During Submaximal Exercise

Vertical bars represent standard error of the mean

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CHAPTER IV

RESULTS AND DISCUSSIONS

Introduction

The VO_2 slow component, terminal heart rate and end lactate are important submaximal response variables in assessment of cardiorespiratory fitness and exercise capacity. With increased levels of fitness, heart rate, lactate and slow component values typically decrease during constant-load submaximal exercise tests. This investigation studied 10 sedentary adult males between the ages of 18-30 years. The subjects participated in a training period 5 days/week for six weeks. Each exercise session lasted ~30 minutes and the workload on the Monarch 818 E Cycle Ergometer was set at 70% of the difference between LT and VO_{2peak} with a cadence of 60 rpm. Maximal and submaximal exercise tests were performed prior to training and immediately following the six weeks of training. The VO_2SC, terminal heart rate and end lactate were the measured response variables. These tests were used to establish that training had taken place. Following this training period the subjects detrained for two weeks. Detraining was defined as continuing with normal daily routines without additional physical activity. After the first seven days of detraining the subjects performed a HCL exercise test to measure possible initial changes. Following the second week of inactivity the subjects repeated a final submaximal and maximal test to measure total physiological adaptations.

The focus of this investigation was the relationship between the submaximal high constant load exercise tests in regards to the VO_2SC, terminal heart rate, and end lactate response variables. It is important to clarify each of the four submaximal trials and the time frame each represents. The first trial (PRE) was taken prior to the six week training protocol for baseline assessment.

The second trial (POST) was taken immediately following the sixth week of training to measure training adaptations. The third trial (DT-1) was taken seven days post-training during which the subjects remained inactive. The fourth and final trial (DT-2) was taken after 14 days of inactivity to measure total detraining adaptations. These trials remained consistent for all measured variables. There were three maximal test trials that will be referred to as PRE-training, POST-training, and DT-2.

Results

Subject descriptive statistics are provided in Table 1. Training compliance was 94% and all subjects were able to exercise for duration of the session (see Table 1). All subjects met two out of the three criteria for maximal exercise testing (see Table 2). These criteria included: leveling off of VO_2 despite an increase in workload, RER of > 1.1, heart rate of ≥ 85% of age predicted maximum. One-way ANOVA with repeated measures across trials were conducted on all maximum response variables which included: VO_2 peak, Power (watts), HR peak, RER, and RPE. The analyses showed a significant ($p<0.001$) difference for VO_2peak between all three trials (3.25 ± 0.22, 3.75 ± 0.18, 3.60 ± 0.19 L/min, PRE, POST, DT-2, respectively). The one-way ANOVA for Power (watts) was also significant ($p < 0.001$) between all three trials (275 ± 19.1, 316 ± 18.5, 307 ± 21.6 watts). There was no significance ($p>0.05$) for HR peak, RER, and RPE.

One-way ANOVA with repeated measures for trials were used for analyses of all submaximal response variables. The analysis for SC revealed statistical significance ($p<0.001$) between PREsc and POSTsc (536 ± 203, 274 ± 133 ml/min). Following one week of detraining (DT-1) SC increased to 365 ± 103 ml/min and 308 ±152 ml/min after two weeks (DT-2). These findings were not significant ($p>0.05$). The subject sample size for all trials was 10 with the exception of trial four with 9 subjects.

Terminal heart rate showed statistical significance ($p>0.001$) between PREhr and POSThr, PREhr and DT-1, PREhr and DT-2, and POSThr and DT-1, and POSThr and

DT-2. The trials of greatest interest due to the detraining time frame were: POSThr and DT-1, and POSThr and DT-2 showed response values of 161± 8.91, 171 ± 7.92, 169 ± 7.66 bpm. The subject sample size for all trials was 10.

End lactate values did show statistical significance ($p<0.001$) between PREHLa and POSTHLa (11.2 ± 2.8, 7.6 ± 2.3 mMol/L). No statistical significance ($p>0.05$) was found between any other trials. However, the trials did seem to approach a pattern: PREHLa 11.2 ± 2.8, POSTHLa 7.6 ± 2.3, DT-1 8.1 ± 1.9, DT-2 8.6 ± 1.1 mMol/L. It is important to note that the subject sample size did not remain consistent for all trials (see Table 5). Due to the small sample size the statistical power was low. An analysis was run on RPE which showed statistical significance ($p<0.001$) between PRErpe and POSTrpe, PRErpe and DT-1, and PRErpe and DT-2. Statistical significance ($p>0.05$) was not found between any other trials.

Discussion

The purpose of this study was to determine possible physiological adaptations related to short periods of inactivity. The measured maximal response variables were useful in determining if training had taken place from baseline assessment and then the amount of detraining that had taken place since training. The results of the analyses showed that both adaptations had taken place. Significance occurred amongst all maximal trials with VO_2peak, and PRE and POST trials with Power. The fact that RER, peak HR, and RPE were not significantly different showed that all test were consistent and maximal in nature.

The measured submaximal response variables VO_2SC, terminal heart rate, and end lactate were useful in assessment of cardiorespiratory fitness. Eighty percent of the subjects obtained maximal responses during submaximal testing. Gaesser (15) states that "eliciting a VO_2max with submaximal work rates is a common consequence of VO_2SC". Significant physiological changes occurred with detraining and the results indicate that just one week of inactivity can impact exercise capacity and thereby affect performance.

The findings of these analyses agreed with some investigators and contradicted others in regards to statistical significance of the various response variables. The mean values of the SC variable followed increases and decreases until DT-2. This may be due to the high variability of a few subjects and possible increases in general activity from week one of detraining to week two. The results of this study were similar to other investigators in regards to SC and training. Womack (27) had a similar training cycling protocol and saw SC rapidly and significantly respond to training after two weeks. The magnitude of reduction was ~ 220 ml/min. The results of this study showed a reduction of ~260 ml/min with a range of 93 to 837 ml/min. Gaesser (15) reported that it was not uncommon to observe a SC range of 500 ml/min to >1000 ml/min. Due to the limited research with submaximal testing following detraining and the SC, no current published data exists in this area. The majority of the investigators concentrated on maximal VO_2 uptake. This study did reveal statistical significance between all three maximal trials. This was similar to other researchers with comparable protocols (16, 9) yet contradicted others (10,17,18) because they did not find significance.

