Effects of a Season of Competition on Anaerobic Performance of Male Collegiate Basketball Players

Marc W. Peterson

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Effects of a Season of Competition on Anaerobic Performance of Male Collegiate Basketball Players

By

Marc W. Peterson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science Major in Health, Physical Education, and Recreation South Dakota State University 1988
Effects of a Season of Competition on Anaerobic Performance of Male Collegiate Basketball Players

This thesis is approved as a creditable and independent investigation by a candidate for the degree, master of Science, and is acceptable for meeting the requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Dr. Jack Ewing, Associate Professor, Thesis Advisor and HPER Graduate Coordinator

Dr. James E. Lidstone, Associate Professor, HPER Research Coordinator

Dr. Harry Forsyth, Professor and Director, Department of HPER and Athletics
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The purpose of this investigation was to determine if a season of basketball competition effects the anaerobic power and capacity of college basketball players. Eleven members of the South Dakota State University men's basketball team and twelve non-athletic college-age males compared the experimental and control groups, respectively. Testing was completed on three different dates which were representative of the stages of a college basketball season. Subjects were tested on a modified Monark bicycle ergometer using the Wingate Anaerobic Test resistance setting of 75 grams per kilogram of body weight. The following variables were investigated over the course of the basketball season: Peak Power, Mean Power, Low Power and Fatigue Index. A repeated measures analysis of variance was used to determine if any significant differences existed at the .05 alpha level. No significant differences were found between the basketball players and the control group for Peak Power yet mean Peak Power did significantly increase over the course of the season. Mean Power increased significantly over the course of the season. The increase in Mean Power for the basketball players was significantly greater than the increases for the control group. The mean Low Power for the basketball players was significantly greater than the mean Low Power of the control group. During the season the Low Power of the basketball players increased significantly while no significant change took place for the control group. The Fatigue Index results indicated that no significant differences existed between the two groups or throughout the course of the season.
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Although there is some ATP stored within the muscle it can only supply enough energy for the first few seconds of exercise. With these muscle stores of ATP are depleted and can only be produced via the anaerobic pathways—glycolysis (with oxygen) or the Embden-Meyerhof (in the absence of oxygen) pathways. In short-term high intensity exercise ATP is produced by the breakdown of carboxylic acids into lactate and (anaerobic) pyruvate. In long-term low intensity exercise ATP is produced by the breakdown of carbohydrates, fats and proteins in the presence of oxygen (aerobic processes). By studying these two energy systems a distinction can be made between the capacity and power of each system. The capacity of a system is the total amount of energy available to perform work within that system. The power of a system is the maximal rate of energy that can be transferred per unit of time (McDonald, 1987).
Chapter I

INTRODUCTION

The energy source that powers muscular exercise in humans is supplied by the splitting of the high energy compound adenosine triphosphate (ATP) into adenosine diphosphate (ADP) and inorganic phosphate (McArdle, Katch & Katch, 1986). Although there is some ATP stored within the muscle it can only supply enough energy for the first few seconds of exercise. When these muscle stores of ATP are depleted ATP can only be produced via two metabolic pathways—one aerobic (with oxygen) the other anaerobic (in the absence of oxygen) (Hermanson, 1969). In short-term high intensity exercise ATP is produced by the breakdown of carbohydrates (glucose) into lactic acid (anaerobic processes). In long-term low intensity exercise ATP is produced by the breakdown of carbohydrates, fats and proteins in the presence of oxygen (aerobic processes). In studying these two energy systems, a distinction must be made between the capacity and power of each system. The capacity of a system is the total amount of energy available to perform work within that system. The power of a system is the maximal amount of energy that can be transformed per unit of time (MacDougall, Wenger, & Green, 1982).

The energy system utilized during exercise is dependent on three factors: mode, intensity, and duration of the exercise (McCafferty & Horvath, 1977). An individual training for a sprint event depends on an energy source (anaerobic) quite different from an
individual training for a long distance event (aerobic). This concept is called the specificity of training, meaning that training must be specific so that the proper energy sources needed for a specific event are stressed. While it may be easy to identify the proper energy source for many track events it is not as easy to do so with the game of basketball.

Basketball has been classified as an anaerobic sport. This does not mean that the entire production of ATP is produced via anaerobic processes because aerobic metabolism does play a significant role in the manufacturing of ATP. This balance between anaerobic and aerobic production of ATP as it applies to the sport of basketball is determined by the pace of the game. A team that wants to play a transition style of basketball will want a fast paced game thus relying more on aerobic metabolism. A team that wants to play a half court style will try and slow the pace of the game and will place more emphasis on the aerobic processes. Coaches need to train their players utilizing the energy system(s) best suited for the sport of basketball.

Basketball is a highly competitive and strenuous sport that encompasses a lengthy season. The duration of the basketball season from the first training session to the last game can be as long as six months. The first two months are devoted to preseason conditioning and practice with the competitive season taking place over the final four months. Most collegiate teams play at least 28 games during the competitive season, averaging about two games per week. Practices average four per week during this period and are one and one-half hour
to two hours in length. The success a basketball team experiences during the course of the season may be related to the overall physical condition of its players. Wooden (1980) stated that physical conditioning is often the deciding factor between victory and defeat when two teams are evenly matched and properly prepared. The conditioning of a basketball team should be as high a priority to a coach as teaching the fundamentals of the game of basketball.

Basketball places a great deal of emphasis on constant movements, quick starts and stops and sudden changes of direction and pace. Also explosive movements such as jumping and accelerating play an important role in the game of basketball. The ability to execute these types of short maximal movements is dependent on the anaerobic power and capacity of the individual (Margaria, 1966; Houston & Thomson, 1977). Basketball is a sport that is played in a relatively small playing area in comparison to other sports such as football, baseball and soccer. The game is divided into two 20 minute halves for college and university teams, with a 15 minute intermission (halftime) separating each half.

Basketball is referred to as a game of transition, meaning that play is continuous with very few stoppages of the action. Ramsey, Ayoub, Dudek, and Edgar (1970) examined the heart rate recovery patterns of two male basketball players for an entire game. They determined that there was a total of 30 stoppages of play, 11 in the first half and 19 in the second half. Typically the second half of a game will include more stoppages of play due to coaches saving most of
their five timeouts for that period. The major stoppages of play involve timeouts, the official signaling a foul or violation, or the shooting of free throws. These various rest intervals last anywhere from 30 to 90 seconds.

The energy source that is most utilized for the sport of basketball is anaerobic metabolism. Several studies have been completed examining the anaerobic aspects of basketball. Vesma, Mohindru, and Kansal (1979) determined from their study of track, basketball, soccer, and women field hockey athletes that basketball players demonstrated the highest anaerobic power values. The researchers based their findings on the Margaria Stair Climb Test. Heart rate is commonly used as an indicator of exercise intensity. McArdle, Magel, and Kyvallos (1971) and Ramsey, Ayoub, Dudek, and Edgar (1970) determined that the heart rate responses of men and women basketball players during a competitive game were significantly above the aerobic training zone and reflect a large dependence on the anaerobic system.

Several studies have examined maximal oxygen uptake ($VO_2^{max}$), an indicator of the body's ability to deliver and utilize oxygen to produce ATP aerobically, and how it relates to basketball. If basketball were predominantly an aerobic sport the aerobic capacities of the basketball players might increase during the course of a season. Yet only one study, Sinning and Adrian (1968), has reported $VO_2^{max}$ to increase during a season of competitive basketball and their increase may be due to the fact that their subjects had very low fitness levels
prior to the season. Other studies have demonstrated that \( \text{VO}_2\text{max} \) does not increase after a season of competitive basketball (Coleman, Dreuzes, Friedrich, and Juvenal, 1974; McArdle et al., 1971; Eidsness, 1971).

The characteristics of play of a sport will be reflected in the relative proportion of energy delivered by the aerobic and anaerobic systems (Green & Houston, 1975). Parr, Wilmore, Hoover, and Bachman (1978) and Withers, Roberts, and Davies (1977) determined that the \( \text{VO}_2\text{max} \) of basketball players were much lower in comparison to athletes in other sports. This adds support that the training stimulus of basketball competition is not sufficient to enhance the aerobic energy processes of the athletes.

While several studies have examined the anaerobic aspects of basketball, only one study has looked at the effects of a season of competition of basketball on the anaerobic systems of athletes. Coleman et al. (1974) determined that a season of basketball competition did enhance the body's ability to produce ATP anaerobically. This study was somewhat limited in that the authors only examined anaerobic power, by the Marygaria Stair Climb Test.

Although the Marygaria Stair Climb Test has been used a great deal in previous research, several limitations have been identified. The test limits itself in that it is only a measure of anaerobic power. The validity of the test has been questioned due to the external resistance (weight of the subject) being too low for maximal power outputs (VanderWalle, Peres and Monod, 1987). Rather than being a
valid measure of power the test may be just a measure of stair climbing ability.

The Wingate Anaerobic Test has been used recently in the measurement of anaerobic performance (Ayalon, Inber, & Bar-or, 1974). It is a 30 second all-out bicycle ergometer test in which the flywheel resistance is based on the subject’s body weight (Inbar, Dotan, Bar-or, 1976). The number of pedal revolutions is recorded every five seconds. Anaerobic power is determined by the maximal power output in a five second period, usually the first five seconds of the test. Anaerobic capacity is the total work performed during the 30 second test or the mean of the six five second periods. The reliability of the Wingate Anaerobic Test is very good ranging from 0.90 to 0.98 (MacDougall, Wenger & Green, 1982). The validity of the test has been supported mainly by research at the Wingate Institute in Israel (Ayalon, et al., 1974; Grodjinovsky, Inbar, Dotan, Bar-Or, 1980; Inbar, et al., 1976).

At the present time no published studies have utilized the Wingate Anaerobic Test to examine anaerobic power and capacity in basketball players. Therefore, this study has been undertaken to examine how a season of basketball affects anaerobic power and capacity as measured by the Wingate Anaerobic Test.

Statement of the Problem

The purpose of this study was to investigate the effects of pre-season basketball practice and a season of competition on the
anaerobic power and capacity of NCAA Division II basketball players as measured by the Wingate Anaerobic Test.

Hypotheses

The specific hypotheses to be tested, stated in the null form, are as follows:

1. There will be no significant difference between the experimental and control groups for anaerobic Peak Power measured preseason, pre-competitive season and post-season.

2. There will be no significant difference between the experimental and control groups for anaerobic Mean Power measured preseason, pre-competitive season and post-season.

3. There will be no significant difference between the experimental and control groups for anaerobic Fatigue Index measured preseason, pre-competitive season and post-season.

