LONGITUDINAL STUDY ON MAXIMAL OXYGEN CONSUMPTION IN
INTERCOLLEGIATE FEMALE CROSS COUNTRY RUNNERS

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by
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ABSTRACT


Female cross country runners were studied to determine if periods of formal and informal training significantly altered VO2max and related physiological variables. Twenty-seven Ss initially tested ranged in age from 18 to 24 yr. Four treadmill VO2max tests conducted over a period of 6 mo included a preseason (T1), postseason (T2), post winter break (T3), and a 30-days post winter break (T4) test. Eight to 11 wk of cross country training took place between T1 and T2, 9 to 12 wk of off-season training from T2 to T3, and an additional 4 to 5 wk of track season to T4. Ten Ss completed all 4 tests. The 27 Ss tested recorded a T1 VO2max of 56.6 ml·kg⁻¹·min⁻¹. The T2 VO2max for 19 Ss was 59.0 ml·kg⁻¹·min⁻¹. Eleven Ss had a VO2max of 56.2 ml·kg⁻¹·min⁻¹ for T3 and 10 Ss recorded 60.7 ml·kg⁻¹·min⁻¹ for T4. A one way ANOVA with repeated measures was calculated using all Ss who completed each test while the 10 Ss who completed all 4 tests were treated separately. No sig (p>.05) diff were found in body weight, VO2max, VO2max (l·min⁻¹ and ml·kg⁻¹·min⁻¹), HRmax, RERmax, and treadmill run time between any of the 4 tests. The results indicated that in-season and off-season training did not differ substantially enough to elicit changes in cardiorespiratory endurance. It was concluded that the high initial fitness level of these Ss contributed to the lack of significant change in these physiological parameters.
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CHAPTER I
INTRODUCTION

Many physiological variables affect distance running performance. With training, a runner may influence some of the variables (i.e., activity level of aerobic system enzymes, actual number of mitochondria within the muscle cells, etc.) (Gollnick et al., 1973) but have no control of others such as gender, genetic inheritance of muscle fiber type, etc. (McArdle, Katch, & Katch, 1981). One factor that has received much attention through applied physiology research is the individual's maximal oxygen consumption (VO₂max). Distance running performance is considered to be partially dependent on VO₂max (Costill, 1967; Conley, Krahenbuhl, Burkett, & Millar, 1981). Cardiovascular, respiratory, and muscular systems adapt with aerobic training and, in turn, can affect VO₂max (McArdle et al., 1981). Hence, VO₂max can be affected by specific training or detraining.

When designing a runner's training program, the frequency, intensity, and duration of exercise should be considered. A proper balance of these three variables will help to promote optimal physiological adaptations. Though each individual responds differently to a specific training regimen, research has served to establish general guidelines for designing training programs.

For developing and maintaining cardiorespiratory fitness in healthy adults, the American College of Sports Medicine (1986) has developed specific recommendations for exercise:
Intensity of exercise: activity producing 65 to 90% of maximum heart rate or 50 to 85% of VO₂max.

Duration of exercise: 15 to 60 minutes of continuous or discontinuous aerobic activity.

Frequency of exercise: three to five days per week.

The objectives of an intercollegiate cross country runner would likely be different. A more probable goal would be to develop to the individual’s full potential with regard to running competitive races.

Accordingly, when developing training programs, it is important to keep in mind the specific purpose of the training. When training for maximal aerobic power, the amount of increase in VO₂max varies greatly and is partly dependent on the amount of training performed by a runner. However, an increase of 5 to 20 percent can be expected for those who initially train for 8 to 12 weeks (Costill, 1986). The major improvements in VO₂max are gained within the first eight weeks of training (Costill, 1986). Also, one should realize that the magnitude of increase in VO₂max depends on a person’s initial or current level of cardiorespiratory fitness (Shephard, 1968). Other aspects to be considered might include the runner’s susceptibility to injury or special demands of future races.

Purpose of the Study

The purpose of this study was to determine if changes occurred in the maximal oxygen consumption of intercollegiate female cross country runners after a competitive cross country season. The objective was to
measure the change, if any, between immediate preseason, immediate postseason, post winter break, and 30-days post break VO₂max.

Null Hypotheses

There will be no significant change in maximal oxygen consumption and related physiological variables between the immediate preseason, immediate postseason, post winter break, and 30-days post break VO₂max test results.

Assumptions

The results of this study were dependent on the following assumptions:

All subjects were free of cardiorespiratory diseases that might have affected maximal oxygen consumption.

All subjects were equally motivated for each of the treadmill tests.

Delimitations

This study was delimited to members of the women's cross country team who participated in the 1986-1987 cross country season at the University of Wisconsin-La Crosse.

Limitations

The effects of preseason training were not determined in this study.
Subjects were not randomly selected.

Motivational aspects may have influenced the VO$_2$max results throughout the experimental period.

Specific effects of cross-training were not accounted for in this study.

The effects of body composition on maximal oxygen consumption were not accounted for in this experiment.

The length of time between preseason and postseason testing varied due to postseason competition (NCAA & NAIA National Championships). All immediate post winter break tests occurred between January 17 and January 29. Final VO$_2$max tests were taken between 30 to 42 days after the third test.

The loss of subjects throughout this study could not be controlled by the researcher.

**Definitions of Terms**

Maximal Oxygen Consumption (Maximal Aerobic Power, VO$_2$max) - the highest amount of oxygen which can be taken in, transported, and utilized during an exhaustive bout of exercise. These values were measured in liters per minute (l·min$^{-1}$) and milliliters per kilogram of body weight per minute (ml·kg$^{-1}$·min$^{-1}$). Running on a motor-driven treadmill was the mode of exercise used to elicit VO$_2$max.

Training Intensity - a relative exercise intensity that elicits a percentage of maximum function, usually a percentage of maximum heart rate, VO$_2$max, or maximum work capacity (McArdle et al., 1981).
Training Duration - the length of time of an exercise bout or exercise session.

Training Frequency - the number of days per week of exercise.
CHAPTER II

REVIEW OF RELATED LITERATURE

Introduction

Researchers have long attempted to determine which factors dictate success in athletics. Distance running has received much attention and participants in this sport have been widely tested. Persons who excel in endurance-type activities (i.e., swimming, bicycling, cross country skiing, etc.) tend to have a large capacity for aerobic energy transfer (McArdle et al., 1981). Among the physiological factors involved in performance ability, data on energy output by the aerobic processes is most advanced (Astrand & Rodahl, 1986).

The measurement of maximal oxygen consumption (VO$_2$max) has been widely used in both clinical and research settings. As an indirect means of assessing energy expenditure, it represents a quantitative measure of an individual's capability for aerobic energy transfer (Weltman & Stamford, 1982). For this reason, VO$_2$max is an important factor in determining a person's ability to sustain high-intensity exercise for relatively long periods of time (McArdle et al., 1981). And because the attainment of VO$_2$max requires the utilization of several physiological processes, it provides information about the ventilatory, cardiovascular and neuromuscular systems, in addition to metabolic significance. Today, measurement of VO$_2$max is commonly used to assess cardiorespiratory endurance of individuals and to measure changes in cardiorespiratory endurance after a period of training or detraining.
This chapter will review the factors of age, sex, body composition, genetics, and training and their effects on VO$_2$max. The primary physiological factors affecting VO$_2$max (i.e., cardiac output, oxygen transportation, oxygen utilization by muscle cells) will also be discussed. Finally, this review will provide information on the relationship between VO$_2$max and distance running performance, running economy and running efficiency, VO$_2$max values of athletes, and the effects of detraining on VO$_2$max.

Factors Affecting VO$_2$max

Age

Although many factors influence an individual's VO$_2$max, the most significant variables include age, sex, body composition, genetics and training. Maximal oxygen consumption reaches its peak between 18 and 25 years of age in the average individual of both sexes. Thereafter, a gradual decline in VO$_2$max generally occurs with age (Astrand & Rodahl, 1986).

Researchers have demonstrated that VO$_2$max generally decreases with increasing age in both sexes (Astrand, Astrand, Hallback & Kilbom, 1973; Dehn & Bruce, 1972; Drinkwater, Horvath & Wells, 1975; Hossack & Bruce, 1982). On the average, individuals decrease their VO$_2$max by 9 to 10% per decade after maturity (Hagberg, 1987; Pollock & Gushiken, 1985). Astrand and Rodahl (1986) stated that a decrease in maximal heart rate and physical activity normally contribute to the decrease in VO$_2$max with aging. However, exercise training may alter the rate of change in VO$_2$max as a person ages (Hagberg, 1987).
In 1972 the American Heart Association published norms on the maximal oxygen uptakes of women and men. For women and men between 20 and 29 years of age, the "average" VO₂max were 31 to 37 and 34 to 42 ml·kg⁻¹·min⁻¹, respectively. Katch, McArdle, Czula and Pechar (1973) found 36 college women (x=20.8 yrs.) to have a mean VO₂max of 38.9 ml·kg⁻¹·min⁻¹. More recently, Vogel, Patton, Mello and Daniels (1986) tested 1,514 men and 375 women entering the US Army as new recruits. Two hundred twelve female recruits (x=19.7 yrs.) and 210 male recruits (x=19.7 yrs.) were tested for VO₂max before initial entry training. The females had a VO₂max of 37.5 ml·kg⁻¹·min⁻¹ and males measured at 51.1 ml·kg⁻¹·min⁻¹. Since these men and women had just entered the service from civilian life, it was claimed that these subjects were representative of a young US population.