Terminal HR was another major response variable. The statistical analyses revealed significance between all trials except for DT-1 and DT-2. This may simply be due to the fact that the first seven days of detraining had a greater cardiovascular impact than the following seven days. The results of this study for terminal HR were similar to the findings of Houmard (16). Houmard found significance ($p<0.05$) in terminal heart rate (173 to 184 bpm) of trained individuals following 14 days of detraining. Few researchers actually have examined submaximal testing so the majority of comparisons were in regards to maximal HR response following periods of detraining. When comparing the maximal trials of this study the results agreed with Cullinane's ten days of detraining investigation. Cullinane found statistical significance ($p<0.05$) in maximum heart rate (183 bpm to 192 bpm) following this period of inactivity. Coyle in 1985 (9) had a detraining study in which the subjects ceased physical activity for twelve days and found a significant increase (158 to 170 bpm) in maximum heart rate response. However, in 1987 Moore (18) contradicted these findings because the researcher found no statistical difference in maximal heart rate following 21 days of detraining.

The final measured submaximal response variable was end lactate. Due to the varied subject sample size, the end lactate response does not have strong statistical power and therefore caution should be used when interpreting results. However, the results of the analyses does show statistical significance between PRE-training and POST-training. These findings are helpful in demonstrating that training had taken place and are similar to Gaesser and Poole's (14) research in 1986. Theses authors found statistical significance ($p<0.05$) following three weeks of intense training ($7.9 \pm 1.3/5.4 \pm 0.9$ mMol/L).

Future Recommendations for Further Study

One aspect that deserves further investigation deals with the duration of the detraining protocol. It would prove beneficial to extend the detraining period to examine the time course of physiological response. Investigators could determine which response variables (i.e. cardiovascular, cardiorespiratory) may deteriorate more rapidly during detraining. It would also be important to go in the other direction and measure even shorter time periods (i.e. 6, 5, 4 or 3 days) since significant changes were detected with heart rate after the initial seven days. Being able to determine the overall time course of adaptations would serve as a useful tool in maintenance of fitness.

Another recommendation might be to follow up the detraining period with the same training protocol and examine how long it takes for individuals to return back to peak training levels. This would be another helpful tool in maintaining fitness. If a situation was to arise when an individual had to cease physical activity for a time period it would be beneficial to know how long it would take to get back to those peak levels.

Changing the training protocol would be another valuable way to continue research in this area. Altering the level of physical fitness, by increasing or decreasing the intensity, and/or duration, and/or frequency would change the fitness level of the individuals. Being able to compare various fitness levels and detraining adaptations to these levels would be of great interest. It would be favorable to know which training levels are more resistant to detraining adaptations. Many areas of investigation are open in regards to physiological adaptations to detraining. This study provides a start for future research in several different directions.

Summary

The purpose of this study was to determine possible physiological adaptations related to brief periods of inactivity. The measured response variables, VO_2SC, terminal heart rate, and end lactate are useful in the assessment of cardiorespiratory fitness. This study provided valuable information regarding changes in physical capacity over short periods of time. The results indicate that just one week of inactivity can impact exercise performance. If given a choice of whether to continue to exercise or take an extended break (i.e. greater than 7 days) then the decision should be to continue with physical exercise and prevent significant loss of cardiorespiratory fitness. This study gives other researchers a start with other possible investigations regarding detraining adaptations over time.

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APPENDIX A

METHODOLOGY

Subjects

Ten sedentary adult males (age 18-30) were recruited on a volunteer basis from the Virginia Tech student body and the surrounding community. All subjects were screened for medical concerns through a health history questionnaire (Appendix B). Current activity level was assessed and if the subject had been active within the prior 6 months they were not considered for inclusion in the study. The subjects were screened for any orthopedic, cardiovascular, and/or cardiorespiratory limitations. Subjects free from all exclusion criteria were then given an informed consent (Appendix C) as approved by the Human Investigation's Committee at Virginia Polytechnic Institute and State University.

Orientation Procedures

The orientation session consisted of familiarization with laboratory equipment and explanation of all procedures. The training sessions were described in great detail and an explanation of how the training intensity was determined was fully explained. The subjects were placed on the Monarch E 818 cycle ergometer. All training was performed on this cycle. The appropriate seat height was set and cycle number recorded. The subject was asked to free-wheel for a few minutes to become more familiar with training cycle. The subjects were then instructed regarding exercise testing. The subjects were asked to sit on the MedGraphics CardiO_2 cycle. This cycle was used for all exercise testing and the seat height was set and recorded. The subjects were instructed to put the mouthpiece in and nose clip on, and to free-wheel for brief period of time. This allowed the subjects ample time to practice and become adjusted to the mouthpiece and testing situation. The subjects were then informed on blood sampling procedures and shown all equipment and instruments to be used for collection.

Experimental Procedures

Subjects went through a training protocol for six weeks and were tested on seven different occasions. Three of the tests were maximal in nature and four were submaximal. Upon entrance into the study the subjects performed one maximal test and one submaximal test to establish baseline measurements. It was from this initial maximal test that the training protocol and workload of the submaximal tests was determined. Following these two baseline measurements was a 6 week training program. The subjects cycled 5 days/wk for six weeks. At completion of the training the subjects returned to the lab for another maximal and submaximal test to measure training adaptations. After the maximal post-training test the subjects were given specific instructions to following regarding detraining (Appendix D) and activity logs (Appendix E). Following seven days of detraining the subjects returned to the lab for one submaximal exercise test and at the conclusion of the second week of inactivity the subjects performed a final submaximal test and maximal exercise test to measure total detraining adaptations.