4. There will be no significant difference between the experimental and control groups for anaerobic Low Power measured preseason, pre-competitive season and post-season.

Definition of Terms

The following terms have been defined for specific use in this study as follows:

Anaerobic Capacity. The total amount of energy available to perform maximal work in 30 seconds which reflects the rate of both the
phosphagen and glycolytic energy systems (Grodjinovsky, Inbar, Dotan, & Bar-Or, 1980).

**Anaerobic Metabolism.** Anaerobic metabolism is the production of ATP in the absence of oxygen. ATP is available anaerobically through stored ATP and CP (phosphagens) and through the glycolytic breakdown of glucose.

**Anaerobic Power.** The energy developed in a very short exercise of no more than 4 to 5 seconds duration which is reflective of the utilization of phosphagens (Margaria, Aghemo, & Rovelli, 1966).

**Anaerobic Training.** A training program that consists of high intensity, short duration workouts (Weltman, Moffat, & Stamford, 1978).

**Fatigue Index.** Fatigue index is a measure of an individual’s ability to maintain power output during the Wingate Anaerobic Test and is calculated by subtracting the lowest five second output from the highest five second output and dividing by the highest five second output and then multiplying by 100 (Dotan & Bar-Or, 1983).

**Low Power.** Low power is the lowest five second power output.

(referenced)

**Mean Power.** Mean power is the average of the six five second power output measures during the 30 second Wingate Anaerobic Test (Jacobs, et al., 1987).

**Peak Power.** Peak power is the highest five second power output during the Wingate Anaerobic Test (reference).

**Pre-competitive Season.** The period of time which includes all practices and scrimmages from the end of the pre-season conditioning
period (October 14, 1987) to the beginning of the scheduled games of competition (November 21, 1987) is known as the pre-competitive season.

Season of Competition. The period of time which includes all practices and games encompassing the time from November 21, 1987 to March 12 1988 is known as the season of competition.

Supramaximal. Refers to power outputs greater than that necessary to elicit VO$_2$ max. Energy requirements for this work are met by the phosphagen and glycolytic energy systems (Evans & Quinney 1981).

Wingate Anaerobic Test. A 30 second supramaximal cycling test designed to measure anaerobic power and capacity (Dotan & Bar-Or, 1980).

**Assumptions**

It is assumed that the South Dakota State University Men's basketball team which was tested is representative of future basketball teams at South Dakota State University, and therefore any findings can be applied to these teams. It is assumed that the control group is representative of other college-age male non-athletic students and any findings could be applied to these groups. Finally, it is assumed that the subjects gave a maximal effort during the testing sessions.

**Limitations**

Among the 11 subjects in the experimental group, the actual amount of time spent participating in game and practice varied. It was not possible to keep the total amount of work for each player equal.
It was not possible to control certain outside factors such as: diet, sickness or minor injuries, amount of sleep prior to testing or the emotional state of the subjects. It is not known how important these factors are in anaerobic testing.

Scope of the Study

This study was conducted at South Dakota State University, Brookings, South Dakota during the 1987-1988 basketball season. The subjects for this study were 11 members of the South Dakota State University men’s basketball team and 12 non-athletic college-age male students who served as the control group. All testing was performed in the Human Performance Lab in the Stanley J. Marshall HPER Center on the campus of South Dakota State University. Data collection was conducted between the hours of 1:30 p.m. and 5:30 p.m. Each testing session was approximately 10 minutes in length. Prior to any participation in testing procedures each subject read and signed an informed consent form (Appendix A). The weight of each subject was recorded prior to the administration of each test. Each subject went through the actual test procedures on at least two separate occasions prior to actual data collection. Anaerobic power and capacity were measured using the Wingate Anaerobic Test (Ayalon, Inbar, & Bar-Or, 1974). Testing at the conclusion of the preseason conditioning program was done on October 13, 1987 for the experimental group and on October 29 to November 2, 1987 for the control group. Testing at the conclusion of the pre-competitive season was done on November 16 to 18, 1987 for the
experimental group and on December 3 and 4, 1987 for the control group. Testing at the end of the competitive season was done on March 15, 1987 for the experimental group and on March 21, 1988 for the control group.

Significance of the Study

Studies that have examined the anaerobic aspects of basketball have concentrated on identifying the energy process (anaerobic, aerobic) which is best utilized in the sport of basketball (Verma, et al., 1979; McArdle, et al., 1971; and Ramsey, et al., 1970). Little research has been done to determine how the anaerobic performances of basketball players are affected by preseason conditioning programs. Only one study, Coleman, et al. (1974) examined how a season of basketball competition affected the anaerobic power of basketball players. No other research has investigated how a season of competition affects the anaerobic capacity of basketball players. Withers (1978) and Green and Houston (1975) were the only other investigators to examine what occurs to anaerobic performances of athletes during a competitive season. The previous research that has investigated the relationship between the anaerobic energy system and the sport of basketball have used the Margaria Stair Climb Test. The present study based its findings on the Wingate Anaerobic Test, which has been proven to be a more valid and reliable measure of anaerobic power and capacity than is the Margaria Stair Climb Test. This study contributes to our knowledge as to the training of college basketball players in preparation for a season of competition. It also helps
establish normative values for college-age basketball players and non-athletes.

REVIEW OF LITERATURE

This chapter reviews the published literature which is relevant to this study. The chapter is divided into four major areas: (1) reliable performance tests, (2) training effects on aerobic performance, (3) the effects of a season of competition on psychological function, and (4) somatic performance values of athletes. The chapter concludes with a summary of the review of literature.

Aerobic Performance Tests

Aerobic performance tests measure an individual's ability to sustain physical activity at submaximal work in a specified period of time, usually in a test of exercise capacity also called a graded exercise test. The test measures the individual's capacity to do work at a constant metabolic rate for a prolonged period of time. The test is conducted on a treadmill or cycle ergometer. The test is designed to assess aerobic power. The test is standardized to ensure that all variables affecting the test are controlled. The test is designed to measure the individual's aerobic capacity, also called work capacity. The test is standardized to ensure that all variables affecting the test are controlled. The test is designed to measure the individual's aerobic capacity, also called work capacity.
Chapter II

REVIEW OF LITERATURE

This chapter reviews the published literature which is relevant to this study. This chapter is divided into four major areas: (1) anaerobic performance tests, (2) training effects on anaerobic performance, (3) the effects of a season of competition on physiological function, and (4) anaerobic performance values of athletes. The chapter concludes with a summary of the review of literature.

Anaerobic Performance Tests

Anaerobic performance tests measure an individual’s ability to accomplish maximal or supramaximal work in a short period of time. Historically these tests have been limited to field tests such as the vertical jump, standing long jump, 50 yard dash (McArdle, Katch & Katch 1986) and the Margaria Stair Climb Test (1966). In 1969 Cunningham and Faulkner introduced a short exhaustive treadmill run as a measure of anaerobic performance. Recently a variety of bicycle ergometer tests have been developed to measure anaerobic performance. These supramaximal bicycle tests have utilized all out pedaling for a specified period of time with either a fixed resistance (Katch, Weltman, & Traeger, 1976) or a relative resistance based on the subject’s body weight (Ayalon, Inbar, & Bar-Or, 1974). In recent years
one relative resistance test has emerged as the most widely used test for measuring anaerobic power and capacity—the Wingate Anaerobic Test (Ayalon et al., 1974).

**Historical Anaerobic Performance Tests**

In an early attempt to measure the general muscular power of man, Sargeant (1921) developed a vertical jump test in which the total work accomplished is dependent on height jumped and body weight. The test involved each subject standing directly underneath a cardboard disk with a diameter of about 12 inches. The subject then bent forward, flexing at the trunk, knees and ankles and jumped upward straightening the legs and spine trying to touch the cardboard disk with the top of his/her head. The height of the disk was adjusted so that it could be just touched by the subject’s head. The difference between the jump height and the stature height of the subject is the height jumped. Sargeant determined that the product of the jump height and subject weight gives the work done against gravity.

Many years after Sargeant’s initial work in anaerobic power Margaria, Aghemo, and Rovelli (1966) developed a stair climbing test to measure anaerobic power. The total test time is four to five seconds and was thought to be sufficient to reach the limits of the phosphagen system. The test involves running up a stair case two steps at a time. Time to climb the stairs is measured by an electronic clock sensitive to .01 seconds which is triggered by two photo electric cells in which the light beams are parallel to the steps. The clock is started and
stopped when the light image is interrupted by the subject. The measurement of power is determined using the time taken to cover the distance between the fourth and sixth steps in relationship to the height of the stairs and the weight of the subject. The authors initially studied 131 subjects ranging in age between 10 and 70 years. Anaerobic power appeared to increase with age to 30 years and then decrease progressively. Based on this initial study, athletes demonstrated much higher values than did nonathletes.

In a further attempt to more accurately assess anaerobic measures Cunningham and Faulkner (1969) developed a test using a short exhaustive run on the treadmill. They were attempting to determine the effects of six weeks of training on both aerobic and anaerobic power and capacity. Eight male subjects between the ages of 23 and 41 years trained 5 days a week for 6 weeks. The training program involved alternating days of interval work and distance runs with both workouts covering the same distance of 2.5 miles. The interval workout consisted of running 220 yards followed by jogging 220 yards while the distance run involved a half mile warm-up proceeded by a 2 mile run at the individual's fastest pace possible. VO₂max was determined using five minute work periods followed by ten minute rest periods. The treadmill speed was held constant at 7 mph and with each successive workload the grade was increased 2.5%. The test was terminated when the subject could no longer complete the full five minute work period. Anaerobic power was measured using a short exhaustive run on the treadmill where the grade and speed were held constant at 20% and 7 to
8 miles per hour, respectively. This was designed to insure a pretest run time of between 30 and 60 seconds. Post exercise lactate samples were taken from 4 to 5 minutes and from 11 to 12 minutes with the higher value being used as the maximum blood lactate value. The results demonstrated that \( \text{VO}_{2\text{max}} \) increased significantly by 8% from 3.75 to 4.06 liters per minute. The short exhaustive run time increased 23%, with a mean time of 52 seconds for test 1 and a mean time of 64 seconds for test 2. This increased time for the short exhaustive run was thought to represent an improvement in the ATP-CP and glycolytic anaerobic energy systems of the body. Blood lactate concentrations also showed a significant increase of 17% with mean values of 101 mg% on test 1 to 118 mg% on test 2. The authors concluded that the training program of alternating interval and distance workouts for six weeks overloaded both the capacities for aerobic and anaerobic metabolism in the subjects.