Sex

As demonstrated above, an individual's sex also affects VO₂max. Astrand and Rodahl (1986) stated that there is no significant difference in VO₂max between males and females up to about ten years of age. Thereafter, females reach an average of 75 to 85% that of the males' maximum. The sex difference in VO₂max has generally been attributed to differences in body composition, lung size, heart size, and blood variables (McArdle et al., 1981). In a meta-analysis of research comparing VO₂max in men and women, Sparling (1980) concluded that males average 12 to 15% higher VO₂max than females even when expressed relative to fat-free weight. Some of the sex differences in VO₂max can also be attributed to differences in cardiorespiratory capacity.
Sparling (1980) suggested that a portion of these differences is due to differences in habitual levels of physical activity in males and females. While hemoglobin concentrations account for some of the sex difference in VO$_2$max, Cureton and his associates (1986) recently concluded that hemoglobin concentrations account for a relatively small portion of this difference. As indicated previously, when VO$_2$max is expressed per kilogram of fat-free body weight, the differences between sexes are much less (Astrand & Rodahl, 1986).

**Body Composition**

Maximal oxygen uptake expressed relative to gross body weight is more relevant than absolute values in work and exercise where individuals must support their own weight (i.e., running, cross country skiing, etc.) and when comparisons between different sized individuals are considered. Miller and Blyth (1955) demonstrated that as body fat content increases, the exercise oxygen requirement per unit of lean body mass also increases. This would be expected since fat tissue is metabolically fairly inert (Astrand & Rodahl, 1986). Therefore, since individuals must carry both fat tissue and lean body mass, VO$_2$max per kilogram of gross body weight better represents an individual's potential for moving their body. Hence, excessive body fat would hinder VO$_2$max (ml·kg$^{-1}$·min$^{-1}$).

**Genetics**

Heredity also influences VO$_2$max. Early research by Klissouras (1971) suggested that over 90% of the variability in maximal aerobic
power was genetically determined. Although the influence of heredity is significant, more recent evidence suggests that it is not as important as previously credited. Bouchard et al. (1986) measured VO₂max in 42 brothers, 66 dizygotic twins of both sexes, and 106 monozygotic twins of both sexes. In this study it was concluded that genetics accounted for 40% of the difference in VO₂max (ml·kg⁻¹·min⁻¹) and 70% of the difference for 90-minute work output (per kg body weight) on a bicycle ergometer. In another study using six pairs of monozygous twins in a 15 week training program, it was concluded that both VO₂max and endurance performance responses to training are largely genotype-dependent (Hamel, Simoneau, Lortie, Boulay & Bouchard, 1986). They found that heredity exerts only a moderate effect on VO₂max and endurance performance within a sedentary population. Genetic factors are likely quite significant for those athletes of Olympic caliber (Astrand & Rodahl, 1986).

Training

The effects of training on VO₂max have been well documented (Hamel et al., 1986; Denis, Dormas & Lacour, 1984; Henritz, Weltman, Schurrer & Barlow, 1985). McArdle and his associates (1981) stated that improvements in VO₂max generally range between 6 and 20%. Astrand and Rodahl (1986) reported that training three times per week at 30 minutes each generally results in a 10 to 20% increase in maximal aerobic power. That an individual's initial fitness level also determines the extent to which training affects VO₂max has long been recognized (Shepard, 1968). Hickson, Bomze and Holloszy (1977) studied the effects of ten weeks of intense endurance training on eight very sedentary to moderately trained
subjects. The total increase in VO$_2$max for these individuals averaged 44% (16.8 ml·kg$^{-1}$·min$^{-1}$). In contrast, Mikesell and Dudley (1984) found no significant increase in treadmill VO$_2$max in seven well trained competitive distance runners who took part in a six-week intense endurance training program. This represents a good example of the range of effect that training may have on VO$_2$max. The specific components of training will be discussed later in this chapter.

**Physiological Factors Affecting VO$_2$max**

Numerous physiological factors affect the rate at which oxygen is taken in, transported and utilized by the working muscles. Though processes such as pulmonary ventilation and oxygen diffusion are essential for oxygen uptake, most researchers agree that VO$_2$max is largely determined by: cardiac output, oxygen-carrying capacity of the blood, and the oxidative capacity of the muscle tissue (Pate & Kriska, 1984).

**Cardiac Output**

The role of cardiovascular performance appears to be the major factor limiting maximal aerobic power in most healthy individuals (Ekblom, 1986; Guyton, 1986). Major differences in maximum cardiac output between highly trained athletes and untrained individuals have been demonstrated. Though cardiac output is a function of both heart rate and stroke volume, these differences are accounted for mainly through variations in stroke volume (Guyton, 1986). In general, endurance athletes have enlarged left ventricles as compared to normal
individuals (Tnaaka, Matsuura, Kato, Demura, & Ogawa, 1985), thus a larger stroke volume. Guyton (1986) stated that the advantage in maximum cardiac output that an endurance athlete has over the average untrained individual is probably the most important physiological benefit of the athlete’s training program.

**Oxygen Transportation**

The oxygen transport capacity of the blood itself is another limiting factor for VO$_2$max. As indicated previously, hemoglobin concentration, a major determinant of the oxygen-carrying capacity of blood, tends to be substantially lower in females than males after puberty. The normal range for hemoglobin is 12 to 16 grams per 100 milliliters of blood in females and 14 to 18 grams per 100 milliliters of blood in males (Pate & Kriska, 1984).

The importance of hemoglobin can be demonstrated through erythrocythemia. Induced erythrocythemia (blood doping) is an artificial way of increasing the oxygen transport capacity of blood. Typically performed by use of blood reinfusion, experimental subjects are given extra blood with the intention of increasing oxygen-carrying capacity of blood, and thus increasing VO$_2$max. In his review of studies on blood doping and exercise, Gledhill (1982) concluded that a significant increase in VO$_2$max and/or endurance exercise capacity was the consequence of a significant increase in hemoglobin concentration. Again, this supports the conclusion that the transport of oxygen to working muscles is a limiting factor of VO$_2$max. More specifically, this
demonstrates the role of hemoglobin concentration as one of the several determinants of maximal aerobic power.

Blood volume is also a determinant of VO2max (Ekblom, 1986). Kanstrop and Ekblom (1984) found that hypervolemia at normal hemoglobin concentration resulted in an elevated VO2max above control levels. It has also been established that total blood volume is lower in females than males (Pate & Kriska, 1984).

Oxygen Extraction By Muscle Cells

Finally, the muscles ability to utilize oxygen is also a limiting factor for VO2max. The arteriovenous oxygen difference (a-vO2 difference) is the difference in the oxygen content of arterial and mixed venous blood. This measurement indicates the rate of oxygen utilization by the tissues relative to cardiac output. Blomqvist and Saltin (1983) stated that a more efficient utilization of available oxygen, reflected by decreased venous oxygen content, may account for as much as one half of the improvement in VO2max produced by a short-term training program in young men. However, increased muscle metabolic adaptation as the result of endurance training may not be as substantial in women (Pate & Kriska, 1984). Currently, limited research exists concerning the effects of training on a-vO2 difference in women.

Holloszy (1975) demonstrated that mitochondrial density and oxidative enzyme activities increase with endurance training and are higher in endurance athletes than in sedentary persons. These factors appear to be the major reasons for the increase in oxidative capacity of muscle tissue (Holloszy, 1975; Fox & Mathews, 1981).
Though a multitude of physiological factors ultimately determine VO₂max, those elements discussed here emphasize the importance of the cardiovascular system, the oxygen transport ability of blood, and the cells' ability to utilize oxygen.

**VO₂max and Running Performance**

The relationship between VO₂max and distance running performance has been extensively studied. In 1967, Costill evaluated the relationship between a battery of test items and the average time to run a 4.7 mile cross country course. Testing 17 male cross country runners (18.0 to 23.2 yrs.) for VO₂max, a direct correlation (r=.832) was found between distance running performance in a 4.7 mile run and VO₂max. Later, Conley and Krahenbuhl (1980) found no significant relationship (r=-0.12) between VO₂max and performance in a ten kilometer run for 12 highly trained males (x=24.6 yrs.) with similar VO₂max values (x=71.7 ml·kg⁻¹·min⁻¹). Conley, Krahenbuhl, Burkett and Millar (1981) studied 14 trained female runners (x=24.1 yrs.) and found a significant relationship (r=-0.66) between VO₂max and a ten kilometer run time. These female runners had a mean VO₂max of 53.0 ml·kg⁻¹·min⁻¹.