All testing was performed at approximately the same time of day. Upon arrival to the lab for testing the subject was questioned for adherence to dietary and exercise rules. If any testing restrictions were broken the subject was asked to return the next day for testing. At the beginning of each session the weight was recorded and appropriate recorded seat height was set. Each subject was asked to rest on the cycle for 5 minutes with the mouthpiece in place. This gave adequate time for the subject to become adjusted to the feel of the mouthpiece. During all exercise testing there was continuous assessment of gas exchange, heart rate was monitored every 2 minutes, and blood samples were collected.

Maximal Incremental Test

Three maximal tests were performed on the MedGraphics CardiO_2 cycle. The tests were administered at baseline, upon completion of the six week training period, and following a two week period of inactivity. All tests started with a five minute rest period and ended with a five minute recovery period. After the five minute initial rest period the subjects started out at a workload of 0 watts and a cadence of 60 rpm. Every minute the workload increased 20 watts until volitional exhaustion. This protocol was designed to elicit VO_{2peak} in 12-15 minutes. VO_{2peak} was determined valid if two of the three criteria were achieved: 1) leveling off of VO_2 despite an increase in workload, 2) RER equal to or greater than 1.1, and 3) HR of at least 85% of age-predicted maximum.

Pulmonary gas exchange and ventilation were measured continuously using the MedGraphics CPX/D metabolic cart. Breath-by-breath measurement was made with 8 breath averaging for analysis. Subjects breathed through a disposable mouthpiece, which allows inspiration of room air and a nose clip. Heart rate was monitored every minute on a Physio-Control Lifepack 9 Portable Defibrillator through an electrical signal from three electrodes that were placed on the torso. Blood samples were collected every minute starting with rest and ending during recovery. Data was recorded on an incremental data sheet specifically constructed for the purpose of these particular tests (Appendix F).

Incremental Blood Draws:

Two blood samples (0.5-1.0 ml) were drawn at rest and at the end of each one minute stage for the duration of the exercise bout through an indwelling venous catheter located in the forearm for determination of lactate. The first sample was drawn to clear the catheter and discarded as waste. The second sample was used for analysis. The exact time of the second sample was recorded. The samples were drawn into a vacutainer tube which contained potassium oxalate to prevent glycolysis and sodium fluoride as an anticoagulant to prevent clotting. Immediately after taking the sample it was placed into a slurry of ice for the duration of the test and sample analysis. When ready for analysis the sample was mixed thoroughly and placed into the YSI model 1500 Sport Lactate Analyzer.

High Constant-Load Exercise Test (HCL)

The workload for the HCL was derived from the initial maximal exercise test. The HCL was set at 70% of the difference between lactate threshold and VO_{2peak}. This initial workload remained constant for each subject throughout the entire study, it was not altered to coincide with the subject's improved exercise capacity. Each exercise session started with a five minute rest period and ended with a five minute recovery period. Pulmonary gas exchange and ventilation was measured continuously with MedGraphics metabolic cart and heart rate was monitored every two minutes by the Lifepak 9. Data was recorded on data sheets made specifically for these exercise tests (Appendix G). The same circumstances applied regarding personnel, emergency procedures, and types of equipment used for all exercise testing.

Constant-Load Blood Draws:

A total of two blood samples (0.5-1.0ml) were drawn at 3 minutes into exercise and immediately following the conclusion of the exercise bout, signifying the peak VO_2. Samples were taken with a 23 gauge butterfly needle and collected into vacutainer tubes containing sodium fluoride and potassium oxalate. The subjects had a total of two blood draws per constant load exercise test.

Determination of VO_{2peak}:

Must meet two or more of the following criteria:

- leveling off of VO_2 despite an increase in workload

-Respiratory exchange ratio (RER) equal to or greater than 1.1

-Heart rate (HR) of at least 85% of age-predicted maximum

Determination of High Constant Load Test & Training Protocol:

Power output (PO) at Lactate Threshold (LT)

.70 (PO at peak _____ - PO at LT _____) =

Power output = _____ watts

watts/cadence = training workload in kilopounds

Determination of Lactate Threshold:

Determined using a modification of the threshold model developed by Beaver, Wasserman, and Whipp 1985. The three-person method was also used to determine the workload at the "lactate threshold". This point was selected as the point just before the sudden increase in lactate accumulation and was used in the development of an appropriate training protocol.

Determination of Slow Component:

Subtract the VO_2 at the third minute from the VO_{2peak} (last minute of exercise). The minutes are based on a 8 second breath averaging.

Reliability of VO_2

A study by Davis et al. (1995) investigated the reliability of VO_2 during heavy exercise. A group of adult males completed a maximal exercise test and a series of 6 submaximal constant load tests on a cycle ergometer. The constant load test was set at >80% VO_{2peak}. The reliability coefficient was r = .91. The results suggested that the VO_2 elicited during heavy exercise has a high test-retest reliability.

Reliability of Heart Rate

Ueda et al. (1995) studied RPE, VO_2, HR, and HLa for reliability. The relationship between VO_2, HR and RPE were linear with a level of fitness correlation. Heart rate is known to be a linear function of power output. Ueda found a reliability coefficient of $r = 0.99$.

Data Analysis

The subject sample was described using descriptive statistics (Appendix H). Means and standard deviations of the mean were recorded. Maximal and submaximal response variables were also described using descriptive statistics (Appendix I). A summary of data tables are provided in Appendix J. Previous literature provided sufficient evidence of the reliability of maximal exercise tests and terminal heart rate. One-way ANOVA with repeated measures on trials were calculated using the 1995 Jandel edition of SigmaSTAT statistical program (Appendix K-L). Raw data appears in Appendix M.