**Cycle Ergometer Anaerobic Tests**

The origin of what is now called the Wingate Anaerobic Test was published by Ayalon, Inbar, and Bar-Or (1974) who studied the relationships between five different anaerobic power performance tests. Fifteen untrained male subjects between the ages of 19 and 21 years with a mean body weight of 71.93 kilograms performed all five tests in one day, with a rest interval of 30 minutes separating each test. The absolute power test involved measuring the power exerted by the left leg in one all-out effort involving 150 degrees of motion pedaling on a
Fleisch bicycle ergometer against a constant force of 2.90 kilograms. A stop clock sensitive to .01 seconds was operated by two microswitches and measured the time needed to move the pedal through 120 degrees. The relative explosive power test followed the same procedures as the absolute power test except that the resistance was 40 grams per kilogram of body weight. The third anaerobic power test was the Margaria Stair Climb Test. A 30 second all-out pedaling test for the legs (now called the Wingate Anaerobic Test) and for the arms was accomplished with resistances of 40 grams per kilogram of body weight and 20 grams per kilogram of body weight, respectively. Margaria's Step Test produced the greatest mean power output ($6160.76 \pm 664.53$ kilogram meters per minute). The 30 second leg test was next at $3607.30 \pm 240.72$ kilogram meters per minute, followed by the relative explosive power test at $2820.77 \pm 507.60$ kilogram meters per minute.

To further examine anaerobic power using a 30 second all-out ride on a bicycle ergometer Inbar, Dotan, and Bar-Or (1976) used sixteen, 15 to 22 year old male and female athletes cycling against a resistance of 40 grams per kilogram of body weight. The total work output was $2440.4 \pm 40.4$ and $3479.1 \pm 160.5$ kilogram meters per minute for females and males, respectively. The authors measured oxygen consumption and determined that the aerobic energy component of the supramaximal anaerobic bike test represented only 13% of total energy utilized. Based on these results, the authors concluded that the
supramaximal bicycle test is a valid measure of anaerobic energy systems.

In a separate laboratory Katch, Weltman, and Traeger (1976) also examined the use of the bicycle ergometer as a mode of measuring anaerobic power and capacity. They studied the effects of all-out pedaling rate and steady-paced pedaling rate during an anaerobic cycle ergometer test of two minutes duration. Twenty-one subjects (mean age 21.9 ± 2.1 years, mean body weight 73.07 ± 9.48 kilograms) participated in the study. The frictional resistance for both conditions was 34.0 kiloponds per revolutions. No warm-up was used prior to each test. The steady paced condition pedaling rate was set at 9.7 revolutions per six seconds which represented approximately 80% to 90% of the subject’s maximum pedaling rate. The all-out pedaling rate significantly produced more total work output 1884.28 ± 54.4 revolutions per minute for 0 to 30 seconds than did the steady paced rate 1649.34 ± 27.2 revolutions per minute. The total cumulative work output for 0 to 60 seconds for the all-out rate was 2988.26 ± 81.6 revolutions per minute which was significantly greater than that for the steady-paced rate (2873.68 ± 54.4 revolutions per minute) after 60 seconds there was no difference among any of the pedaling rates for work output.

As a follow-up to the previous study Katch, Weltman, Martin, and Gray (1977) attempted to determine the revolution rate, duration, and optimum resistance setting needed to elicit the highest results for an anaerobic bicycle ergometer test. For determining the correct revolution rate and duration, 30 subjects (mean age 20.87 ± 2.51 years,
mean body weight 74.83 ± 15.39 kilogram) pedaled for 2 minutes against a constant resistance of 5.5 kiloponds at 60, 80, 100 and revolutions per minute, and all-out. The amount of time between tests was at least 24 hours. For determining the optimal resistance setting a separate group of 28 subjects (mean age 21.29 ± 2.21 years, mean body weight 74.59 ± 7.59 kilograms) were studied. Each subject pedaled all-out for 40 seconds at 4.0 kiloponds, 5.0 kiloponds, and 6.0 kiloponds. This duration (40 seconds) was chosen based on the results from the first part of this study which demonstrated a high correlation (r = .95) with the total cumulative work at 40 seconds compared to total cumulative work at 2 minutes. Only one test was performed per day. Total cumulative work for the frequency determination test was as follows: all-out - 4129.3 kilopond meters, 100 revolutions per minute - 4120.5 kilopond meters, 80 revolutions per minute - 3996 kilopond meters, 60 revolutions per minute - 3662.5 kilopond meters. Cumulative work outputs for the resistance determination test were: 6.0 kiloponds - 2161.8 kilopond meters, 5.0 kiloponds - 2099.0 kilopond meters, and 4.0 kiloponds - 1928.9 kilopond meters. The optimal test characteristics for an anaerobic cycle ergometer test as determined by this study were 40 seconds duration, frictional resistance of 5.0 to 6.0 kiloponds, and all-out pedaling frequency.

Evans and Quinney (1981) attempted to identify the optimal resistance setting on the anaerobic bicycle ergometer test by establishing a power output curve for each subject. The power curve for each subject was determined by plotting power output versus
flywheel resistance. This power curve was developed with an initial resistance of 1.0 kilopond which increased by 1.0 kilopond on each successive ergometer test until the power output decreased. Prior to each exercise bout, a two minute warm-up at 50 watts was completed by each subject. At the conclusion of the warm-up, the ergometer test immediately began. Mean maximal power based on the optimal resistance setting was significantly greater than the Wingate Anaerobic Test power value (661.6 watts and 588.4 watts, respectively. The authors concluded that higher resistances than prescribed in the Wingate Test are needed to elicit maximal power output.

A similar study for determining the optimal load for producing maximal power outputs in the Wingate Anaerobic Test for arms and legs was examined by Dotan and Bar-Or (1983). Eighteen female and seventeen male physical education students, mean ages of 20.6 ± 1.6 years and 24.1 ± 2.5 years, respectively, served as subjects for the study. Five different testing sessions were completed by each subject. At least 24 hours separated each session. In each session, the 30 second Wingate Anaerobic Test was performed once with the arms only and once with the legs only with at least 30 minutes of rest separating the two tests. Load resistances were based on body weight. The following load resistances in grams per kilogram of body weight were used for the leg tests: 35, 40, 45, 50, 55. The resistances for the arm test were 20, 25, 30, 35, 40 grams per kilogram of body weight. A three to five minute warm-up preceded each test and consisted of low intensity cranking/pedaling at the load to be tested interspace by two to three
all-out sprints of four to seven seconds of duration. The men’s optimal resistance load for the legs was 52.3 grams per kilogram of body weight and for the arms was 36.9 grams per kilogram body weight. The women’s optimal resistance loads for the legs and arms were 51.4 grams per kilogram body weight and 28.8 grams per kilogram body weight, respectively.

Several studies have been completed examining the effects of activity and environment on the subject prior to the Wingate Anaerobic Test. Dotan and Bar-Or (1980) studied the effects of climatic heat stress on performance capacities in the Wingate Anaerobic Test. Fourteen boys and 14 girls between the ages of 10 and 12 years, who were moderately active in a track training program served as subjects. Testing was conducted on a Fleisch cycle ergometer and consisted of a 30 second all-out cycling bout at a resistance of 3.92 joules per crank revolution per kilogram of body weight. Each child was exposed to three climatic conditions: neutral (22 to 23 degrees C, 55 to 60% relative humidity), hot-dry (38 to 39 degrees C, 25 to 30% relative humidity), and warm-humid (30 degrees C, 85-90% relative humidity). Nineteen children went through a ten minute intermittent running warm-up of 30 seconds on and 30 seconds off a treadmill followed by a rest of five minutes prior to the initiation of the bike test. Prior to the treadmill running warm-up, the children sat for 30 minutes in the climatic condition in which they were to be tested. Nine children participated in no warm-up and after resting 45 minutes in the climatic condition in which they were to be tested they performed the cycle
ergometer test. No significant difference was noted between the warm-up and no warm-up groups for any of the climatic conditions. Performance values for the Wingate test showed no significant difference between climatic conditions in the girls while the boys demonstrated a significant difference between the warm-humid condition (7.06 ± .74 watts per kilogram of body weight) and the hot-dry (6.76 ± .60 watts per kilogram of body weight). No significant differences could be determined when the values from each group were combined. The authors concluded that the Wingate Anaerobic Test is not affected by hot or humid climatic conditions.

Inbar and Bar-Or (1975) examined the effects of an intermittent warm-up exercise on the Wingate Anaerobic Test. Twelve healthy boys between the ages of 7 and 9 years with a mean body weight of 27.2 ± 3.3 kilograms served as subjects for this study. The boys completed two anaerobic bicycle ergometer tests with and without the intermittent warm-up. The warm-up duration was 15 minutes, during which time each boy alternated running on a treadmill and resting, every 30 seconds. The warm-up represented 60% of the subject’s VO₂max. The 30 second all-out bicycle ergometer test was performed on a Fleisch ergometer at a resistance of 35 grams per kilogram of body weight. Total work output was significantly greater after the warm-up (910 ± 167 kilopond meters) than without the warm-up (850 ± 161 kilopond meters). The revolutions per 30 seconds were also significantly greater following the warm-up, 49.4 ± 6.7 revolutions compared with no warm-up 46.1 ± 6.1
revolutions. These results indicate that anaerobic performance test measures were significantly increased with the use of a warm-up.

DeBruyn-Prevost and Lefebvre (1980) conducted a similar study investigating the effects of a light (30% $V_O^2_{max}$) and strenuous (75% $V_O^2_{max}$) five minute warm up on maximal anaerobic exercise which lead to exhaustion in less than one minute. Nine subjects, five female and four male (mean body weight 67.1 ± 9.0 kilograms) participated in the study. The anaerobic exercise was completed on an electromagnetically braked bicycle ergometer and the resistance was set at 50 to 400 watts for the males and 25 to 350 watts for the females with the set pedaling rate between 124 and 128 revolutions per minutes for the males and between and 104 and 108 revolutions per minutes for the females. The exercise stopped when the subject reached exhaustion, which was defined as the subject's inability to maintain the prescribed pedaling rate. Each subject performed the bicycle ergometer test once without a warm-up. Two different test situations were utilized with the warm-up—the continuous set in which the bike test immediately followed the warm-up and the discontinuous set in which there was a five minute resting period between the warm-up and the bike test. The results showed that only the warm-up at 30% $V_O^2_{max}$ significantly improved the performance on the cycle ergometer test (47.6 ± 11.3 seconds) as compared to without a warm-up (42.7 ± 5.5 seconds). Continuous warm-up at 75% $V_O^2_{max}$ significantly decreased performance (33.3 ± 6.9 seconds). No significant difference existed between the no warm-up performance times and the discontinuous warm-up performance times. The results
indicate that a light warm-up immediately preceding the anaerobic exercise significantly improves performance. The discontinuous warm-up set which is more representative of field conditions did not significantly improve performance.