Today it appears that most researchers agree on the importance of VO₂max in distance running performance. Though VO₂max did not discriminate success in their study, Conley and Krohenbuhl (1980) did not deny the importance of VO₂max in distance running success. They suggested that the high VO₂max helped each of their subjects gain membership into the elite performance group. In other words, though a relatively high VO₂max is necessary for distance running success, it
often fails to predict the winner when similarly talented runners compete (Costill, 1986). Elite runners typically require VO2max greater than 65 or 70 ml·kg⁻¹·min⁻¹ for females and males, respectively for success (Astrand & Rodahl, 1986).

Running Economy vs Running Efficiency

Running economy and running efficiency may also affect performance. These two variables, economy and efficiency, have received considerable attention only recently. In the past, these terms were often used interchangeably which may result in various interpretations of previous research. Recently, Daniels (1985) provided insight on the definition of these terms and their effects on performance.

Efficiency describes the relationship between work done and energy expended. Daniels (1985) contended that efficiency should not be used to relate energy demands of running to velocity of running because moving the body from one point to another represents only part of the work done by the body during running. Indeed, it may be quite difficult to determine which individual is more efficient when considering work done internally.

Running economy refers to the relationship between running velocity and energy expenditure. More often, it is expressed as the steady-state VO2 corresponding with a given velocity of running (Daniels, 1985). An individual would be considered more economical if he or she had a lower VO2submax than another runner for a given running velocity. If a runner uses less energy (consumes less oxygen) than his or her opponent for specific running velocities, then this more economical runner may prove
to have a decided advantage during competition. This is not to say that
running efficiency and economy are without relationship. For example,
if a runner becomes more efficient through improved technique, then he
or she will likely be a more economical runner.

Conley and his associates (1981) found no relationship between
running economy and a ten kilometer run time for 14 trained female
runners. Costill, Thomason and Roberts (1973) also failed to establish
a relationship between running economy and performance in a ten-mile
road race unless $V_{O_2\text{submax}}$ was expressed as a percentage of $V_{O_2\text{max}}$. In
contrast, Conley and Krahenbuhl (1980) found direct relationships
between steady-state $V_{O_2}$ at three different treadmill speeds and a ten
kilometer run time for 12 highly trained male runners. In this study,
64.5% of the variation in race time was explained by variation in
running economy. It appears that among well-trained, experienced
runners of similar ability and $V_{O_2\text{max}}$, running economy accounts for a
significant amount of variation in performance (Conley & Krahenbuhl,
1980). Daniels (1985) stated that running economy has the potential of
being the most important characteristic in the determination of success
within groups of runners with similar abilities.

While some researchers (Burkett, Fernhall & Walters, 1985) have
demonstrated improvement in running economy as the result of training,
others (Wilcox & Bulbulian, 1984) found no change in economy following
training. A certain threshold of training or a particular type of
training may be necessary in order to significantly change running
economy (Daniels, 1985). Daniels (1985) believed that the factors of age, wind resistance, body temperature, stride length, weight added or
taken from the body, and training influence running economy within an individual.

The actual oxygen consumption that can be maintained during exercise is at a certain percentage of VO\textsubscript{2max}, this percentage becoming reduced with an increase in duration (Astrand & Rodahl, 1986). The ability to work at a high percentage of VO\textsubscript{2max} is also significant in determining distance running success. Most distance runners maintain a pace requiring 75 to 80% of their VO\textsubscript{2max} during a marathon. However, Costill (1986) reported that world class runners Salazar, Rogers, and Waitz were able to run comfortably at 86 to 90% of their VO\textsubscript{2max}. The ability to utilize a large fraction of VO\textsubscript{2max} without the accumulation of lactic acid appears to be a distinct factor for successful distance running (Costill et al., 1973).

**VO\textsubscript{2max} of Athletes**

It is interesting to compare the maximal oxygen uptakes of athletes and nonathletes of different abilities. Trained endurance athletes normally exhibit higher VO\textsubscript{2max} values than the "average" population.

In 1967, Saltin and Astrand tested 38 female athletes representing the Swedish National Team in nine different sports. For females, the highest VO\textsubscript{2max} values were recorded by athletes in cross-country skiing and orienteering. Publishing data on the top ten subjects (x=22.9 yrs.) only, the mean VO\textsubscript{2max} was 61.8 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}. The highest VO\textsubscript{2max} values recorded for the female subjects in this study were 4.07 l·min\textsuperscript{-1} or 66.3 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}. More recently, Upton et al. (1984) tested 98 female volunteers (19 to 54 yrs.) for maximal aerobic power. Comprising four
separate groups, 42 middle-aged marathoners (x=38.2 yrs.), nine young
marathoners (x=25.2 yrs.), nine middle-aged ten kilometer runners
(x=33.1 yrs.) and 37 middle-aged sedentary women (x=38.8 yrs.) had mean
VO$_{2 \text{max}}$ values of 55.5, 59.8, 48.5 and 31.4 ml·kg$^{-1}$·min$^{-1}$, respectively.
Christensen and Ruhling (1983) studied 23 non-elite women marathoners.
Ten "novice" subjects (x=29.6 yrs.) had a VO$_{2 \text{max}}$ of 45.8 ml·kg$^{-1}$·min$^{-1}$
while 13 experienced marathoners (x=32.7 yrs.) measured at
51.8 ml·kg$^{-1}$·min$^{-1}$. Butts (1982) assessed the maximal aerobic power of
127 high school female cross country runners (x=15.6 yrs.). These young
athletes had a mean VO$_{2 \text{max}}$ of 50.8 ml·kg$^{-1}$·min$^{-1}$. In a study involving
29 intercollegiate female cross country runners (x=19.3 yrs.), Larson
(1984) found a mean post season VO$_{2 \text{max}}$ of 59.8 ml·kg$^{-1}$·min$^{-1}$. The
VO$_{2 \text{max}}$ for six female ultraendurance triathletes was 65.9 ml·kg$^{-1}$·min$^{-1}$
in a recent study by O'Toole, Hiller, Crosby and Douglas (1987).

Costill (1986) stated that elite female runners have maximal
aerobic powers above 65 ml·kg$^{-1}$·min$^{-1}$. The highest VO$_{2 \text{max}}$ values
reported so far are 94 ml·kg$^{-1}$·min$^{-1}$ for a male and 80 ml·kg$^{-1}$·min$^{-1}$ for
a female (Astrand & Rodahl, 1986; O'Toole et al., 1987). It is evident
that endurance athletes are likely to have a higher VO$_{2 \text{max}}$ than
untrained individuals. Also, elite and world class endurance athletes
tend to have higher values than similar athletes of lower caliber.

**Detraining**

As endurance training has been shown to have a positive influences
on physical endurance and VO$_{2 \text{max}}$, detraining can cause a corresponding
decrease in endurance and VO$_{2 \text{max}}$. Drinkwater and Horvath (1972)
measured the effects of detraining in seven female track athletes (15 to 17 yrs.). With a trained VO₂max of 47.8 ml·kg⁻¹·min⁻¹, the subjects significantly decreased their mean VO₂max to 40.4 ml·kg⁻¹·min⁻¹ three months after formal training had stopped. Pedersen and Jorgensen (1978) tested the effects of two 7-week periods of training separated by seven weeks of inactivity in six female college students. While training only two days per week for seven weeks increased VO₂max 13.8%, VO₂max receded to the initial values following seven weeks of inactivity. Coyle, Martin, Bloomfield, Lowry and Holloszy (1985) demonstrated similar effects of detraining on responses to submaximal exercise.

When detraining is not characterized by large decreases in training frequency, intensity, and/or duration, trained-level VO₂max may be maintained in some individuals. When 15 male competitive distance runners (x=28.2 yrs.) were measured for maximal oxygen uptake before and after ten days of exercise cessation, VO₂max was not altered (Cullinane, Sady, Vadeboncoeur, Burke & Thompson, 1986). Hickson and Rosenkoetter (1981) also found that increased aerobic power could be maintained with a reduction in training frequency from six days per week to either two or four days per week.

If a reduction in training frequency, intensity and/or duration is of significant magnitude or length of time, then a corresponding reduction in maximal aerobic power will also result. If training is reduced only minimally or for short periods of time, VO₂max may be maintained. This could apply to those athletes who need brief periods of rest to treat minor injuries. Also, it would be beneficial for
athletes to be aware of the amount of conditioning needed to sustain a trained-level VO₂max during off-season training.