Research Hypotheses

H_{O1}: Following a two week period of inactivity there was no difference on ventilatory kinetics (VO_2SC) after six weeks of high-intensity cycle ergometer training at 70% of the difference between lactate threshold (LT) and VO_{2peak}.

Test: One-way ANOVA with repeated measures

Conclusion: Fail to reject the null hypothesis

H_{O2}: Following a two week period of inactivity there was no difference on terminal heart rate after six weeks of high-intensity cycle ergometer training at 70% of the difference between lactate threshold (LT) and VO_{2peak}.

Test: One-way ANOVA with repeated measures

Conclusion: Reject the null hypothesis

H_{O3}: Following a two week period of inactivity there was no difference on end lactate after six weeks of a high-intensity cycle ergometer training at 70% of the difference between lactate threshold (LT) and VO_{2peak}.

Test: One-way ANOVA with repeated measures

Conclusion: Fail to reject the null hypothesis

APPENDIX B

HEALTH HISTORY QUESTIONNAIRE

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Health History Questionnaire

Subject #: ______

Title of Project: Detraining on Cardiorespiratory and Metabolic Responses

Investigator: Laurie A. Bullock, B.S., Shala E. Davis, Ph.D., William G. Herbert, Ph.D., Don Sebolt, P.E.D.

Please complete the following questionnaire as accurately as possible.

Name:____________________ Age: ______ Date of Birth: ______________

Address: ____

____

____

Phone: (540) ________________________ (home)
(540) ________________________ (work)

1. Do you have any known allergies? Y N

   If yes, please explain:

2. Do you currently take any medications? Y N

   If yes, please explain:

3. Do you currently exercise regularly? (greater than 1 time per week)

   Y N

   If yes, please explain:

4. Please mark those that apply to you:

high blood pressure	Y	N
skipped heart beats	Y	N
diabetes	Y	N

dizziness or fainting	Y	N
asthma	Y	N
chest discomfort	Y	N
heart murmur	Y	N
musculoskeletal disorder	Y	N
smoking/tobacco	Y	N
fast heart rate	Y	N
shortness of breath	Y	N
joint soreness	Y	N

If yes, please explain:

5. Is there any reason not mentioned above that would limit your ability to perform high-intensity exercise?

Y N

If yes, please explain:

6. Has a physician ever told you to refrain from activity or exercise for an extended period of time?

Y N

If yes, please explain:

7. Do you have any difficulty with getting your blood taken?

Y N

If yes, please explain:

Signature: ______________________

Date: ______________________

APPENDIX C

INFORMED CONSENT

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigational Projects

Subject #: _______

Title of Project: Effects of detraining on cardiorespiratory and metabolic responses after six weeks high-intensity cycling

Investigator: Laurie A. Bullock, B.S.

I. The Purpose of the Research/Project

I am being asked to participate in a research study about exercise training and a brief period of inactivity for two weeks post-exercise. This research study will involve exercise testing for the purpose of assessing the changes in oxygen consumption to exercise over 6 weeks of endurance training on a bicycle ergometer followed by two weeks of detraining. Although most experts agree that, following an endurance training program, I will be able to exercise at a higher maximal workload and my maximal oxygen consumption will increase, it remains unclear whether changes in exercise performance and oxygen consumption occur at submaximal exercise work levels. Ten healthy, physically inactive, males are being asked to participate in this research study.

II. Procedures

Prior to being included in the research study, I will complete a health history that will help to determine if there may be reasons why I should not participate in this study. If the results of the health history indicate that I am an appropriate subject for this study, than I will be informed of when I should report to the Laboratory for Health and Exercise Sciences at 230 War Memorial Hall for initial exercise testing.

Maximal exercise testing. As a subject, I understand that I will perform 3 maximal exercise tests on a cycle ergometer to determine the maximal amount of exercise that I can perform. One test will be performed at the start of the research study, after the 6 week training period, and immediately following a two week period of inactivity. I will need to report to the laboratory 30 minutes before each test is to begin, and at least 4 hours after consuming any food or caffeinated beverage.

Prior to each test, I will be connected by electrodes and cables to an electrocardiograph recorder which will enable the technician to monitor my heart rate. I will also be fitted with a breathing apparatus (mouthpiece and nose clip) which will measure my exhaled gases to properly measure oxygen consumption. A registered nurse/licensed medical technician will insert a special tube called an intravenous catheter into a vein in my arm to collect blood samples for blood lactate analysis. I will remain in place for the entire testing period: approximately 45 to 60 minutes. Through the course of each maximal exercise test, a total of approximately 12.5 mls (amount is approximately equal to 2.5-3.0 teaspoons) of blood will be taken for laboratory analysis. These samples will be taken at rest and every minute during exercise and recovery.

The maximal exercise test which I will undergo will be performed on a stationary cycle ergometer with the amount of effort gradually increased. As I understand it, the increase in effort will continue until I report to the technician that I am unable to continue. I will decide when I am unable to continue and the technician will stop the test when I so request.

Submaximal testing. Approximately two days after completing the first maximal test I will be asked to perform a high-intensity submaximal bicycle ergometer test. Unlike during the maximal exercise test where the amount of effort is gradually increasing, I will pedal at the same work rate for the entire duration of the test. The period during the study where I will perform the high-intensity test will include: the beginning of the research study, after 6 weeks, one week post-exercise, and two weeks post-exercise. Therefore, upon completion of the study I will have completed 4 high-intensity exercise tests over the 6 week period.

I understand that I will need to report to the laboratory 30 minutes before these test are to begin, and at least 4 hours after consuming any food or caffeinated beverage. I will again be connected with electrodes and cables to an electrocardiograph recorder which will enable the technician to monitor my heart rate. I will also be fitted with the breathing apparatus (mouthpiece and nose clip) to measure my exhaled gases. During each test, a registered nurse/licensed medical technician will insert an 23 gauge butterfly needle into my arm after first three minutes of exercise and again at the end of my exercise bout. Through the course of each submaximal test, a total of approximately 3 mls (a little less than 0.5 teaspoons) of blood will be taken for laboratory analysis.