Various studies have attempted to determine the best predictor of anaerobic performance by comparing different modes of testing and investigating the correlations between the tests. Tharp, Newhouse, Uffelman, Thorland, & Johnson (1985) studied the relationships between the Wingate Anaerobic Test and the 50 yard dash, 600 yard run, standing long jump, and the vertical jump. They also examined how age and weight influence Wingate Test scores. Fifty-six boys (mean age 13.26 ± 1.20 years, mean body weight 48.85 ± 11.68 kilogram) with a wide range of athletic ability served as subjects. The resistance setting for the 30 second bicycle ergometer test was adjusted relative to body weight using the standard 75 grams per kilogram body weight. A warm-up period of four minutes of pedaling at 0.50 kilograms of resistance at 20 kilometers per hour with a sprint of ten pedal revolutions every minute preceded each test. Following the warm-up, the subjects rested for four minutes during which time the subject received directions concerning the test. Wingate test scores for anaerobic power and capacity showed very little correlation to 600 yard run times (r = -.26 and r = -.29, respectively) and only slightly better correlations to 50 yard dash times (r = -.53 and r = -.53, respectively). The anaerobic power and capacity values demonstrated a higher correlation to the vertical jump (r = .70 and r = .74, respectively) than they did to the
long jump ($r = .59$ and $r = .59$, respectively). Body weight values were highly correlated to anaerobic power and capacity ($r = .90$ and $r = .91$, respectively). Age values were moderately correlated with anaerobic power and capacity ($r = .73$ and $r = .76$, respectively). The results indicate that the Wingate Anaerobic Test is a poor predictor of dash and run times, and a moderately good indicator for long jump and vertical jump performances. Wingate scores are highly correlated with body weight and this must be taken into account when comparing results between individuals and therefore should be expressed in a relative manner, i.e., power or capacity units per kilogram of body weight.

LaVoie and Brayne (1984) examined changes in power output and fatigue with and without toe stirrups during bicycle ergometer tests using the Wingate Anaerobic Test and the Evans-Quinney protocol which is based on leg volume and body weight. Fifty physical education and varsity athletes (mean age 22.6 ± 1.85 years, mean body weight 74.88 ± 8.37 kilograms) volunteered for this study. Testing involved four maximal 30 second anaerobic power tests over a two day period on a modified Monark bicycle ergometer. Two tests were completed using the Wingate protocol with and without toe stirrups and two tests were completed using the Evans-Quinney protocol with and without toe stirrups. Each testing session consisted of two 30 second maximal cycling performances separated by 30 minute rest periods. At the completion of a two minute warm-up at 50 watts the subject then proceeded directly into the 30 second test. The Evans-Quinney protocol with toe stirrups produced a significantly higher peak power ($860 ± 10$
watts) as compared to the Wingate protocol also with toe stirrups (780 ± 9 watts). Both protocols with toe stirrups produced significantly higher values as opposed to the same protocols without stirrups. The measurements of 30 second anaerobic capacity again demonstrated that significantly higher values were produced with the Evans-Quinney protocol using toe stirrups (680 ± 15 watts) than did the Wingate protocol (640 ± 15 watts). Both of these values were significantly greater than the values obtained with both protocols without toe stirrups. (Evans-Quinney - 625 ± 12 watts, Wingate - 625 ± 10 watts). This study indicates that the Evans-Quinney protocol using toe stirrups produced significantly higher anaerobic peak power and capacity outputs when compared to the Wingate protocol. The results indicate that bicycle ergometer testing using toe stirrups is essential.

Training Effects on Anaerobic Performance

For training to be effective it must follow the principle of specificity of exercise particularly in regards to the energy system being used (McCafferty & Horvath, 1977). A second important principle which is known as the overload principle states that for physiological adaptations to occur an individual must exercise at a level above normal. Overload can be accomplished by manipulating intensity, duration, and/or frequency (Weltman et al., 1978). The major determining factor between aerobic and anaerobic training is the intensity of exercise. The intensity level of anaerobic training is
such that ATP cannot be produced aerobically, but via anaerobic metabolism (Jacobs et al., 1987).

The duration of anaerobic exercise should not exceed two minutes due to the fact that the body switches over to produce the majority of ATP aerobically. All of the following studies are very similar in their training methods concerning intensity and duration. Differences in frequency range from 2.5 (Jacobs et al. 1987) to 6 times a week (Withers 1978).

Testing of the effectiveness of training programs is commonly done by performance tests, primarily bicycle ergometry tests although some studies have used the Margaria Stair Climb Test or the Cunningham and Faulkner treadmill test.

Fox, Bartles, Klinzing, and Ragg (1977) examined the metabolic changes which resulted from a high power interval training program (short duration, high intensity) as compared to a low power interval training program (long duration, low intensity). Thirty subjects (mean age 22 years) were pre- and post-tested for the following variables: \( \dot{V}O_2 \text{max} \), blood lactic acid accumulation following a short exhaustive run, and anaerobic power as measured by the Margaria Stair Climb Test. Training occurred three days a week for eight weeks. Training for the high power group \((n = 16)\) consisted of 19 high intensity treadmill runs of 30 seconds duration alternated with recovery intervals long enough to return the heart rate to between 120 and 140 beats per minutes. The treadmill speeds and grades ranged between 15 and 17 kilometers per hour and 5% and 10%, respectively. The low power group \((n = 14)\)
trained for 2.0 minutes with 7 lower intensity treadmill runs of speeds and grades between 10 and 12 kilometers per hour and 5% and 12%, respectively. The recovery intervals were the same as for the high power group. VO₂ max increased significantly for both groups—52.7 ± 4.5 milliliters per kilogram per minute to 55.1 ± 5.1 milliliters per kilogram per minute for the high power group and 51.5 ± 4.6 milliliters per kilogram per minute to 55.6 ± 4.7 milliliters per kilogram per minute for the low power training group. No significant change was observed in anaerobic muscular power output. Post training net lactic acid was significantly lower for both groups, with the low power group exhibiting the greater decline. Post training treadmill running times were similar for both groups (118.3 ± 27.4 seconds and 115.9 ± 20.2 seconds for the high and low power groups, respectively). In summary both training programs elicited similar changes in maximal aerobic and anaerobic metabolism.

Weltman, Moffatt, and Stamford (1978) examined the effects of anaerobic training and de-training on the aerobic power and anaerobic power and capacity on 19 college-age women (mean age 20.6 years). Aerobic power was determined using a stepwise increment bicycle ergometer test protocol. The anaerobic performance test involved an all-out pedaling task on a mechanically braked bicycle ergometer against a 4.0 kilogram resistance for 40 seconds. Both capacity and peak power were determined from the 40 second all-out test. Training occurred three times a week for six weeks and involved two all-out bicycle rides (4.0 kilogram resistance for 40 seconds), with each
exercise bout being separated by 10 minutes of rest. At the conclusion of the training period, the subjects experienced six weeks of detraining and were retested. VO\textsubscript{2} max values showed a 10% increase (28.10 ± 4.8 milliliters per kilogram per minute to 31.03 ± 4.6 milliliter per kilogram per minute). The effects of detraining lowered the VO\textsubscript{2} max to 27.24 ± 3.70 milliliters per kilogram per minute. Mean anaerobic power increased significantly from 7.69 ± 7.5 revolutions to 8.69 ± 9.5 revolutions, a significant 13% increase. Detraining lowered the anaerobic power to 5.65 ± 6.31 revolutions, which was still 12% above the pretest mean values. Anaerobic capacity values increased significantly by 12.1% above pretest values—53.80 ± 5.9 revolutions to 60.30 ± 7.04 revolutions. Detraining resulted in significantly lower anaerobic capacity (56.50 ± 6.31 revolutions) values below the posttest values but were still 5.0% higher than pretest figures. Six weeks of anaerobic training significantly increased aerobic power and anaerobic power and capacity with six weeks of detraining significantly lowering aerobic power. Anaerobic performance measures were still significantly higher after detraining.

Jacobs, Esbjornsson, Sylven, Holm, and Jansson (1987) studied the changes in intramuscular myoglobin concentration in response to supramaximal exercise training. Seven males and four females participated as the experimental group which trained on the average of 2.5 times a week for six weeks on a mechanically braked cycle ergometer. Each training session consisted of two 15 second and two 30 second all-out cycle sprints against a resistance of 75 grams per
kilogram body weight and were separated by rest intervals of 45 seconds and 15 minutes, respectively. Training was progressive such that by the sixth week each session consisted of six 15 second and six 30 second cycle sprints. A pre- and post-test was conducted using the Wingate Anaerobic Test with the resistance set at 75 grams per kilogram body weight. Blood lactate samples were taken from the finger tip immediately following the Wingate Anaerobic Test. Muscle biopsies were taken from the vastus lateralis one day prior to and two days following the final training session. Training did not produce any significant changes in performance measures using the Wingate Anaerobic Test. Peak lactate concentrations significantly increased due to training: 11.4 ± 1.0 milliosmols per liter to 12.5 ± 1.3 milliosmols per liter before and after training, respectively. Muscle myoglobin concentration significantly decreased after training: 17.6 ± 4.3 milligrams per gram to 15.3 ± 3.0 milligrams per gram. The results of this study indicate that supramaximal training two times a week does not provide adequate stimulus to improve anaerobic performance as measured by the Wingate Anaerobic Test.

Inbar and Bar-Or (1980) studied the effects of seven weeks of anaerobic and aerobic training on arm and leg anaerobic performance. Fifty-two males, mean age 20.7 years, trained 4 to 5 times a week for 3 to 4 hours per session. The anaerobic training included push-ups, pull-ups, rope-climbing, uphill-running, stair-climbing, squats, and other various weight lifting exercises. A distance run of up to 5 kilometers per day and completion of an obstacle course made-up the
aerobic workouts. The lab testing involved the Wingate Anaerobic Test using a Monark bicycle ergometer. The resistance for the arms and legs was 0.30 kilogram meters per kilogram of body weight and 0.45 kilogram meters per kilogram of body weight, respectively. The field tests included hill running (25% grade for 170 meters), 100 meter dash, and pull-ups. The results indicate that both mean and peak power improved significantly for the arms (mean power pretest - 29.7 ± .58 kilogram meters per minute and posttest 32.2 ± .56 kilogram meters per minute; peak power pretest 35.5 kilogram meters per minute ± .75 and posttest - 40.5 kilogram meters per minute ± 6.9. Only the leg mean power increased significantly (43.0 kilogram meters per minute ± .53 pretest to a posttest value of 44.2 kilogram meters per minute ± .58). In the field tests pull-ups increased significantly from a pretest mean of 9.77 to a posttest value of 11.71. Hill running also increased significantly (pretest 60.79 seconds to posttest 58.81 seconds). No significant change was noted in the 100 meter dash times. The anaerobic training methods employed in this study did improve anaerobic performance as measured by laboratory and field tests.