Few studies have investigated detraining in the highly trained. Daniels (1974) conducted a unique study testing former mile record holder Jim Ryun at various times over a period of five years. In a highly-trained state, Ryun recorded a VO₂max of 5.9 l·min⁻¹ and 81.0 ml·kg⁻¹·min⁻¹ in 1968. After one year of inactivity this value dropped to 5.3 l·min⁻¹ and 65.0 ml·kg⁻¹·min⁻¹. This represented a 10% and 20% decrease in absolute (l·min⁻¹) and relative (ml·kg⁻¹·min⁻¹) VO₂max values, respectively. The greater decrease in relative VO₂max was attributed to increases in body weight and body fat composition. Ryun increased in weight from 72.5 to 82.0 kg. after a year without training. After conditioning resumed, Ryun’s weight returned to normal within six months while his VO₂max (ml·kg⁻¹·min⁻¹) steadily increased throughout the following two years of retraining to a value of 78.3 ml·kg⁻¹·min⁻¹ in 1972. Though Ryun recorded a VO₂max of 65.0 ml·kg⁻¹·min⁻¹ in 1970 (age=23 yrs.) in the detrained state, this value was still much greater than the norm for untrained individuals. Daniels (1974) concluded that this runner had an inherent capacity for a high VO₂max, or that after intense training, VO₂max decreases only 10 to 20% with one year of detraining.

**Training**

Little research depicts typical training regimens of modern endurance athletes. Knowlton, Miles, Sawka, Critz and Blackman (1978) described the training program of 11 members of the 1976-1977 Illinois
Women's State Championship Cross Country Team. Through 11 weeks of training, the women ran an average of 38.8 miles per week. A portion (8.3%) of that distance consisted of interval training. Early season conditioning included moderately-paced distance runs to establish a training "foundation." A low resistance weight training program was also utilized two to three times per week. Near the championship season, 220, 330, and 440 yard interval sprints were emphasized. The runners increased their VO2max significantly from a preseason 50.1 ml·kg⁻¹·min⁻¹ to a postseason 54.8 ml·kg⁻¹·min⁻¹.

In his research involving female collegiate cross country runners, Larson (1984) reviewed the training program of these runners. Larson found that the runners averaged 40 to 50 miles per week at estimated heart rate intensities of 70 to 85% of maximum. Testing 29 young women (x=19.3 yrs.), maximal aerobic power significantly increased from 56.6 ml·kg⁻¹·min⁻¹ to 59.8 ml·kg⁻¹·min⁻¹ following a cross country season of 10 or 12 weeks duration.

More recently, R. J. Smith (personal communication, October 20, 1987) described the training schedule of members of the women's cross country team at the University of Wisconsin-La Crosse. Generally, runners averaged 35 to 55 miles of running per week. High-intensity intervals and fartlek-type activities were usually conducted on Mondays and Wednesdays in order to increase muscular strength and speed. Tapering began with a reduction in weekly mileage near the end of the season.

Mahler, Parker and Andersen (1985) measured maximal aerobic power three times at 3-month intervals in seven collegiate women rowers to
evaluate the physiological changes in rowing performance during a training season. Subjects were tested on three occasions: November, February and May of the following year. Before November, training was outdoors, generally consisting of rowing on the water at "moderate" intensity for approximately 60 to 75 minutes. The first VO$_2$max test corresponded with the end of daily rowing outdoors. During the next 3.5 months, training took place indoors six days per week and generally involved aerobic conditioning of moderate intensity (140-160 beats·min$^{-1}$) on a rowing ergometer, technique practice in water tanks, and circuit weight training. Beginning in mid-March, practice was generally conducted outdoors six days per week on the water. At this time, training emphasis gradually shifted from "aerobic workouts" to high-intensity, short-duration conditioning for anaerobic improvement. Anaerobic training involved interval-type work including 10 to 20 strokes at 80 to 100% effort with rest periods and simulated competition racing. The final testing in May occurred at the end of the competitive rowing season.

For these seven women rowers, VO$_2$max was initially 40.0 ml·kg$^{-1}$·min$^{-1}$ and 2.8 l·min$^{-1}$ in November and did not increase significantly until May at 46.2 ml·kg$^{-1}$·min$^{-1}$ and 3.2 l·min$^{-1}$. This represented a 14% increase in VO$_2$max (l·min$^{-1}$) for six months of training. The authors stated that the absolute VO$_2$max (l·min$^{-1}$) was more appropriate in assessing endurance capacity for the sport of rowing since the individual’s weight is supported by the boat. The subjects’ weight did not change throughout the experimental period.

Conley et al. (1984) published data on Steve Scott, American mile
record holder. Three tests were conducted on Scott over a nine-month period (September, 1980; March, 1981; June, 1981). These tests covered a period that included off-season, preseason, indoor season, and part of the outdoor season. Scott's VO$_{2}$max improved significantly from 74.4 to 77.2 to 80.1 ml·kg$^{-1}$·min$^{-1}$ in September, March, and June, respectively. In l·min$^{-1}$, these values represented 5.51, 5.73, and 5.85 l·min$^{-1}$.

Scott also improved in running economy 5% between the first and last test.

In the fall, Scott mostly concentrated on distance workouts. In December, he began running long intervals (1,000 to 5,000 meters). Shorter intervals (200 to 600 meters) were added in January.

**Testing**

Researchers in exercise physiology agree that the most reliable direct measurement of cardiorespiratory endurance is that of VO$_{2}$max. Researchers have demonstrated that VO$_{2}$max is highly reproducible (Katch et al., 1973). Taylor, Buskirk and Henschel (1955) stated that VO$_{2}$max will remain relatively stable over the period of a year if activity levels remain constant.

Katch, Sady and Freedson (1982) conducted a unique study to assess the amount of "biological variation" and technological error accountable for the variation in VO$_{2}$max. Biological variation reflects intrinsic biological fluctuations within an individual. In this study, four trained females and one trained male each performed 8 to 20 repeat VO$_{2}$max treadmill tests within a period of two to four weeks. A total of 80 max tests were conducted. The mean total variance in VO$_{2}$max for all
tests was $+5.6\%$. The authors found that $90\%$ of this variation was due to biological variability and less than $10\%$ was due to technological error.

Katch and his associates (1982) stressed the need for control data when attempting to demonstrate changes in VO$_2$max as the result of training, thus allowing differentiation between treatment effects and biological variation. Though causes of biological variation in VO$_2$max cannot be measured, motivation would be considered a contributing factor.

**Summary**

Testing for maximal aerobic power has become one of the fundamental measures in exercise physiology. An individual's VO$_2$max reflects the coordination of several physiological functions that transport oxygen to the muscles. Age, sex, body composition, genetics and training are among the many factors that influence VO$_2$max (McArdle et al., 1981). Maximum cardiac output, oxygen transport capacity of blood, and the ability of muscle tissue to utilize oxygen are considered to be the major physiological factors that limit VO$_2$max (Pate & Kriska, 1984).

Though a high VO$_2$max does not guarantee superior performance, it is considered essential for distance running success (Costill, 1986). Other factors (i.e., technique, experience, motivation, etc.) also affect performance. While the potential, upper limit for VO$_2$max may be controlled by genetics (Astrand & Rodahl, 1986), the average person can expect a 10 to 20% increase in VO$_2$max after a ten-week training period (Weltman & Stamford, 1982). Running economy, the steady-state oxygen
consumption for a given submaximal running velocity, also has a significant influence on performance as evidenced when runners with similar VO_2max compete (Daniels, 1985).

Detraining can cause a reverse in the enhanced, physiological adaptations acquired through a training program. Costill (1986) estimated that a runner could lose all of the endurance advantage gained from five months of training within six to eight weeks of detraining. However, with moderate amounts of training or short periods of exercise cessation, trained-level VO_2max may be maintained.

Today, distance runners, coaches of distance runners, and other endurance athletes seem to follow a similar program of training. Early-season workouts emphasize use of the aerobic energy system. High-intensity, interval-type practices are typically conducted two days per week during the competitive season. Near the championship season, total, weekly mileage is reduced while the quality (intensity) of interval runs is increased.
CHAPTER III

METHODS

Introduction

The purpose of this study was to determine the effects of a cross country training season on VO_2max. It was also the intent of the researcher to discern any changes in VO_2max immediately after "winter break" and again 30 days later to define the possible effects of detraining and retraining, respectively. A total of four VO_2max tests were conducted for each subject completing the study. Treadmill running was the mode of exercise used to elicit maximal aerobic power. An informed consent was obtained prior to testing of any subjects (see Appendix A).

Subject Selection

Subjects for this experiment initially included 27 volunteers from members of the 1986-1987 women's cross country team at the University of Wisconsin-La Crosse. All team members were encouraged to participate.

VO_2max Testing Procedures

All team members were instructed on procedures of maximal oxygen consumption testing at the preseason team meeting. As a means to familiarize the subjects with treadmill running, all participants were scheduled to practice running (7 mph) on and dismounting the treadmill a minimum of one day prior to their first test. The runners were asked to
refrain from strenuous exercise at least 12 hours prior to testing. More complete instructions were given on each subject's actual testing day.