I understand that the workload used for this high-intensity exercise test will be determined from the first maximal exercise test. This workload will not be changed throughout the duration of the study. For each constant-load test I will be asked to exercise for a period not greater than 15 minutes.

Exercise Training. Following the first maximal and submaximal tests it is my understand that I will be participating in a high intensity exercise program. I will report to the Laboratory for Health and Exercise Science for 5 exercise sessions per week, with each session lasting ~30-45 minutes. I understand that this training period will last 6 weeks followed by a two week period of inactivity. I understand that it is important that I do not perform additional physical training outside of the study (running, biking, swimming, etc.).

It is my understanding that each training session will include a brief warm-up including light stretching, followed by the cycle training period, and a brief cool-down. My training workload will be depend on my maximal exercise test.

III. Risks

It is my understand and I have been informed that there exists the possibility during exercise of adverse physiologic responses during the tests. I have been informed that these changes could include abnormal blood pressure, fainting, disorders of the heart beat, and in rare instances, heart attack, stroke, or death. Every effort will be make to minimize these risks by evaluation of the preliminary information relating to your health and by observations during testing. Other possible discomforts I may experience in this study include leg fatigue, muscle soreness, a dry mouth (from the mouthpiece), pain, bleeding and local bruising at the site the blood was taken. I understand that the registered nurse/licensed medical technician collecting the samples, and that the technicians who may be handling samples, will be wearing gloves at all times. I also understand that a registered nurse or licensed medical technician, certified exercise specialist and other support personnel will be present during all exercise testing to minimize the risks during exercise. I also understand that there is also a working telephone in the exercise testing area that can be used to alert the emergency rescue squad on the campus of Virginia Tech. Their average response time in getting to the Laboratory for Health and Exercise Science is approximately 4 to 5 minutes.

IV. Benefits of the Project

My participation in the project will provide valuable information that will help clarify the type of training and time needed to change my ability to exercise at high intensity levels. In addition, I will receive information regarding my physical condition, exercise tolerance, and changes during two week period of inactivity. I will also be provided, at no cost, the use of exercise training equipment and facilities.

V. Extent of Anonymity and Confidentiality

The results of this study will be kept strictly confidential. At no time will the researchers release my results of this study to anyone other than the individuals working on the project without your written consent. The information I provide will have my name removed and only a subject number (excluding social security numbers) will identify me during analyses and written reports of this research.

VI. Compensation

I understand that there is no monetary or course credit compensation available for participants in this project.

VII. Freedom to Withdraw

I understand that if I refuse to participate in this research study or choose to discontinue my participation at anytime, no penalties or loss of benefits to which I am otherwise entitled to will occur.

VIII. Approval of Research

This project has been approved, as required, by the Institutional Review Board for projects involving human subjects at Virginia Polytechnic Institute and State University and the Department of Human Nutrition and Foods and Exercise.

IX. Subject's Responsibilities

I know of no reason I cannot participate in this study. I have the following responsibilities:

1. Accurately report my medical history

2. Arrive at the laboratory 30 minutes prior to all exercise testing

3. Arrive at the testing laboratory 4 hours post-absorptive for all testing
4. Report and complete all training sessions (5 sessions/wk; 6 wks)
5. Report and complete two week period of inactivity through use of activity logs
6. Refrain from other forms of physical training (i.e. jogging, biking, etc.) for the duration of the study
7. Report any unusual signs/symptoms during the study

X. Subject's Permission

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at anytime without penalty. I agree to abide by all rules of this project.

______________________________ ____________________

Signature Date

Should I have any questions about this research or its conduct, I will contact:

Laurie A. Bullock
Investigator

961-2925
Phone (home)

231-5006
Phone (laboratory)

231-4900
Phone (office)

APPENDIX D

INSTRUCTIONS

INSTRUCTIONS

*All testing will be at least **4 hours post-absorptive**. This includes **no** food, caffeinated beverages, and/or nicotine

*Please notify the lab if you are going to miss an exercise test and/or training session

*Keep all other activity to a minimum while participating in this study

*Relay any activity to the researcher upon arrival of training/testing to assure proper documentation

*Continue to eat a balanced diet, drink plenty of fluids and get lots of rest

*Avoid excessive walking and/or stair climbing

Diet logs and Detraining:

*Please **record all significant activity** during the day. If nothing is written down it will suggest that the subject was sitting or standing still.

*Please record all walking time during the day. This includes walking around the house, at work, shopping, etc. It is an estimate of total time walking throughout one day.

*Weight training of the upper body is permitted if **kept at a minimum and had been maintained prior to and during the training portion of the study**. Please allow sufficient rest between sets and lower repetitions. Record the *various equipment used, the duration, approximate time in-between sets, number of sets, number of repetitions, and RPE.*

*Absolutely **no lower body training**!!

IF YOU HAVE ANY QUESTIONS OR CONCERNS PLEASE DO NOT HESITATE TO CALL ME:

LAURIE BULLOCK
231-5006 (lab)
231-4900 (office)
951-2247 (home)

Your participation in this study is greatly appreciated.