The effect of a short moderately intense anaerobic training program on fifty boys, ages 11 to 13 years, as determined by the Wingate Anaerobic Test was conducted by Grodjinovskv, Inbar, Dotan, and Bar-Or (1980). The training period was six weeks, with the subjects exercising three times per week. The subjects were randomly divided into two training groups. One group trained using only sprint running, which consisted of three maximal 40 meter runs proceeded by 3 maximal
150 meter runs per workout. The other group trained only with the use of a bicycle ergometer and consisted of three eight second all-out pedaling bouts followed by three 30 second all-out bicycle sprints. Every two weeks the rides and runs were increased to maintain overload. Anerobic power, capacity, and fatigue index were tested using the Wingate Anaerobic Test. Each subject pedaled for a 12 minute warm-up to raise the heart rate to approximately 150 beats per minute. This was then followed by a 4 to 5 minute rest prior to the actual test. A Fleisch ergometer was used for the test and the resistance was set relative to the subject’s body weight (45 grams per kilogram body weight). Both training groups increased their anaerobic capacity when expressed as kilogram meters per minute or as by total work kilogram meters per minute. The mean values for total work for the bicycle group increased significantly when expressed in an absolute manner (1534.3 ± 57.6 kilogram meters per minute to 1607.4 ± 65.2 kilogram meters per minute) and relative to body weight (43.7 ± 1.0 kilogram meters per minute to 45.2 ± 1.2 kilogram meters per minute). The sprint group had similar significant improvements for absolute total work (1678.2 ± 55.6 kilogram meters per minute to 1760.9 ± 53.6 kilogram meters per minute) and relative to body weight (43.6 ± 1.3 kilogram meters per minute to 45.2 ± 1.3 kilogram meters per minute). The effect of training on anaerobic power (the highest work output in a five second period) only improved significantly for the bicycle group (1806.1 ± 65.9 kilogram meters per minute to 1902 ± 85.0 kilogram meters per minute. It was determined that the Wingate Anaerobic Test
was sensitive enough to detect changes in anaerobic capacity in children after a six week anaerobic training period emphasizing short intense work bouts.

Houston and Thomson (1977) studied the ability of five middle aged men (34 to 37 years) who were experienced endurance runners (approximately 35 kilometers per week), to adapt to an intense anaerobic hill running program. The following variables were investigated: \( \text{VO}_2\text{max} \) as measured on a treadmill test (Balke protocol), anaerobic capacity (Cunningham & Faulkner method), and anaerobic power (Margaria Stair Climb Test). Training was conducted four times a week for six weeks on a paved hill (3.3% grade) and a grassy hill (44% grade). The training on the 3.3% graded hill involved 3 maximal 60 second and 2 maximal 90 second runs, with two and three minutes of recovery between runs, respectively. The training on the 44% graded hill involved five 6 second runs with 24 seconds of recovery between bouts. At the conclusion of the six week training period, the five subjects significantly increased the mean distance covered for both the 60 second and 90 second running bouts by 13.7% and 13.4%, respectively.

Anaerobic capacity increased by 16.7% as measured by the short exhaustive run. No significant increase in \( \text{VO}_2\text{max} \) was found. Anaerobic power did not significantly increase with training as measured by the Margaria Stair Climb Test.

A study examining the effects of 3 months of pre-season conditioning on several parameters of seven international female lacrosse players was conducted by Withers (1978). Four tests were
completed during the course of the pre-season: body composition determined by skinfold measurements, \( V_O^2 \text{max} \) as measured on the treadmill using the Froelicher Protocol, anaerobic power as measured using the Margaria Step Test, and anaerobic capacity as measured by the Cunningham and Faulkner short exhaustive run. All the athletes trained twice a day, six times per week. The running program began with continuous workouts and gradually shifted over to interval training. Training significantly \((p<0.05)\) increased the \( V_O^2 \text{max} \) of the athletes \((44.0 \pm 3.8 \text{ milliliters per kilogram per minute to } 52.9 \pm 3.8 \text{ milliliters per kilogram per minute})\). Run time for the short exhaustive treadmill run also increased significantly \((42.5 \pm 6.3 \text{ seconds to } 61.4 \pm 7.6 \text{ seconds})\). Time in the Margaria Stair Climb Test significantly decreased \((527 \pm 050 \text{ milliseconds to } 478 \pm 050 \text{ milliseconds})\). It was evident that the preseason conditioning did significantly enhance the athlete's aerobic and anaerobic energy systems.

The Effects of a Season of Competition

Research has indicated that preseason training programs will improve the anaerobic performance of athletes. What happens to the physical fitness levels of athletes during a season of competition is still unclear.

In one of the few studies which examined the effects of a season of competition on anaerobic and aerobic variables Green and Houston (1975) utilized members of two junior ice hockey teams whose
ages ranged between 16 and 20 years. The pretest was conducted four weeks into the preseason training period and the posttest took place five months later, just prior to the end of the regular season. Skinfolds, bodyweight, VO$_2$max as determined by a graded treadmill test (Balke method), anaerobic power (Margaria Stair Climb Test), and anaerobic capacity (Cunningham & Faulkner protocol) were all evaluated. No significant difference was found between the pretest and posttest mean values for VO$_2$max, body weight, percent body fat and blood lactates. The short exhaustive mean run times (anaerobic capacity) increased significantly by 16.3% (64.3 ± 13.1 seconds to 74.8 ± 10.2 seconds). The anaerobic power increased significantly as well (130.3 ± 18.0 kilograms per second to 137.8 ± 17.2 kilograms per second).

Coleman, Kreuzer, Friedrich, and Juvenal (1974) conducted a similar study except that they examined the effects of a season of basketball competition on the aerobic and anaerobic energy systems of nine freshmen basketball players. VO$_2$max was determined using the Balke treadmill protocol and anaerobic power was determined according to the Margaria Stair Climb Test protocol. The pretest was conducted one week prior to the first game and the posttest was accomplished one week after the final game. Twenty weeks separated the two tests. At the conclusion of the season there were no significant changes in treadmill performance time or VO$_2$max. Anaerobic power as measured in vertical velocity did significantly improve (4.99 ± .34 feet per second to 5.33 ± .31 feet per second). The results of this study indicate
that a season of basketball competition was of adequate intensity to maintain aerobic fitness and to improve anaerobic power performance.

To further examine how anaerobic metabolism and basketball are related, Ramsey, Ayoub, Dudek, and Edgar (1970) studied the effects of brief rest intervals (timeouts and freethrows) on the recovery heart rates of two freshmen basketball players during a single game. Heart rates were monitored every 30 seconds using telemetry for the two basketball players, one a starter and one a reserve player. During the course of the game, 18 freethrows were taken by other players. The amount of time from when the foul was whistled to the resuming of play averaged between 30 to 40 seconds. The mean heart rate during the first 10 seconds of recovery (180 beats per minute) was significantly different from that of the last 10 seconds of recovery (168.5 beats per minute). No significant difference was determined from the first or last 10 seconds of recovery during a freethrow when the athlete himself was taking the foul shot. During the six timeouts of the game there was a significant drop in mean heart rate (176 beats per minute to 153 beats per minute). It is evident from the results that timeouts and freethrows by other players provide enough time for significant decreases in heart rate.

Instead of examining the effects of a season of competition on anaerobic performance, Sinning and Adrian (1968) investigated how cardiorespiratory parameters were effected by a season of competition. Seventeen women (mean age 20.8 years) volunteered as subjects for the study. Eight women, who were members of a collegiate basketball team
participated in 25 practices and 7 games during the course of the 66-day season. VO$_2$max increased from the beginning (34.4 ± 5.1 milliliters per kilogram per minute) to the end (38.7 ± 4.1 milliliters per kilogram per minute) of the season.

A similar study conducted by McArdle, Magel, and Kyvallos (1971) examined the changes in maximal oxygen uptake over the course of a basketball season in six women basketball players. The first test was conducted two weeks before the first game and the last test within one week after the last game. The course of the season included 17 games and 41 practices. VO$_2$max was determined using the graded treadmill test protocol described by Balke. No significant difference was observed between the pretest and posttest values for VO$_2$max. The authors felt that the lack of improvement in VO$_2$max was due to lack of sufficient intensity to properly overload the aerobic energy system.

In an attempt to further examine how a season affects cardiorespiratory functions Campbell (1968) also studied the effects of a season (21 week) of competition on the cardiac functions of 7 male freshmen basketball players. The following cardiac functions were studied: resting heart rate, minutes of treadmill performance to attain a heart rate of 180 beats per minute using the Balke treadmill test protocol, amount of time for heart rate to drop to 90 beats per minute from the peak of 180 beats per minute, and recovery heart rates at 30 seconds, 60 seconds, and 90 seconds after the completion of the treadmill test. No significant difference was found between the pretest and posttest values for resting heart rate. The time to reach
a recovery heart rate of 90 beats per minute following the treadmill
test was significantly longer at the end of the season than at the
beginning. A similar significant difference was determined for the
recovery heart rates at 30, 60, and 90 seconds of recovery. A
significant difference in performance time to elicit a maximum heart
rate of 180 beats per minute was found.

Anaerobic Performance Values of Athletes

Despite the fact that many sports rely on anaerobic energy
sources, few studies have examined the differences that exist in
anaerobic power and capacity of athletes. This type of data would make
it possible to draw comparisons between athletes of different sporting
activities and with non-athletes.

In an attempt to establish better anaerobic performance norms
Crielaard and Pirmay (1981) compared the anaerobic power of various
track athletes and non-athletes. Six sprinters, three short-middle-
distance runners, six long middle distance runners, and six marathoners
comprised the track group. The nonathletic group consisted of 32
subjects. Anaerobic power was measured using an all-out bicycle
ergometer test in which the subject pedaled against a resistance
ranging from four to seven kilograms for less than ten seconds. The
marathon runners exhibited the lowest anaerobic power values 8.93 ± .4
watts per kilogram. The anaerobic power values for the sprinters were
the highest 14.16 ± 1.36 watts per kilogram. The mean anaerobic power
outputs for the short and long middle distance runners were similar to
the marathon runners, (10.63 ± .32 watts per kilogram and 10.51 ± .21 watts per kilogram, respectively). The mean anaerobic power for the nonathletic group was (10.1 ± 1.2 watts per kilogram).