**Electrode Placement:** Electrocardiograms were obtained throughout the tests for each subject to determine heart rate and monitor rhythm. The skin was cleansed with alcohol and brushed with an abrasive to obtain less than 15,000 ohms resistance in conduction prior to electrode placement. Two electrodes were placed mid clavicular near the seventh intercostal space on both the right and left sides. The third electrode was placed mid clavicular just inferior to the clavicle on the subject's right side.

**Treadmill VO2max:** Before testing, subjects were given instructions on use of the Borg scale of perceived exertion (Borg, 1973). Runners were told that the speed and elevation of the treadmill would increase every two minutes throughout the test. They were also instructed to grasp the handrails and to straddle the treadmill after having reached complete exhaustion. At this point, the speed and/or elevation of the treadmill would be decreased to its initial level for cool down.

A model 24-72 Quinton treadmill was used for treadmill testing. During testing, all expired air was analyzed via a Beckman Metabolic Measurement Cart (MMC) (Wilmore, Davis, & Norton, 1976). The MMC recorded the volume of expired air (V̇e), the volume of oxygen consumed (VO2 in ml·kg⁻¹·min⁻¹ & l·min⁻¹), the respiratory exchange ratio (RER), the fraction of expired carbon dioxide (FeCO₂), and the fraction of expired oxygen (FeO₂). The gas analyzers were calibrated before and after each test using a known mixture of gas previously determined by
the Scholander technique and room air. A standard mercury barometer and thermometer were also used to calibrate the MMC.

The protocol used for VO$_2$max testing was that used in an earlier thesis studying female cross country runners at the University of Wisconsin-La Crosse (Larson, 1984). The warmup consisted of a three-minute walk at 3.5 mph and 10% grade. At the end of the warmup, the treadmill was brought to 0% grade and the test protocol began. Perceived exertion was also recorded every two minutes throughout the test (Borg, 1973). The protocol used is depicted in Table 1.

**TABLE 1**

<table>
<thead>
<tr>
<th>STAGE</th>
<th>TIME (min)</th>
<th>SPEED (mph)</th>
<th>GRADE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-2</td>
<td>7.0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>2-4</td>
<td>7.0</td>
<td>2.5</td>
</tr>
<tr>
<td>3</td>
<td>4-6</td>
<td>7.0</td>
<td>5.0</td>
</tr>
<tr>
<td>4</td>
<td>6-8</td>
<td>7.0</td>
<td>7.5</td>
</tr>
<tr>
<td>5</td>
<td>8-10</td>
<td>7.0</td>
<td>10.0</td>
</tr>
<tr>
<td>6</td>
<td>10-12</td>
<td>7.5</td>
<td>10.0</td>
</tr>
<tr>
<td>7</td>
<td>12-14</td>
<td>8.0</td>
<td>10.0</td>
</tr>
<tr>
<td>8</td>
<td>14-16</td>
<td>8.5</td>
<td>10.0</td>
</tr>
<tr>
<td>9</td>
<td>16-18</td>
<td>9.0</td>
<td>10.0</td>
</tr>
</tbody>
</table>

Electrocardiograms were obtained through a Burdick EK-8 electrocardiograph. Tracings for heart rates were recorded during the last 15 seconds of each minute.

Subjects were encouraged to continue to a point of complete exhaustion. Metabolic measurements were obtained at the end of each minute. Final oxygen consumption values were considered valid if the
subject ran 30 seconds or more into the last minute as recorded by the MMC. A respiratory exchange ratio of 1.0 was used as a criterion for reaching VO$_2$max. The highest VO$_2$ value obtained was considered to be the subject's VO$_2$max. At the end of the test, the treadmill was reduced to 3.5 mph and 0% grade for a cool down period of at least three minutes.

**Scheduling of VO$_2$max Tests**

A total of four VO$_2$max tests were scheduled for each runner participating in the study. The preseason VO$_2$max test (Test 1) was conducted between August 31 and September 2, 1986. The post season test (Test 2) occurred at the end of the runner's competitive season which varied according to the individual. Some runners completed their season on October 25 while those qualifying for the NCAA and NAIA National Championships concluded their season on November 15. These represented 8 and 11 weeks of training, respectively. Post break tests (Test 3) were taken between January 17 and January 25, 1987. The final VO$_2$max tests (Test 4) were taken 30 to 40 days later between February 16 and March 2, 1987.

**Conditioning Program of Runners**

Daily training for the runners was under the direction of the women's cross country coach at the University of Wisconsin-La Crosse. R. J. Smith (personal communication, October 20, 1987) described the training schedule of these runners. Provided runners started competing as freshmen and were healthy throughout all four years, weekly mileage
averaged 35-40, 40-45, 45-50, and 50-55 miles for freshman, sophomores, juniors, and seniors, respectively. The season was somewhat divided into three parts. The first three weeks were concentrated on endurance and increasing the runner's "base." The next five to six weeks included high-intensity intervals and fartlek-type activities on Mondays and Wednesdays in order to increase muscular strength and speed. Most races, also considered as part of the training schedule, were conducted on Saturdays. Two weeks before the conference meet, "championship time," tapering began with a reduction in weekly mileage. A decrease in duration and an increase in speed (running velocity) also described the interval work performed at this time. Generally, total distance per interval practice session was greater than race distance (5 kilometers) until the conference race. Most subjects who completed all four tests were also training under the supervision of a track coach between Test 3 and Test 4.

**Statistical Treatment**

Means and standard deviations were calculated for standard descriptive characteristics (height, weight, age) and for the following physiological responses: $V_E$, HR, $V_O_2$ ($l·min^{-1}$ & $ml·kg^{-1}·min^{-1}$), RER. A one way ANOVA with repeated measures was calculated for all physiological variables. The Tukey post hoc test was employed when a significant F was observed. The 0.05 level of confidence was used to discern differences between means.
CHAPTER IV

RESULTS AND DISCUSSION

Introduction

The purpose of this study was to determine if significant changes occurred in VO₂max and related physiological variables of intercollegiate female cross country runners during a six month period which included both formal and informal training. A total of four VO₂max tests were conducted for the 10 subjects who completed the entire study. This chapter provides descriptive characteristics of the subjects and discusses the statistical analyses of these test results.

Descriptive Characteristics

The number of runners participating in each test included 27 for the preseason, 19 for the postseason, 11 for the post winter break, and 10 for the final, 30-days post break VO₂max test. The length of time between the preseason and postseason max tests consisted of approximately 8 or 11 weeks, contingent on qualification for championship competition. The post winter break test took place in January, 9 to 12 weeks later, depending on the postseason testing date. The final max test occurred four to five weeks after the post winter break test. The means, standard deviations and ranges were calculated for all variables using the total number of subjects who completed each test while those ten subjects who completed all four tests were treated...
separately. The data for descriptive characteristics are presented in Table 2 and Table 3.

Twenty-seven cross country runners participated in the initial, preseason V02max test. The mean age for these subjects was 19.7 years with a range of 18 to 24 years of age. The runners averaged 164.7 cm in height and body weights varied from 46.8 to 73.5 kg. The mean weight of 57.1 kg for the preseason test did not change significantly (p>.05) throughout the study, however, subject number decreased with subsequent tests.

**TABLE 2**

Means, Standard Deviations and Ranges of Weight (kg) for all Subjects

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Test 1 (n=27)</th>
<th>Test 2 (n=19)</th>
<th>Test 3 (n=11)</th>
<th>Test 4 (n=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>57.1</td>
<td>57.3</td>
<td>56.5</td>
<td>56.5</td>
</tr>
<tr>
<td>SD</td>
<td>6.3</td>
<td>6.2</td>
<td>5.0</td>
<td>5.5</td>
</tr>
<tr>
<td>Range</td>
<td>46.8-73.5</td>
<td>45.8-71.2</td>
<td>47.8-64.2</td>
<td>46.7-64.5</td>
</tr>
</tbody>
</table>

The 27 subjects initially tested had a mean weight of 57.1 kg. The post season testing of 19 runners established a similar weight of 57.3 kg. When subject number dropped to 11 by the post winter break test, mean weight decreased to 56.5 kg. This appears to be due to the loss of heavier subjects between the second and third tests (see Table 2). This can be noted by the slightly lower mean weight obtained in the preseason test for the 10 subjects who completed the entire study.

The weights of these initial 27 runners appear to be similar but slightly less than other college-aged females. Katch and his associates
(1973) tested 36 college women (x=20.8 yrs.) consisting of varsity athletes, physical education majors, and nonathletes. These subjects had a mean weight of 58.9 kg and mean body fat content of 21.8%.