APPENDIX E

ACTIVITY LOGS

ACTIVITY LOG

Date: Typical Day

Walking Time (minutes)

Sleeping time (including naps)

Activity (type activity, duration, RPE)

Scale for Ratings of Perceived Exertion

0.5 = very, very light; just noticeable
1 = very light
2 = light
3 = moderate
4 = somewhat hard
5-6 = heavy, strong
7-9 = very hard
10 = very, very hard; almost maximum

ACTIVITY LOG

Date: Detraining

Walking Time (minutes)

Sleeping time (including naps)

Activity (type activity, duration, RPE)

Scale for Ratings of Perceived Exertion

0.5 = very, very light; just noticeable
1 = very light
2 = light
3 = moderate
4 = somewhat hard
5-6 = heavy, strong
7-9 = very hard
10 = very, very hard; almost maximum

APPENDIX F

INCREMENTAL DATA SHEET

INCREMENTAL TEST # ____

Subject # _____ Wt: _____ kg Date: ______ Time of day: _______ Seat ht: ___

Min	HR	HLa: time	Sample 1	Sample 2	Load (W)	RPE (L/O)
0-5	___	_______	_______	_______		____/____
5	start exercise					
6		_______	_______	_______	20	____/____
7	___	_______	_______	_______	40	____/____
8	___	_______	_______	_______	60	____/____
9	___	_______	_______	_______	80	____/____
10	___	_______	_______	_______	100	____/____
11	___	_______	_______	_______	120	____/____
12	___	_______	_______	_______	140	____/____
13	___	_______	_______	_______	160	____/____
14	___	_______	_______	_______	180	____/____
15	___	_______	_______	_______	190	____/____
16	___	_______	_______	_______	200	____/____
17	___	_______	_______	_______	210	____/____
18	___	_______	_______	_______	220	____/____
19	___	_______	_______	_______	240	____/____
20	___	_______	_______	_______	260	____/____
21	___	_______	_______	_______	280	____/____
22	___	_______	_______	_______	300	____/____
23	___	_______	_______	_______	320	____/____
24	___	_______	_______	_______	340	____/____
25	___	_______	_______	_______	360	____/____

APPENDIX G

SUBMAXIMAL DATA SHEET

SUBMAXIMAL HIGH CONSTANT-LOAD TEST # ____

Subject #: _____ Wt: _______ kg Date: __________ Time of day: _______ am/pm

Seat height: __________

Power (watts): __________

Time (HCL): __________

RESTING DATA

Min	HR	HLa: time	Sample 1	Sample 2	RPE (L/O)
0-5	___	_______	_______	_______	____/____

*(resting data taken between 4:30 - 5:00)

5 Start Exercise

EXERCISE DATA (collected every three minutes)

8	___	_______	_______	_______	____/____
11	___	_______	_______	_______	____/____
14	___	_______	_______	_______	____/____
17	___	_______	_______	_______	____/____
20	___	_______	_______	_______	____/____

APPENDIX H

DESCRIPTIVE CHARACTERISTICS OF SUBJECTS

Table 1. Descriptive Characteristics of the Subjects

Subject (Males)	Age (years)	Height (cm)	Weight (kg)	Training Compliance (%)
1	25	174	83	93
2	23	177	92	93
3	27	171	99	90
4	26	183	78	97
5	22	184	85	100
6	23	182	82	90
7	24	183	96	97
8	30	174	76	100
9	26	178	79	93
10	30	181	80	90
Mean ± SE	26 ± 1	179 ±2	85 ± 3	94 ± 1

APPENDIX I

DESCRIPTIVE STATISTICS FOR MAXIMAL AND SUBMAXIMAL RESPONSE VARIABLES

Table 2. Descriptive Statistics for Maximal Test Variables

Variables	Trials	Mean	Std. Dev.	SEM
VO_2 peak	1	3.3	0.2	0.1
	2	3.8	0.2	0.1
	3	3.6	0.2	0.1
Power (watts)	1	275	19	6.0
	2	316	19	5.8
	3	307	22	6.8
HR peak	1	185	7	2.2
	2	182	10	3.1
	3	182	10	3.2
RER	1	1.2	0.1	0.0
	2	1.2	0.1	0.0
	3	1.2	0.1	0.0
RPE	1	17	2	0.7
	2	18	1	0.4
	3	19	2	0.5

*Subject sample size N=10

Table 3. Descriptive Statistics on Submaximal Response Variables

Variables	Trial	Subjects (n)	Mean	Std Dev	SEM
SC	1	10	536	203	64
	2	10	274	133	42
	3	10	365	103	33
	4	9*	308	152	51
HR	1	10	186	9	3
	2	10	161	9	3
	3	10	171	8	3
	4	10	169	8	2
HLa	1	7*	11.2	2.8	1.1
	2	8*	7.6	2.3	0.8
	3	7*	8.1	1.9	0.7
	4	6*	8.6	1.1	0.5
RPE	1	10	17	3	0.8
	2	10	12	3	0.9
	3	10	13	2	0.7
	4	10	14	1	0.4

*Denotes a subject sample size <10.

APPENDIX J

SUMMARY DATA TABLES

Table 4. Peak Test Summary Data

Subject	Trial	VO_2 (L/min)	HR (bpm)	RER	RPE	Power (Watts)
1	1	3.39	190	1.27	19	300
	2	3.99	185	1.2	17	351
	3	3.67	188	1.22	15	341
2	1	3.38	178	1.23	17	294
	2	3.93	170	1.15	16	327
	3	3.58	169	1.14	20	288
3	1	3.30	182	1.14	16	254
	2	3.97	182	1.16	17	326
	3	3.85	175	1.13	20	309
4	1	2.99	188	1.19	16	268
	2	3.78	186	1.17	17	314
	3	3.63	197	1.18	20	312
5	1	3.38	198	1.21	13	265
	2	3.69	196	1.27	16	310
	3	3.72	196	1.26	20	331
6	1	3.39	181	1.16	17	275
	2	3.69	186	1.28	19	315
	3	3.49	178	1.14	18	300
7	1	3.43	174	1.23	19	279
	2	3.63	162	1.17	19	300
	3	3.55	171	1.18	19	280
8	1	2.73	188	1.32	20	238
	2	3.38	190	1.22	19	280
	3	3.12	188	1.22	19	280
9	1	3.23	187	1.19	20	292
	2	3.68	180	1.22	19	320
	3	3.66	179	1.21	20	330
10	1	3.25	187	1.23	15	280
	2	3.72	185	1.16	17	320
	3	3.68	176	1.10	17	300
Mean ± SEM	1	3.25 ± 0.07	185 ± 2.15	1.22 ± 0.02	17 ± 0.7	275 ± 6.0
	2	3.75 ± 0.06	182 ± 3.09	1.20 ± 0.01	18 ± 0.4	316 ± 5.8
	3	3.60 ± 0.06	181 ± 3.15	1.17 ± 0.02	19± 0.5	306 ± 7.0