A similar study by Withers, Roberts, and Davies (1977) examined VO\textsubscript{2}max and anaerobic power in males who participated in track (n = 13), soccer (n = 5), hockey (n = 9) and basketball (n = 11). The track group was composed of two sprinters, three middle distance runners, and eight long distance runners. VO\textsubscript{2}max was measured on a treadmill at a constant speed of 11.3 kilometers per hour with the elevation being raised 2.5% every two minutes. Anaerobic power was measured by the Margaria Stair Climb Test. The highest mean VO\textsubscript{2}max was determined in the track athletes (72.0 milliliters per kilogram per minute) and the lowest mean value was in the basketball players (58.5 milliliters per kilogram per minute). The highest mean anaerobic power output was found in the soccer players (1.65 ± .14 kilogram meters per second), followed by the hockey players (1.56 ± .09 kilogram meters per second) and then basketball players (1.44 ± .13 kilogram meters per second).

More anaerobic power values of athletes from track (n = 10), basketball (n = 16), soccer (n = 23), and women's field hockey (n = 23) were examined by Verma, Mohindrov and Kansal (1979). Seventy six athletes ranging in age from 16 to 27 years were studied. Anaerobic power was measured by the Margaria Stair Climb Test. The results indicated that soccer players demonstrated the highest mean anaerobic power (1.766 ± .175 kilogram meters per second) followed by basketball players (1.555 ± .1285 kilogram meters per second). Track athletes
were next, (1.39 ± .0867 kilogram meters per second) and the women
field hockey players had the lowest power output (1.174 ± .1524
kilogram meters per second). The authors believed that the variability
in the anaerobic power of the different athletes were valid reflections
of the energy demands of each particular sport.

Summary of Review of Literature

In an attempt to accurately measure the anaerobic performance
of man, various laboratory tests have been developed; jump tests, stair
climb tests, treadmill tests, and cycle-ergometer tests. Early
performance tests (Sargeant Jump Test and Margaria Stair Climb Test)
lasted less than one second and measured only anaerobic power and not
capacity. Some researchers believe that the Sargeant jump test is more
a measurement of impulse than of power (Ayalon et al, 1974). The
validity of the Margaria Stair Climb Test has been questioned, i.e., is
it a test of anaerobic power or just a measure of stair climbing
ability? The Cunningham and Faulkner Treadmill Test (1969) only
measures anaerobic capacity. Due to its ability to measure both
anaerobic power and capacity, the bicycle ergometer test using the
Wingate protocol is a much more feasible performance test. The
reliability of the Wingate Anaerobic Test ranges from 0.90 to 0.98
(MacDougall, Wenger, and Green 1982). Inbar et al. (1976) demonstrated
the validity of the Wingate Anaerobic Test when they determined that
the 87% of all energy utilized during the test came from anaerobic
sources. To measure true maximal power in a 30 second bicycle
ergometer test, an optimal combination of resistance setting and pedaling rate must be accomplished. Katch et al. (1976) determined that the pedaling rate must be all-out to produce the highest power output. The majority of the research presented in this chapter has utilized the standard Wingate resistance setting of 75 grams per kilogram of body weight. A light warm-up immediately followed by the bicycle ergometry test has been shown to significantly improve anaerobic performance (Inbar and Bar-Or, 1975; Prevost and Lefebvre, 1980).

While two studies (Grodjinovsky et al. 1980; Weltman et al. 1978) have shown both anaerobic power and capacity to improve following anaerobic training, two other studies (Inbar and Bar-Or, 1980; Houston and Thomson, 1977) reported only improvements in anaerobic capacity. Only one study (Jacobs et al., 1987) reported no improvement in either anaerobic power or capacity. This may be due to the fact that the chosen frequency (two times per week) may not have provided sufficient overload.

A number of studies were reviewed examining both aerobic and anaerobic response to exercise. It was interesting to note that both the aerobic and anaerobic energy systems could be significantly improved as a result of training programs (Cunningham and Faulkner, 1969; Fox et al., 1977; Inbar and Bar-Or, 1981; Withers, 1978). The effects of detraining on aerobic and anaerobic performance revealed that after six weeks of detraining VO\textsubscript{2max} values fell below pretest
values but both anaerobic power and capacity were still significantly greater than the pretest values.

In addition to examining how training effects anaerobic and aerobic performance, several researchers have studied how a season of competition affects both anaerobic and aerobic metabolism. Coleman et al. (1974) reported that anaerobic power as measured by the Margaria Stair Climb Test improved significantly as a result of participation during the course of a competitive season. Green and Houston (1975) and Withers (1978) determined that both anaerobic power and capacity improved significantly as a result of a season of competition. Sinning and Adrian (1968) reported that as a result of a season of competition VO₂max increased. All other research has determined that VO₂max does not increase after a season of basketball competition (Coleman et al., 1974; McArdle et al., 1971; Eidsness, 1971).

Another area of research is concerned with evaluating the anaerobic power and capacity levels of individuals. Criclaard and Pirmay (1981) in comparing the anaerobic power values of track athletes and non-athletes determined that the athletes possessed greater anaerobic power. Withers (1977) and Verma (1970) compared the anaerobic power values of basketball players to athletes of other sports. They concluded that basketball players exhibited average power outputs.
Chapter III

METHODS AND PROCEDURES

The purpose of this study was to investigate the effects of pre-season practices and a season of competition on the anaerobic power and capacity of a collegiate basketball team. In this chapter the procedures employed are described in the following sections: subjects, facilities, equipment, testing procedures, and statistical analyses.

Subjects

Twenty-three subjects volunteered for this study and consented to all the requirements presented in the informed consent form (Appendix A). The experimental group was comprised of 11 members of the 1987-88 South Dakota State University men's varsity basketball team. South Dakota State University is a member of the NCAA and maintains a Division II status and is a charter member of the North Central Conference. All of the athletes were recruited by the university to compete at the Division II level and are receiving either a full or partial athletic scholarship. During the 1987-88 season, this basketball team finished second in the North Central Conference and participated in NCAA post season play. The overall record for the 1987-88 season was 21-9. This overall record exemplifies that these athletes were highly skilled in the sport of basketball. The mean characteristics of the subjects can be found in Table 1. The age of
the basketball players was 19.7 ± 1.1 years. The weight and height of the players, respectively, were 87.9 ± 11.5 kilograms and 191.7 ± 8.9 centimeters.

The 12 members of the control group were recruited from the PE 100 lifetime and fitness activity classes at South Dakota State University during the fall semester of 1987. These subjects did not participate in any intercollegiate athletics and had exercised less than 30 minutes of continuous activity three times a week for at least a year. The age of the control group was 18.7 ± 5.2 years. The mean weight and height, respectively, were 73.5 ± 8.7 kilograms and 181.8 ± 4.7 centimeters.

Facilities

All testing was performed in the Human Performance Lab in the Stanley J. Marshall HPER Center on the campus of South Dakota State University. The minor fluctuations in environmental factors such as temperature and relative humidity were not recorded since it has been documented that the Wingate Anaerobic Test is not affected by climatic conditions (Dotan & Bar-Or, 1980).
Table 1

Mean Characteristics of Subjects

<table>
<thead>
<tr>
<th></th>
<th>Basketball Players (n=11)</th>
<th>Control Group (n=12)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>87.86 ± 11.47</td>
<td>73.46 ± 8.67</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>191.67 ± 8.88</td>
<td>181.82 ± 4.66</td>
</tr>
<tr>
<td>Age</td>
<td>19.72 ± 1.05</td>
<td>18.70 ± 5.16</td>
</tr>
</tbody>
</table>
Equipment

All testing was performed on a modified Monark bicycle ergometer (see Figure 1). In its unmodified state the resistance applied to the ergometer’s flywheel was by the use of a pendulum system. The amount of resistance that could be applied to the flywheel ranged from 0.0 to 7.0 kilograms. According to the standard Wingate Anaerobic Test protocol, the flywheel resistance should be equal to 75 grams per kilogram of body weight. Using this guide the flywheel resistance for many of the basketball players exceeded the 7.0 kilogram limit on the standard Monark ergometer. The apparatus had to be modified to allow for the application of these greater resistances because of the basketball player’s relatively heavy body weights. The pendulum apparatus was removed from the bicycle ergometer and the belt pulley was repositioned to allow for the hanging of weights in front of the flywheel. The opposite end of the belt was attached to a Chatillon spring scale which was anchored to a wall and positioned such that the scale was directly above the tangent of the flywheel. The spring scale allowed for the measuring of resistances ranging from 0.0 to 15.0 kilograms.

In addition to modifying the resistance application system the standard seat post was also modified. Due to the height of the basketball players, a reinforced and lengthened seat post was used to ensure proper leg extension during the ergometer test. LaVoie & Brayne (1984) determined that the use of toe stirrups for the Wingate
Anaerobic Test produced significantly higher anaerobic powers and capacities. Due to the large shoe sizes of the basketball players toe stirrups could not be used. Christophe pedal straps were employed to keep the subject’s feet from slipping off of the pedals. The strap was made of leather and fastened to each side of the pedal and was positioned over the top of each subject’s foot.

To facilitate the counting of pedal revolutions, a Sony video camera recorder were employed. The camera was positioned such that the subject’s feet while resting on the pedals were centered on the television screen. The camera was equipped with a stopwatch that was recorded on the tape. This stopwatch was used for the timing of the 30 second ergometer test.

Testing Procedures

Familiarization Session

The purpose of the familiarization session was to acquaint each subject with the equipment and testing procedures. Prior to the familiarization session each subject was given an informed consent form to read and sign (Appendix A). Each subject was given verbal instructions as to the procedures that would be implemented during the 30 second bicycle ergometer test and the weight of each subject was measured and recorded and the optimal seat height was determined. The benefits and risks involved with the study were explained.
Each subject performed the complete Wingate Anaerobic Test procedure at least once prior to the collection of data. During the testing procedure, four people were present in the testing lab: the subject, test instructor, video cameraman, and an individual to record the resistance settings. All subjects refrained from vigorous exercise for at least 24 hours and were at least two hours post absorptive prior to each testing session. The correct weight necessary to provide the desired resistance was hung from the flywheel belt. This weight was determined with the standard Wingate Anaerobic Test protocol of 75 grams of resistance per kilogram of body weight (Ayalon et al., 1974).