Kearney, Stull, Ewing and Strein (1976) found 27 sedentary college women between 17 and 22 years of age to weigh 57.4 kg. Two hundred twelve new female recruits (x=19.7 yrs.) entering the US Army measured at 58.6 kg and an estimated 28.4% body fat in a recent study by Vogel and his co-workers (1986). In another study of untrained college women (x=19.4 yrs.), the subjects' mean weight was 57.9 kg (Michael & Horvath, 1965).

<table>
<thead>
<tr>
<th>TABLE 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Means, Standard Deviations and Ranges of Weight (kg) for Ten Subjects Completing Four Tests</td>
</tr>
<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>sample size</td>
</tr>
<tr>
<td>mean</td>
</tr>
<tr>
<td>SD</td>
</tr>
<tr>
<td>range</td>
</tr>
</tbody>
</table>

Trained distance runners tend to be lower in total body weight but are more notably lower in percent body fat. A subgroup of nine young marathoners (x=25.2 yrs.) had a mean body weight of 52.3 kg in a study by Upton and her associates (1984). Thirteen top female national and international marathon runners (x=24.6 yrs.) had a mean weight of 55.5 kg (Forenbach, Mader & Hollmann, 1987). Body compositions were not reported in these two studies. Costill (1986) reported that elite female distance runners range within 9 to 14% body fat. Wilmore and
Brown (1974) found 11 elite female distance runners (x=32.4 yrs.) to weigh 57.2 kg and have 15.3% body fat. In earlier research similar to the present study, Larson (1984) reported a preseason weight of 55.1 kg and body fat content of 17.4% for 29 female intercollegiate cross country runners whose mean age was 19.3 years.

When considering changes in body weight, it is more objective to consider the changes that occurred in the ten subjects who completed all four tests. These runners had a preseason weight 55.6 kg, more closely resembling body weights of other female distance runners. Post season weight increased slightly to 56.0 kg. Post break weight increased to 56.7 kg. With eight of these ten subjects resuming formal track training in January, weight decreased only slightly to 56.5 kg one month later.

As would be expected, the mean weight of the 27 runners initially tested in this study seems to be slightly less than the weight of the average, untrained college-aged female. Their mean weight was also slightly higher than that of other trained female distance runners. Those runners completing all tests, however, were quite similar in body weight to other trained female distance runners. Though distance runners tend to have a lower percent body fat than the normal population, body compositions were not determined for subjects of this study.

Physiological Characteristics

The physiological responses to maximal exercise for all subjects and for the ten finishers are presented in Tables 4 and 5, respectively.
Means, standard deviations and ranges are provided for maximal ventilation ($V_{E\text{max}}$), $VO_2\text{max}$ ($l\cdot min^{-1}$ and $ml\cdot kg^{-1}\cdot min^{-1}$), maximum heart rate ($HR_{\text{max}}$), maximal respiratory exchange ratio ($RER_{\text{max}}$) and maximum time on treadmill ($TMT$).

<table>
<thead>
<tr>
<th>Sample Size</th>
<th>Test 1 ($n=27$)</th>
<th>Test 2 ($n=19$)</th>
<th>Test 3 ($n=11$)</th>
<th>Test 4 ($n=10$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{E\text{max}}$ ($l\cdot min^{-1}$)</td>
<td>99.1 a</td>
<td>106.9</td>
<td>106.1</td>
<td>107.0</td>
</tr>
<tr>
<td>$VO_2\text{max}$ ($ml\cdot kg^{-1}\cdot min^{-1}$)</td>
<td>12.5 b</td>
<td>14.2</td>
<td>10.6</td>
<td>16.3</td>
</tr>
<tr>
<td>$RER_{\text{max}}$</td>
<td>67.1-132.5 c</td>
<td>80.6-138.1</td>
<td>86.0-129.1</td>
<td>83.0-131.0</td>
</tr>
<tr>
<td>$VO_2\text{max}$ ($l\cdot min^{-1}$)</td>
<td>56.6</td>
<td>59.0</td>
<td>56.2</td>
<td>60.7</td>
</tr>
<tr>
<td>$HR_{\text{max}}$ (beats $\cdot min^{-1}$)</td>
<td>4.8</td>
<td>3.6</td>
<td>4.6</td>
<td>5.8</td>
</tr>
<tr>
<td>$RTER_{\text{max}}$</td>
<td>45.3-67.5</td>
<td>52.8-66.6</td>
<td>49.7-64.4</td>
<td>46.4-67.2</td>
</tr>
<tr>
<td>$HR_{\text{max}}$ (beats $\cdot min^{-1}$)</td>
<td>3.2</td>
<td>3.4</td>
<td>3.2</td>
<td>3.4</td>
</tr>
<tr>
<td>$HR_{\text{max}}$ (beats $\cdot min^{-1}$)</td>
<td>2.4-3.9</td>
<td>2.7-4.1</td>
<td>2.7-3.6</td>
<td>2.5-3.9</td>
</tr>
<tr>
<td>$RER_{\text{max}}$</td>
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<td>448-794</td>
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</tbody>
</table>

**a** = means, **b** = standard deviations, **c** = ranges.

**Maximal Ventilation**

Ventilation volume ($V_E$) during maximal exercise closely resembled those elicited by highly-trained and elite female distance runners.
Wilmore and Brown (1974) tested 11 elite women long distance runners and reported a $V_{Emax}$ of 108.9 l·min$^{-1}$. Christensen and Ruhling's (1983) research on experienced marathon runners stated a $V_{Emax}$ of 94.7 l·min$^{-1}$. The runners in these two studies, 32.4 and 32.7 years of age, respectively, were somewhat older than the runners in the present study.

Research involving the 1976-1977 Illinois Women's State Championship Cross Country Team reported a $V_{Emax}$ range of 85 to 125 l·min$^{-1}$ (Knowlton et al., 1978). These 11 runners (x=18-20 yrs.) recorded values similar to those obtained by the La Crosse athletes.

The preseason testing of all subjects in this study resulted in a $V_{Emax}$ of 99.1 l·min$^{-1}$. The post season testing of 19 subjects produced a mean $V_{Emax}$ of 106.9 l·min$^{-1}$, although this was not significantly (p>.05) different from the preseason value. The ten subjects completing all tests elicited very similar $V_{Emax}$ values. The ten finishers recorded preseason and postseason $V_{Emax}$ values of 98.0 l·min$^{-1}$ and 106.8 l·min$^{-1}$, respectively. These also were not significantly (p>.05) different from each other. For these ten subjects, $V_{Emax}$ then decreased slightly to a post break of 105.7 l·min$^{-1}$. This value increased slightly one month later to 107.0 l·min$^{-1}$. None of these changes in $V_{Emax}$ were significant (p>.05).

As with VO$_{2max}$, maximum ventilation is notably less in the normal population. Twenty-seven sedentary college women between 17 and 22 years of age had a $V_{Emax}$ of 77.4 l·min$^{-1}$ in a study by Kearney and his associates (1976). Research involving 212 female army recruits (x=19.7 yrs.) reported $V_{Emax}$ of 88.6 l·min$^{-1}$ (Vogel et al., 1986).
Guyton (1986) stated that pulmonary ventilation at maximal exercise for the "normal" male averaged 100 to 110 l·min⁻¹.

### TABLE 5

Means, Standard Deviations and Ranges of $V_{\text{E}max}$, $V_{O2\text{max}}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and $\text{l} \cdot \text{min}^{-1}$), $\text{HRmax}$, $\text{RERmax}$ and $\text{TMT}$ for Ten Subjects Completing All Four Tests

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<td>3.4</td>
<td>3.1</td>
<td>3.4</td>
</tr>
<tr>
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<td>.3</td>
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<td>500-766</td>
<td>461-806</td>
<td>448-794</td>
</tr>
</tbody>
</table>

a = means, b = standard deviations, c = ranges.

**Maximum Heart Rate**

As with maximal ventilation, maximum heart rate ($\text{HRmax}$) also did not change significantly ($p > 0.05$) throughout this study. Heart rate values resembled those attained by females of similar age, both trained and untrained. Kearney and his associates (1976) tested 27 sedentary
college females 17 to 22 years of age. These women recorded a HRmax of 192.7 beats·min⁻¹. Vogel and his co-workers (1986) reported a HRmax of 189.8 beats·min⁻¹ for 212 female army recruits whose mean age was 19.7 years. Daniels, Scardina, Hayes and Foley (1986) studied elite and subelite female middle- and long-distance runners. The 30 subjects (x=22.5 yrs.) in this study had a HRmax of 194 beats·min⁻¹. Another group (n=11) of female college cross country runners between 17 and 22 years of age had a HRmax range of 168 to 200 beats·min⁻¹ (Knowlton et al., 1978).