Table 5. Submaximal Test Summary Data

Subject	Trials	SC (ml/min)	VO_2 term (L/min)	HLa term (mMol/L)	HR term (bpm)	RPE
1	1	402	3.27		186	19
	2	184	3.15		159	8
	3	281	3.27		172	10
	4	245	3.19	7.3	169	12
2	1	529	3.64		182	15
	2	174	3.39		147	11
	3	389	3.53	8.9	164	13
	4	422	3.52	9.0	177	14
3	1	504	3.53	8.4	180	18
	2	093	3.07	3.6	155	13
	3	235	3.09	4.3	162	13
	4	247	3.24		162	16
4	1	779	3.15	13.2	197	17
	2	380	2.93	9.1	171	12
	3	349	2.90	9.1	176	13
	4	322	3.00	9.3	178	13
5	1	770	3.47	14.3	205	20
	2	240	3.00	7.9	175	10
	3	380	3.12	7.7	178	10
	4	480	3.20	10.3	181	12
6	1	415	3.31	10.3	186	16
	2	250	3.25	4.8	162	10
	3	400	3.12	9.6	178	13
	4				170	14
7	1	837	3.74		179	18
	2	342	3.45	9.4	163	16
	3	590	3.59		169	15
	4	570	3.51		160	13
8	1	555	2.89	13.0	190	17
	2	239	2.56	7.4	164	16
	3	446	2.73		175	17
	4	156	2.61		167	16
9	1	329	3.32	12.4	183	20
	2	267	3.15	8.3	150	15
	3	270	3.24	7.3	155	15
	4	143	3.06	7.6	159	14
10	1	235	2.98	6.7	176	11
	2	571	3.27	10.3	168	13
	3	312	3.15	9.8	177	14
	4	189	3.02	8.3	167	13

Trial 1: Pre - train submaximal test
Trial 2: Post - six weeks training submaximal test
Trial 3: Post- detrain one week submaximal test
Trial 4: Post - detrain two weeks submaximal test

APPENDIX K

STATISTICAL TABLES

(MAXIMAL TEST VARIABLES)

Table 6. One-way ANOVA with Repeated Measures for VO_2 peak (L/min)

Source	DF	SS	MS	F	P
Subjects	9	0.8	0.1		
Trials	2	1.3	0.7	47.2	**0.001***
Residual	18	0.3	0.0		
Total	29	2.4	0.1		

*Significant difference at p<0.001

Bonferoni's Comparison (0.05)

Comparison (trials)	p<0.05
1 vs 3	**yes**
1 vs 2	**yes**
2 vs 3	**yes**

Table 7. One-way ANOVA with Repeated Measures for Power (Watts)

Source	DF	SS	MS	F	P
Subjects	9	7548	839		
Trials	2	9649	4824	28.9	**0.001***
Residual	18	3002	167		
Total	29	20198	696		

*Significant difference at p<0.001

Bonferoni's Comparison (0.05)

Comparison (trials)	p<0.05
1 vs 3	**yes**
1 vs 2	**yes**
2 vs 3	**no**

Table 8. One-way ANOVA with Repeated Measures Across Trials on Maximal Test Criteria

One-way ANOVA with Repeated Measures for **peak Heart Rate (bpm)**

Source	DF	SS	MS	F	P
Subjects	9	1855	206		
Trials	2	76	38	2.21	0.138
Residual	18	309	17		
Total	29	2240	77		

*No significant difference (p>0.05) was found between trials.

One-way ANOVA with Repeated Measures on **RER**

Source	DF	SS	MS	F	P
Subjects	9	0.036	0.004		
Trials	2	0.008	0.004	2.22	0.137
Residual	18	0.033	0.002		
Total	29	0.076	0.003		

*No significant difference (p>0.05) was found between trials.

One-way ANOVA with Repeated Measures **RPE**

Source	DF	SS	MS	F	P
Subjects	9	37	4.09		
Trials	2	14	6.93	2.46	0.114
Residual	18	51	2.82		
Total	29	102	3.5		

*No significant difference (p>0.05) was found between trials.

APPENDIX L

STATISTICAL TABLES

(SUBMAXIMAL RESPONSE VARIABLES)

Table 9. One-way ANOVA with Repeated Measures for SC (ml/min)

Source	DF	SS	MS	F	P
Subjects	9	396115.3	44012.8		
Trials	3	403909.6	134636.5	8.48	**0.001***
Residual	26	412562.4	15867.8		
Total	38	1209106.7	31818.6		

*Significant difference at $p<0.001$

Bonferoni's Comparison (0.05)

Comparison (trials)	$p<0.05$
1 vs 4	**yes**
1 vs 3	**yes**
1 vs 2	**yes**
2 vs 4	**no**
2 vs 3	**no**
3 vs 4	**no**

Table 10. One-way ANOVA with Repeated Measures for Terminal Heart Rate (bpm)

Source	DF	SS	MS	F	P
Subjects	9	1755.1	195		
Trials	3	3305.9	1102	39.2	**0.001***
Residual	27	758.1	28		
Total	39	5819.1	149		

*Significant difference at p<0.001

Bonferoni's Comparison (0.05)

Comparison (trials)	p<0.05
1 vs 4	**yes**
1 vs 3	**yes**
1 vs 2	**yes**
2 vs 4	**yes**
2 vs 3	**yes**
3 vs 4	**no**

Table 11. One-way ANOVA with Repeated Measures for End Lactate (mMol/L)

Source	DF	SS	MS	F	P
Subjects	9	59	6.59		
Trials	3	58	19.46	5.51	**0.001***
Residual	15	53	3.53		
Total	27	167	6.17		