A warm-up of 2 minutes at a pace of 50 beats per minute, as set by a Franz electric metronome preceded each test. At each beat the subject was to be at the down stroke of each pedal phase, alternating right and left feet with each successive beat. During the warm-up, the test instructor suspended the weight in his right hand such that the resistance on the spring scale was approximately .5 kilograms. With approximately 15 seconds left in the warm-up, the test instructor motioned the cameraman to begin recording. At the completion of the warm-up phase the test instructor called "now" at which time the subject increased the pedal rate to a maximal level. As the speed increased the test instructor lowered the weight such that the full resistance was applied to the flywheel within two seconds. When the weight had been completely lowered, the cameraman started the stopwatch. The subject pedaled as fast as possible for the full 30 second test. To insure against pacing, each subject was not told how
much time remained in the test by the cameraman. Strong verbal encouragement was given throughout the test. The subject was instructed to remain seated throughout the test. At approximately 35 seconds the cameraman called "stop" to terminate the test. Following the test, the subject pedalled with no resistance slowly for approximately two to five minutes.

Wingate Bicycle Ergometer Tests

Three testing dates were chosen to reflect the three different phases of a college basketball season. The first test for the basketball players was completed at the conclusion of the pre-season training period, October 13, 1987. The second testing dates, November 16 to 18, 1987, were at the end of the pre-competitive practice season. The final testing date, March 21, 1987, was conducted at the conclusion of the basketball season. The three testing dates for the control group were: test one; October 29, 1987, test two; December 3 and 4, 1987 and test three; March 21, 1988.

Upon entering the Human Performance Lab for the actual testing session, the weight of the subject was recorded to the nearest .5 kilogram. The seat height was adjusted to the previously determined level from the familiarization test. After the subject was seated on the bicycle ergometer and the correct weight had been placed on the flywheel belt, the test protocol was reviewed by the test instructor. The testing procedures for the three actual tests were carried out in
the same manner as has been previously described for the familiarization test.

**Season of Basketball Training**

The goal of this study was to determine how a season of basketball affects the anaerobic performances of basketball players. A major part of the season of basketball pertains to training. The goal of a pre-season conditioning program is to improve the overall fitness level of the basketball players. The five week pre-season conditioning program involved both running and weight training. The running program primarily consisted of interval workouts. The weight training programs were designed to develop basic strength. A summary of the pre-season conditioning program is found in Appendix B. A sample weight training program is provided in Appendix C. During the five week pre-season period, a Shooting Workout was completed once per week. This workout lasted approximately 20 minutes. It involved the player shooting a prescribed type of shot as many times as possible for one minute. Ten free throws were shot between each one minute shooting session. By the fifth week each player was shooting 10 different shots.

The pre-competitive period and season of competition followed the pre-season conditioning period. Conditioning during these time periods was accomplished through drill work, interval and sprint running and scrimmages. Practices during the basketball season lasted on the average of two hours. A 10 to 15 minute light warm-up preceded each practice session. This consisted of a series of running and
footwork drills. After this the players participated in flexibility exercises for approximately 15 minutes. The majority of each practice session was devoted to skill development. This was accomplished primarily in half court drill situations. Team scrimmages were usually 10 to 20 minutes in length, during which time multiple substitutions were made. Running workouts lasted from 5 to 10 minutes and were usually at the end of each practice. A major part of the running workout was five second sprints, from baseline to baseline. A ten second sprint involved running to the opposite baseline and returning to the starting baseline. An interval type run which lasted from 25 to 35 seconds involved the following routine: starting from the baseline, each player sprints to the free throw line and then back to the starting baseline, then sprints to the half court line and back to the starting baseline, each player then sprints to the opposite baseline and finally back to the starting baseline. A sample practice plan is located in Appendix E.

Data Reduction

The quantification of anaerobic power and capacity is accomplished by measuring external work which is the product of the distance the flywheel travels, and the frictional resistance being applied to the flywheel (Tharp et. al., 1985). In order to calculate anaerobic measures, it was necessary to record resistances and pedal revolutions. The actual frictional resistance was determined by
subtracting the initial weight hung on the belt from the spring scale reading during pedaling.

The counting of the pedal revolutions was accomplished by replaying the recorded ergometer test using a Panasonic video cassette recorder NV 8950 at a super slow motion speed onto a standard television screen. To facilitate the counting of quarter revolutions, a 12" by 8" transparency, which was divided into fourths by two lines which intersected at the center of the transparency, was placed onto the tv screen. When the stop watch reflected zero on the tv screen, the pause button was depressed thus stopping the action on the screen. One of the two lines drawn on the transparency was then aligned with the pedal crank as seen on the screen. This line then became the zero point, and all counting points were based on the line: one fourth, one half, three fourths, one and so on.

The bicycle ergometer used in the present study was a Monark bicycle ergometer whose flywheel rotates a distance of six meters for every revolution of the pedals. Anaerobic power in watts was calculated by multiplying 11.765 by the number of pedal revolutions and by the frictional resistance on the flywheel in kilograms. Anaerobic power, in watts per kilogram, was calculated by dividing anaerobic power in watts by kilograms of body weight. The Peak Power was the highest power output during any five second period. This is usually the first or second five second period. Mean Power was used as a measure of anaerobic capacity for this study. It was calculated by taking the average of the six five second power outputs. Low Power was
the lowest power output for any five second period. This is usually the last five second period. Fatigue Index reflects the ability of the subject to maintain power output over the 30 second test. It was calculated by subtracting the Low Power from the Peak Power divided by the peak power.

Statistical Analysis

The Statistical Analysis System (SAS) GLE computer software used to complete the statistical analysis. A 2x3 factorial design was used in which 2 levels of group (experimental and control) were combined with 3 levels of time (T1, T2, T3). Means and standard deviations for Peak Power, Mean Power, Low Power and Fatigue Index were determined. A repeated measure analysis of variance procedure was used to determine if there were any significant differences between the basketball players and control group at each of the three testing dates for Peak Power, Mean Power, Low Power and Fatigue Index. The alpha level was set at .05 for this investigation.
Chapter IV

RESULTS AND DISCUSSION

Presented in this chapter are the results and discussion regarding the effects of a season of basketball competition on the anaerobic power and capacity of 11 NCAA Division II basketball players and 12 non-athlete males. The chapter has been divided into the following sections according to the dependent variables: Peak Power, Mean Power, Fatigue Index, and Low Power. A discussion of the comparison between the results of the present study and the results of previous research concludes this chapter.

Results

Peak Power

The descriptive statistics for Peak Power are presented in Table 1. The mean Peak Power for basketball players for Test 1 (T1) was 11.31 watts per kilogram of body weight with a standard deviation of 1.07 watts per kilogram. The mean Peak Power for the control group for T1 was 11.55 watts per kilogram with a standard deviation of .76 watts per kilogram. The mean Peak Powers of the basketball players and the control group, respectively, for Test 2 (T2) were 11.71 watts per kilogram with a standard deviation of .78 watts per kilogram and 11.84 watts per kilogram and a standard deviation of 1.31 watts per kilogram. The mean Peak Power for Test 3 (T3) for the basketball players was 12.53 watts per kilogram with a standard deviation of .62 watts per
<table>
<thead>
<tr>
<th>Group</th>
<th>Basketball Players n=11</th>
<th>Control Group n=12</th>
<th>Mean Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁</td>
<td>11.31 ± 1.07</td>
<td>11.55 ± .76</td>
<td>11.43</td>
</tr>
<tr>
<td>T₂</td>
<td>11.71 ± .78</td>
<td>11.84 ± 1.31</td>
<td>11.77</td>
</tr>
<tr>
<td>T₃</td>
<td>12.53 ± .62</td>
<td>11.84 ± .88</td>
<td>12.18*</td>
</tr>
<tr>
<td>Group Mean</td>
<td>11.85</td>
<td></td>
<td>11.74</td>
</tr>
</tbody>
</table>

*Means and standard deviations measured in watts per kilogram.
*Significantly different from the Group Mean T₁ (p<0.05).
kilogram. The $T_3$ mean Peak Power for the control group was 11.84 watts per kilogram with a standard deviation of .88 watts per kilogram. A graphic presentation of these means can be seen in Figure 1. It was surprising to note that for both $T_1$ and $T_2$ the control group exhibited a higher mean Peak Power value than did the basketball players. It is important to realize that Peak Power is expressed in watts per kilogram of body weight and not simply in total watts. The resistance in the Wingate Anaerobic Test is based on the body weight of the subject, thus the heavier subjects will experience greater resistances on the flywheel. Their power outputs in watts per kilogram may appear lower than the power outputs of lighter individuals, when in fact the heavier subjects are producing much greater total watts. When expressed in total watts the mean Peak Power for $T_1$ for the basketball players was 993.69 watts and for the control group was 848.46 watts. The total watts for $T_2$ for the basketball players and control group, respectively, were 1028.84 and 869.76.

A summary of the analysis of variance for Peak Power is presented in Table 2. A significant difference for the main effect of time was indicated by an $F$ value of 6.29 ($p<.05$). To determine which of the main effects for time means were significantly different the Least Squares post-hoc test was completed. The mean Peak Power value for $T_3$ was significantly greater than the mean Peak Power value for the $T_1$. Table 2 indicates that there was no significant difference between the means for Peak Power for the main effects of group and there was no significant interaction between group and time. This demonstrates that no significant difference existed between the basketball players and
Figure 2

Peak Power

![Graph showing peak power over time for Basketball Players and Control Group.](image)

Table 3

<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>11.5</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>11</td>
<td>11.5</td>
<td>12</td>
</tr>
</tbody>
</table>

- Basketball Players
- Control Group
### Table 3
Summary of Analysis of Variance for Peak Power

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>F Value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1</td>
<td>0.19002540</td>
<td>0.10</td>
<td>0.7506</td>
</tr>
<tr>
<td>Time</td>
<td>2</td>
<td>6.49711048</td>
<td>6.29</td>
<td>0.0041</td>
</tr>
<tr>
<td>Group*Time</td>
<td>2</td>
<td>2.98578681</td>
<td>2.89</td>
<td>0.0668</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>38.46054375</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
control group as measured by Peak Power. The mean Peak Power of basketball players across all three tests was not significantly different from the control group.