All subjects tested in the preseason of this study recorded a HRmax of 194.6 beats·min⁻¹. The postseason HRmax for 19 subjects was 191.1 beats·min⁻¹. Concerning the ten subjects who completed all tests, the preseason HRmax reached 195.1 beats·min⁻¹ while the postseason also decreased slightly to 190.7 beats·min⁻¹. None of these changes in HRmax were significant (p>.05). The post winter break test for the ten finishers resulted in a 190.3 beats·min⁻¹ HRmax. The HRmax for the final test was 191.0 beats·min⁻¹. Maximum heart rate decreased slightly for all subjects and for the ten finishers after cross country training, although this was not a significant (p>.05) change. The post season HRmax remained relatively stable with subsequent tests. As expected, the changes in HRmax were not statistically significant (p>.05). These heart rates also support a maximal effort.

Maximal Oxygen Consumption

Of the initial 27 subjects, 19 completed the second tests. Their VO₂max increased by 4.4% in relative value and 4.3% in absolute value,
but these increases were not significant (p > .05). Post winter break
\( \text{VO}_2\text{max} \) (56.2 ml·kg\(^{-1}\)·min\(^{-1}\)) exhibited a 4.8% decrease while the final,
30-days post break \( \text{VO}_2\text{max} \) increased 8.0% to 60.7 ml·kg\(^{-1}\)·min\(^{-1}\).

Although the 10 "completers" showed similar trends of \( \text{VO}_2\text{max} \)
changes, none of these changes were significant (p > .05). These ten
runners had a slightly higher preseason \( \text{VO}_2\text{max} \) (57.4 ml·kg\(^{-1}\)·min\(^{-1}\)) than
the total group. Post season \( \text{VO}_2\text{max} \) increased to 60.1 ml·kg\(^{-1}\)·min\(^{-1}\).
Seven of these ten runners were involved in championship competition.
Post break \( \text{VO}_2\text{max} \) experienced a decrease to 55.6 ml·kg\(^{-1}\)·min\(^{-1}\). Again,
as eight of these runners resumed formal training in January, \( \text{VO}_2\text{max} \)
increased to 60.7 ml·kg\(^{-1}\)·min\(^{-1}\). The preseason max test for the final
10 subjects included both the highest and lowest \( \text{VO}_2\text{max} \) (ml·kg\(^{-1}\)·min\(^{-1}\))
values recorded by any subject (see Table 4 and 5). This wide range in
\( \text{VO}_2\text{max} \), in addition to the small number of subjects, may have
contributed to the lack of significant findings.

The \( \text{VO}_2\text{max} \) values of these athletes were substantially higher than
values reported for normal college-aged females. Kearney and his
associates (1976) found 27 sedentary college women 17 to 22 years of age
to have a mean \( \text{VO}_2\text{max} \) of 38.4 ml·kg\(^{-1}\)·min\(^{-1}\) and 2.2 l·min\(^{-1}\). Other
researchers (Katch et al., 1973) reported similar values of
38.9 ml·kg\(^{-1}\)·min\(^{-1}\) and 2.29 l·min\(^{-1}\) when testing 36 college women with a
mean of 20.8 years. Vogel and coworkers (1986) measured 212 female army
recruits (x = 19.7 yrs.) and reported a \( \text{VO}_2\text{max} \) of 37.5 ml·kg\(^{-1}\)·min\(^{-1}\) and
2.18 l·min\(^{-1}\). All of the \( \text{VO}_2\text{max} \) values for these college-aged females
are quite similar, suggesting that they closely reflect the norm for
young women.
The subjects of this study exhibited VO₂max values similar to those of other female distance runners. Larson (1984) measured nearly the identical preseason VO₂max of 56.6 ml·kg⁻¹·min⁻¹ and 3.1 l·min⁻¹ for cross country runners in an earlier study. A group of nine young marathoners (x=25.2 yrs.) were found to have a VO₂max of 59.8 ml·kg⁻¹·min⁻¹ and 3.1 l·min⁻¹ (Upton et al., 1984). These runners had been running an average of 4.8 years and had averaged 88.7 km per week for the previous six months. Christensen and Ruhling (1983) tested ten novice (x=29.6 yrs.) and 13 experienced (x=32.7 yrs.) women marathon runners. These 23 non-elite runners had maximal oxygen uptakes of 45.8 ml·kg⁻¹·min⁻¹ and 51.8 ml·kg⁻¹·min⁻¹, respectively. Testing 127 female high school cross country runners, Butts (1982) reported a mean VO₂max of 50.8 ml·kg⁻¹·min⁻¹ and 2.6 l·min⁻¹. These runners had a mean age of 15.6 years. Costill (1986) stated that elite female distance runners have VO₂max values greater than 65 ml·kg⁻¹·min⁻¹.

As expected, the runners in this study displayed maximal aerobic powers substantially higher than those of untrained females of similar age reported earlier. The top seven runners finished fourth at the NCAA Division III National Championships while the second team finished sixteenth at the NAIA National Championship Meet. Undoubtedly these runners would be considered highly trained. Although these athletes did not significantly alter their VO₂max as the result of training or detraining, this may be due to the small sample sizes and large standard deviations of the means.
Training and Detraining

While most research have studied the effects of training in sedentary or untrained individuals, few studies have considered the effects of training in females who already exhibit high VO2max values. The subjects in this study recorded a VO2max of 55.6 ml·kg⁻¹·min⁻¹ and 3.2 l·min⁻¹ before formal training had begun. Compared to the normal college-aged female, these runners would be considered "trained" at the onset of this experiment.

Although these subjects were well above the norm for cardiovascular endurance, the fairly rigorous training of the cross-country season appeared to have a positive but not statistically significant influence on VO2max. At the end of the competitive season, weekly mileage decreased for most of these subjects. Also, it is unlikely that the intensity of training remained at such a high level during off-season running. Finally, some athletes engage in other activities (i.e., cross country skiing, swimming, etc.) as an alternate form of training during the off-season. These factors would be expected to cause a decrease in the treadmill VO2max in January. The ten subjects in this study had a post break decrease in VO2max to 55.6 ml·kg⁻¹·min⁻¹. Again, however, this was not a significant change. Since eight of these ten runners resumed formal training in January with the beginning of track season, an increase in training frequency, intensity and/or duration occurred. Also, the mode of exercise would be specific to running. The final VO2max increased to 60.7 ml·kg⁻¹·min⁻¹. While these expected changes in VO2max appear to occur, these changes were not significant (p>.05).

While all 27 runners had a preseason mean VO2max of
56.6 ml·kg⁻¹·min⁻¹, the ten "completers" had a preseason VO₂max of 57.4 ml·kg⁻¹·min⁻¹. This difference in preseason max is probably due to the fact that seven of the final ten were represented in championship competitions while only four additional runners involved in championship competition were included in all 27, thus 70% of the final ten were in the top 14 runners on the team and only 41% of the initial 27 runners were within the top 14 on the team. It would appear that those subjects completing all four tests were generally more "elite" than the initial group as a whole.

Larson (1984) measured the effects of training in 29 female intercollegiate cross country runners. Training generally consisted of running 40 to 50 miles per week at estimated heart rate intensities of 70 to 85% of maximum. These runners significantly increased their VO₂max from 56.6 ml·kg⁻¹·min⁻¹ to 59.8 ml·kg⁻¹·min⁻¹ with 10 to 12 weeks of cross country training. Their preseason VO₂max of 105.2 l·min⁻¹ did not change significantly.

Knowlton et al. (1978) also studied the effects of cross country training on female college runners (n=11). These runners increased their VO₂max from 50.1 ml·kg⁻¹·min⁻¹ to 54.8 ml·kg⁻¹·min⁻¹. Maximal ventilation also increased from 82.4 l·min⁻¹ to 90.5 l·min⁻¹.

These two studies reported increases in relative VO₂max of 5.5% and 9.2%, respectively, as the result of cross country training. The ten subjects in this study increased their VO₂max by 4.7%, but this was not a significant (p>.05) change. Although an expected trend of increasing and decreasing VO₂max seems to be evident, these were not significant (p>.05) changes.
While other researchers (Milburn & Butts, 1983) have demonstrated increases in \( V_{\text{Emax}} \) to accompany training and increases in \( VO_{2\text{max}} \), \( V_{\text{Emax}} \) was not significantly (\( p > 0.05 \)) altered for the subjects in this study. The initial 27 subjects recorded a \( V_{\text{Emax}} \) of 99.1 l·min\(^{-1}\). The post season \( V_{\text{Emax}} \) for 19 subjects was 106.9 l·min\(^{-1}\).

The 10 finishers showed changes in \( V_{\text{Emax}} \) similar to the shifts in \( VO_{2\text{max}} \), although these also were not significant (\( p > 0.05 \)). The preseason \( V_{\text{Emax}} \) for these 10 subjects was 98.0 l·min\(^{-1}\) followed by a postseason of 106.8 l·min\(^{-1}\). The post winter break \( V_{\text{Emax}} \) test elicited a slight decrease to 105.7 l·min\(^{-1}\). With most subjects resuming formal training in January, \( V_{\text{Emax}} \) slightly increased to 107.0 l·min\(^{-1}\). Again, these changes were not significant (\( p > 0.05 \)). The maximal ventilation volumes recorded by these subjects were similar to values recorded by other female college cross country runners (Larson, 1984; Knowlton et al., 1978).