*Significant difference at p<0.001

Bonferoni's Comparison (0.05)

Comparison (trials)	p<0.05
1 vs 4	**no**
1 vs 3	**no**
1 vs 2	**yes**
2 vs 4	**no**
2 vs 3	**no**
3 vs 4	**no**

Table 12. One-way ANOVA with Repeated Measures for Rate of Perceived Exertion (RPE)

Source	DF	SS	MS	F	P
Subjects	9	81	9		
Trials	3	127	42	10.3	**0.001***
Residual	27	111	4		
Total	39	318	8		

*Significant difference at $p<0.001$

Bonferoni's Comparison (0.05)

Comparison (trials)	$p<0.05$
1 vs 4	**yes**
1 vs 3	**yes**
1 vs 2	**yes**
2 vs 4	**no**
2 vs 3	**no**
3 vs 4	**no**

APPENDIX M

RAW DATA

RAW DATA: PEAK EXERCISE

Subject	Trial	VO_2 (L/min)	HR (bpm)	RER	RPE	Power (Watts)
1	1	3.39	190	1.27	19	300
	2	3.99	185	1.20	17	351
	3	3.67	188	1.22	15	341
2	1	3.38	178	1.23	17	294
	2	3.93	170	1.15	16	327
	3	3.58	169	1.14	20	288
3	1	3.30	182	1.14	16	254
	2	3.97	182	1.16	17	326
	3	3.85	175	1.13	20	309
4	1	2.99	188	1.19	16	268
	2	3.78	186	1.17	17	314
	3	3.63	197	1.18	20	312
5	1	3.38	198	1.21	13	265
	2	3.69	196	1.27	16	310
	3	3.72	196	1.26	20	331
6	1	3.39	181	1.16	17	275
	2	3.69	186	1.28	19	315
	3	3.49	178	1.14	18	300
7	1	3.43	174	1.23	19	279
	2	3.63	162	1.17	19	300
	3	3.55	171	1.18	19	280
8	1	2.73	188	1.32	20	238
	2	3.38	190	1.22	19	280
	3	3.12	188	1.22	19	280
9	1	3.23	187	1.19	20	292
	2	3.68	180	1.22	19	320
	3	3.66	179	1.21	20	330
10	1	3.25	187	1.23	15	280
	2	3.72	185	1.16	17	320
	3	3.68	176	1.10	17	300

trial 1: Pre-training maximal value
trial 2: Post-training maximal value
trial 3: Post-detraining two weeks maximal value

RAW DATA: SUBMAXIMAL EXERCISE

Subject	Trials	SC (ml/min)	VO_2 term (L/min)	HLa term (mMol/L)	HR term (bpm)	RPE
1	1	402	3.27		186	19
	2	184	3.15		159	8
	3	281	3.27		172	10
	4	245	3.19	7.3	169	12
2	1	529	3.64		182	15
	2	174	3.39		147	11
	3	389	3.53	8.9	164	13
	4	422	3.52	9.0	177	14
3	1	504	3.53	8.4	180	18
	2	093	3.07	3.6	155	13
	3	235	3.09	4.3	162	13
	4	247	3.24		162	16
4	1	779	3.15	13.0	197	17
	2	380	2.93	9.0	171	12
	3	349	2.90	9.1	176	13
	4	322	3.00	9.3	178	13
5	1	770	3.47	14.3	205	20
	2	240	3.00	7.9	175	10
	3	380	3.12	7.7	178	10
	4	480	3.20	10.3	181	12
6	1	415	3.31	10.3	186	16
	2	250	3.25	4.8	162	10
	3	400	3.12	9.6	178	13
	4				170	14
7	1	837	3.74		179	18
	2	342	3.45	9.4	163	16
	3	590	3.59		169	15
	4	570	3.51		160	13
8	1	555	2.89	13.0	190	17
	2	239	2.56	7.4	164	16
	3	446	2.73		175	17
	4	156	2.61		167	16
9	1	329	3.32	12.4	183	20
	2	267	3.15	8.3	150	15
	3	270	3.24	7.3	155	15
	4	143	3.06	7.6	159	14
10	1	235	2.98	6.7	176	11
	2	571	3.27	10.3	168	13
	3	312	3.15	9.8	177	14
	4	189	3.02	8.3	167	13

Trial 1: Pre - train submaximal test
Trial 2: Post - six weeks training submaximal test
Trial 3: Post- detrain one week submaximal test
Trial 4: Post - detrain two weeks submaximal test

VITA

Laurie Ann Bullock was born on January 13, 1973 in Arlington, Virginia. She has an older brother and a younger sister. Laurie moved to McLean, Virginia in the second grade where she became involved in numerous physical activities. Laurie attended McLean High School where she played basketball. Upon completion of High School Laurie moved to Blacksburg, Virginia where she attended Virginia Polytechnic Institute and State University. Laurie received a Bachelor of Science degree in psychology, with a minor in exercise science. While at Virginia Tech, she became involved in various activities, some of which included: Delta Zeta sorority, Student Alumni Association, and Intramural Sports. Laurie finished her undergraduate degree in Spring of 1995.

That spring Laurie received her acceptance into the Masters program at Virginia Tech and began school early that fall. Upon completion of her Masters of Science degree in Human Nutrition, Foods & Exercise, with a focus in the area of cardiac rehabilitation, Laurie plans on continuing in this field. Her short term goal is to gain experience in all the phases of cardiac rehabilitation and to expand into the area of invasive cardiology and special procedures. Laurie's long term goal may take one of two directions. One option would be to go back to school and receive an associate degree in nursing to pursue an career in special procedures (i.e. the operating room), still remaining in the scope of cardiology. Another potential path may be that of attending a physician's assistant school. Her ultimate goal is to be a physician's assistant or special procedures nurse for a cardiologist in either a hospital or office setting.

Laurie Bullock