As expected, the treadmill times seemed to parallel changes in \( VO_{2\text{max}} \) and \( V_{\text{Emax}} \). Twenty-seven runners recorded a total treadmill time of 595 seconds. An earlier study by Larson (1984) utilized the same exercise protocol for treadmill testing of similar types of subjects. Larson (1984) recorded a preseason treadmill time of 612 seconds for 29 female cross country runners. Treadmill time increased significantly for these subjects to a post season of 666 seconds. The 19 subjects tested in the post season in this study recorded a treadmill time of 624 seconds.

The treadmill times recorded by the 10 completers more closely depicted trends similar to changes in \( VO_{2\text{max}} \). These 10 subjects
recorded a preseason of 595 seconds. The post season time increased to 650 seconds. While the post break treadmill time decreased to 609 seconds, the final max test showed an increase to 641 seconds. Although these changes would be expected to accompany training and detraining, treadmill times were not significantly (p>.05) altered.

VO2max and all other related physiological variables were not significantly (p>.05) altered. The extreme variance in VO2max values, specifically within the 10 subjects who completed the entire study, may have contributed to the lack of significance in these findings. Also, the loss of subjects (resulting in smaller sample sizes) may have affected the outcome.

**Summary**

This study was designed to examine VO2max and related physiological variables over a period of time that included the cross country season, winter break, and part of the indoor track season. Although VO2max showed a slight increase with cross country training, a decrease following winter break, and another increase with one month of track training, these were not significant changes. Also, none of the other physiological variables (Vpmax, HRmax, RERmax) measured during maximal exercise experienced significant changes. Since these subjects entered this study with relatively high VO2max values, VO2max was less likely to change as the result of training. The runners appeared to have started with VO2max values close to their potential, thus making it more difficult to improve in this variable.
CHAPTER V
SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

This study was designed to examine the effects of formal and informal training on VO$_2$max and related physiological variables in intercollegiate female cross country runners. The experiment included a total of four VO$_2$max tests for each subject. The four tests were comprised of a preseason, postseason, post winter break, and a 30-days post winter break test. Tests were performed on a motor-driven treadmill to voluntary exhaustion. Participants initially included 27 members of the women's cross country team at the University of Wisconsin - La Crosse. Nineteen subjects participated in test 2, 11 in test 3, and 10 in the last VO$_2$max test.

Training for these subjects was under the direction of the women's cross country coach. Although in-season training was individualized, runners generally ran 35 to 55 miles per week, participated in higher-intensity interval workouts twice per week, and raced (5 km) once each week. The length of time between the preseason and postseason testing varied according to the individual based on qualification for championship races.

Prior to each test the heights and weights of subjects were measured. During testing, $V_E$, VO$_2$ ($ml\cdot kg^{-1}\cdot min^{-1}$ and $l\cdot min^{-1}$), HR, and RER were recorded. Means, standard deviations and ranges were compiled for the descriptive and physiological characteristics of each subject.
A one way ANOVA with repeated measures was used to discern any changes in the physiological parameters between VO₂max tests. The .05 level of confidence was used to determine differences between means.

**Conclusions**

Based on the limitations of this research, various conclusions were drawn. Body weight did not change significantly throughout the experimental period. This was probably due to the fact that the runners entered the study relatively lighter and leaner than the average college-aged female, typical of trained female endurance athletes.

The physiological parameters of VO₂max (ml·kg⁻¹·min⁻¹ and l·min⁻¹), V̇o₂max, HRmax and RERmax were not altered significantly as the result of in-season or off-season training. This would imply that either the training frequency, intensity and/or duration during the season was not great enough to elicit a change in VO₂max or that the runners entered this study with a high VO₂max close to their potential. Also, either the seven to eight week period of off-season training was not long enough to alter physiological variables effecting VO₂max or the runners continued training at a frequency, intensity and duration sufficient to retain existing levels of VO₂max.

The subjects in this study elicited a high VO₂max at the onset of this experiment. The fact that the runners did not significantly alter their VO₂max after fairly rigorous training of 8 to 11 weeks duration further assures the fact that these individuals were highly trained relative to the normal college-aged female. Also, initial fitness level effects the amount of increase in VO₂max as the result of training.
The subjects in this study did not significantly alter their cardiorespiratory endurance over the course of six months. Cross country runners and other endurance athletes typically engage in regular physical activity and training during their noncompetitive seasons. This would tend cause minimal shifts in VO$_2$max and its related physiological parameters. The runners in this study followed this pattern of lifestyle and this may account for the lack of significant change in VO$_2$max.

It is also important to consider the fact that subject numbers in this study ultimately decreased by over 60%. This decrease in sample size may have contributed to the lack of significant findings in this study.

**Recommendations for Future Study**

It is recommended that future researchers involved with similar longitudinal studies attempt to establish a larger sample size at the beginning of their experiment. Also, efforts should be made to ensure that subject loss remains at a minimum.

It is recommended that similar longitudinal studies involve athletes of other sports such as swimming or cross country skiing. These athletes may have training programs that are highly dictated by their competitive season, possibly giving rise to greater shifts in cardiorespiratory endurance.

Other researchers may consider measuring changes in anaerobic power in athletes involved in sports such as wrestling, basketball, volleyball.
or soccer. The anaerobic energy transfer component becomes more critical in these activities.

Also, it would be interesting to test VO$_2$max in distance running track athletes at the end of the competitive season and again immediately after the summer.
REFERENCES CITED


INFORMED CONSENT

LONGITUDINAL STUDY ON MAXIMAL OXYGEN CONSUMPTION

IN FEMALE CROSS COUNTRY RUNNERS

I, ____________________________, volunteer to participate in the maximal treadmill test to measure maximal aerobic capacity. I understand that there will be four identical tests that will take place at the following times: TEST #1 - immediately prior to the cross country season, TEST #2 - immediately following the cross country season, TEST #3 - 30 days after test #2, TEST #4 - 30 days after test #3.

I understand that the maximal aerobic test consists of a run to voluntary exhaustion on a motor-driven treadmill. The speed and the incline of the treadmill will be gradually increased throughout the run. During this test, heart rates will be monitored on an ECG and exhaled air will be collected. This test requires a maximal effort, however, I can terminate the run at anytime I wish. As with any exercise, there exists the possibility of adverse changes (i.e.: dizziness, etc.) to occur during the test. If any abnormal observations are noted, the test will be terminated immediately.

To my knowledge I am not infected with any disease or have any limiting physical conditions or disabilities, especially with respect to my heart, that would preclude such a strenuous exercise.

I have read the foregoing and fully understand the statement of informed consent. Any questions that I had have been fully answered to my satisfaction. The potential risks have been explained to me and I fully understand their implications. I hereby acknowledge that no representation, warranties, guarantees, or assurances of any kind pertaining to the procedures have been made to me by the University of Wisconsin-La Crosse, the officers, administrators, employees or by anyone acting on behalf of any of them.

Signed: ____________________________ Date: ____________________________

Witness: ____________________________ Date: ____________________________
Appendix B

Data Recording Form
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ABSTRACT


Female cross country runners were studied to determine if periods of formal and informal training significantly altered VO2max and related physiological variables. Twenty-seven Ss initially tested ranged in age from 18 to 24 yr. Four treadmill VO2max tests conducted over a period of 6 mo included a preseason (T1), post season (T2), post winter break (T3), and a 30-days post winter break (T4) test. Eight to 11 wk of cross country training took place between T1 and T2, 9 to 12 wk of off-season training from T2 to T3, and an additional 4 to 5 wk of track season to T4. Ten Ss completed all 4 tests. The 27 Ss tested recorded a T1 VO2max of 56.6 ml·kg⁻¹·min⁻¹. The T2 VO2max for 19 Ss was 59.0 ml·kg⁻¹·min⁻¹. Eleven Ss had a VO2max of 56.2 ml·kg⁻¹·min⁻¹ for T3 and 10 Ss recorded 60.7 ml·kg⁻¹·min⁻¹ for T4. A one way ANOVA with repeated measures was calculated using all Ss who completed each test while the 10 Ss who completed all 4 tests were treated separately. No sig (p>.05) diff were found in body weight, V̇E, VO2max (l·min⁻¹ and ml·kg⁻¹·min⁻¹), HRmax, RERmax, and treadmill run time between any of the 4 tests. The results indicated that in-season and off-season training did not differ substantially enough to elicit changes in cardiorespiratory endurance. It was concluded that the high initial fitness level of these Ss contributed to the lack of significant change in these physiological parameters.