**Mean Power**

The means and standard deviations for Mean Power are presented in Table 3. The $T_1$ mean and standard deviations for Mean Power for the basketball players and control group, respectively, were $8.89 \pm 0.5$ watts per kilogram and $8.72 \pm 0.62$ watts per kilogram. The Mean Power for $T_2$ for the basketball players was $9.24$ watts per kilogram with a standard deviation of $0.60$ watts per kilogram. The control group value for $T_2$ was $8.99$ watts per kilogram with a standard deviation of $1.12$ watts per kilogram. $T_3$ mean of the Mean Power measure for the basketball players was $9.79$ watts per kilogram with a standard deviation of $0.49$ watts per kilogram. The mean for the control group for Mean Power for $T_3$ was $8.78$ watts per kilogram with a standard deviation of $0.75$ watts per kilogram. As can be seen in Figure 2 the graphic depiction of the means for Mean Power was similar to that for Peak Power with the exception that the mean value for the basketball players was higher than the control group at all three times of testing. A repeated measures analysis of variance was applied to these data the summary of which is presented in Table 4. A significant difference for the main effect of time was indicated by an F value of 7.11 ($p<0.05$). The treatment by time interaction F value of 6.45 was
Table 4

Descriptive Statistics for Mean Power\textsuperscript{a}

<table>
<thead>
<tr>
<th>Group</th>
<th>Basketball Players n=11</th>
<th>Control Group n=12</th>
<th>Mean Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>( T_1 )</td>
<td>8.89 ± .50</td>
<td>8.72 ± .62</td>
<td>8.80</td>
</tr>
<tr>
<td>( T_2 )</td>
<td>9.24 ± .60\textsuperscript{**}</td>
<td>8.99 ± 1.12</td>
<td>9.11</td>
</tr>
<tr>
<td>( T_3 )</td>
<td>9.79 ± .49\textsuperscript{*}</td>
<td>8.78 ± .75</td>
<td>9.28</td>
</tr>
<tr>
<td>Group Mean</td>
<td>9.30</td>
<td>8.83</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} Means and standard deviations measured in watts per kilogram.

* Significant difference from \( T_1 \) in basketball players (p<0.05).

** Significant difference from \( T_3 \) in basketball players (p<0.05).
Figure 3
Mean Power
### Table 5

**Summary of Analysis of Variance for Mean Power**

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>F Value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1</td>
<td>3.93010071</td>
<td>2.99</td>
<td>0.0982</td>
</tr>
<tr>
<td>Time</td>
<td>2</td>
<td>2.71628956</td>
<td>7.11</td>
<td>0.0022</td>
</tr>
<tr>
<td>Group*Time</td>
<td>2</td>
<td>2.46613703</td>
<td>6.45</td>
<td>0.0036</td>
</tr>
<tr>
<td>Error</td>
<td>21</td>
<td>27.55789306</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
significant at the 0.05 level, thus indicating that the Mean Power
cchanges for basketball players was different than the Mean Power
cchanges for the control group. The Least Squares post-hoc test
revealed that the basketball players exhibited a significant increase
from T₁ to T₃ and from T₂ to T₃, while the control group did not
demonstrate any significant changes over the three testing periods.
The analysis for the main effects of group was not significant at the
0.05 level.

Fatigue Index

The descriptive statistics for Fatigue Index are presented in
Table 5. The Fatigue Index for T₁ for the basketball players was 41% 
with a standard deviation of .08%. The Fatigue Index for the control
group on T₁ was 46% with a standard deviation of .09%. T₂ Fatigue
Index values were 42% with a standard deviation of ± .07% for the
basketball players and 46% with a standard deviation of .08% for the
control group. The Fatigue Index of the basketball players and control
group for T₃, respectively, were 41% with a standard deviation of .08%
and 47% with a standard deviation of .04%. The graphic representation
of the Fatigue Index data is presented in Figure 3. As can be noted in
the summary of the analysis of variance for Fatigue Index presented in
Table 6, there were no significant differences for the main effects of
group or time or for group by time interaction. While no significant
difference was found for the groups there does appear to be a trend
indicating that basketball players fatigued less than the control group
(Figure 3).
Table 6

Descriptive Statistics for Fatigue Index

<table>
<thead>
<tr>
<th>Group</th>
<th>Basketball Players n=11</th>
<th>Control Group n=12</th>
<th>Mean Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>T₁</td>
<td>41 ± .08</td>
<td>46 ± .09</td>
<td>43</td>
</tr>
<tr>
<td>T₂</td>
<td>42 ± .07</td>
<td>46 ± .08</td>
<td>44</td>
</tr>
<tr>
<td>T₃</td>
<td>41 ± .08</td>
<td>47 ± .04</td>
<td>44</td>
</tr>
<tr>
<td>Group Mean</td>
<td>41</td>
<td>46</td>
<td></td>
</tr>
</tbody>
</table>

*a Means and standard deviations measured in percentages.*
Figure 4

Fatigue Index
Table 7

Summary of Analysis of Variance for Fatigue Power

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>F Value</th>
<th>Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1</td>
<td>0.04398632</td>
<td>3.55</td>
<td>0.0736</td>
</tr>
<tr>
<td>Time</td>
<td>2</td>
<td>0.00102534</td>
<td>0.21</td>
<td>0.8110</td>
</tr>
<tr>
<td>Group*Time</td>
<td>2</td>
<td>0.00135951</td>
<td>0.28</td>
<td>0.7578</td>
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<tr>
<td>Error</td>
<td>21</td>
<td>0.26038715</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The means and standard deviations for Low Power are presented in Table 7. The mean Low Power for T₁ for the basketball players was 6.61 watts per kilogram with a standard deviation of .46 watts per kilogram. The mean Low Power for T₁ for the control group was 6.21 watts per kilogram with a standard deviation of .78 watts per kilogram. The mean Low Power of the basketball players and control group for T₂, respectively, were 6.80 watts per kilogram with a standard deviation of .75 watts per kilogram and 6.42 watts per kilogram with a standard deviation of 1.09 watts per kilogram. The T₃ mean Low Power for the basketball players was 7.34 watts per kilogram with a standard deviation of .87 watts per kilogram. The T₃ Low Power results for the control group were 6.22 watts per kilogram with a standard deviation of .64 watts per kilogram. As can be seen in Figure 4, Low Power means are graphically similar to those of Peak Power (Figure 1) and Mean Power (Figure 2). The summary of the analysis of variance for Low Power is presented in Table 8. The F value for the main effects of group (4.56) was significant at the 0.05 level. This indicates that the basketball players demonstrated a higher mean Low Power than did the control group. The F value for the main effect of time was not significant at the 0.05 level. The F value for group by time interaction (3.61) was significant at the 0.05 level, demonstrating that the pattern of response for the basketball players was different than that of the control group. Post hoc tests reflected that the
Table 8
Descriptive Statistics for Low Power$^a$

<table>
<thead>
<tr>
<th>Group</th>
<th>Basketball Players n=11</th>
<th>Control Group n=12</th>
<th>Mean Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_1$</td>
<td>6.61 ± .46</td>
<td>6.21 ± .78</td>
<td>6.41</td>
</tr>
<tr>
<td>$T_2$</td>
<td>6.80 ± .75***</td>
<td>6.42 ± 1.09</td>
<td>6.61</td>
</tr>
<tr>
<td>$T_3$</td>
<td>7.34 ± .87**</td>
<td>6.22 ± .64</td>
<td>6.78</td>
</tr>
<tr>
<td>Group Mean</td>
<td>6.91*</td>
<td>6.28</td>
<td></td>
</tr>
</tbody>
</table>

$^a$ Means and standard deviations measured in watts per kilogram.

* Significantly different from control group.

** Significantly different from $T_1$ in basketball players.

*** Significantly different from $T_3$ in basketball players.
Figure 5

Low Power

![Graph showing the comparison of Watts per Kilogram between Basketball Players and Control Group over Time of Testing (T1, T2, T3). The graph indicates a trend of increasing power output over time for the Basketball Players, while the Control Group remains relatively stable.]
Table 9

Summary of Analysis of Variance for Low Power

<table>
<thead>
<tr>
<th>Source</th>
<th>df</th>
<th>SS</th>
<th>F Value</th>
<th>Probability</th>
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</thead>
<tbody>
<tr>
<td>Group</td>
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<td>6.79820826</td>
<td>4.56</td>
<td>0.0447</td>
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<tr>
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<td>2.78</td>
<td>0.0736</td>
</tr>
<tr>
<td>Group*Time</td>
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<td>2.04831614</td>
<td>3.61</td>
<td>0.0358</td>
</tr>
<tr>
<td>Error</td>
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<td>31.32724264</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
basketball players exhibited significant improvement in low power from T1 to T3 and from T2 to T3. The control group did not exhibit any significant changes in Low Power between any of the tests.

Discussion

The results of this study indicate that anaerobic power, as measured by Peak Power, and capacity, as measured by Mean Power, increased as a result of a season of basketball competition. The group means for Peak Power from the present study demonstrate that anaerobic power increased significantly from T1 (11.4 watts per kilogram) to T3 (12.2 watts per kilogram), a 7% increase. Closer examination of the results presented in Table 1 reveals that the major contributing factor to the increase in the group mean Peak Power was the Peak Power increase of the basketball players and not of the control group. This supports previous research by Coleman et al. (1974), Green and Houston (1975), and Withers (1978) that anaerobic performance can be increased due to a season of athletic competition. While the methods of testing in these studies are not the same as those of the present study and the units of measure are not comparable, it is possible to compare the results of the studies by expressing the change in anaerobic performance as a percent. Coleman et al. (1974) was able to show a 6.7% increase (75.03 kilocalories per minute to 80.09 kilocalories per minute) in anaerobic power, as measured on the Margaria Stair Climb Test, as a result of a season of basketball competition. Green and Houston (1975) demonstrated a 5.7% increase (130.3 kilogram meters per
second to 137.8 kilogram meters per second) in anaerobic power, also measured on the Margaria Stair Climb Test, as a result of a season of ice hockey competition. Withers (1978) also was able to demonstrate a similar percentage increase (8.8%) in anaerobic power as a result of a season of competition, in this case using female lacrosse players. The 7.0% increase in anaerobic power of the present study certainly supports the results of all three of the above mentioned research projects. It is interesting to note that a season of competition in three different sports (basketball, ice hockey, and lacrosse) all produced similar changes in anaerobic power.

While there were only three studies identified that examined the effects of a season of competition on anaerobic performance there are a number of studies which have examined the effects of an anaerobic training program on anaerobic power (Fox et al., 1977; Inbar et al., 1983; Grodjinouisky et al., 1980; Weltman et al., 1978). In all cases anaerobic power increased as a result of the training. Assuming that the training which the basketball players experienced in the present study is somewhat similar to the anaerobic training the subjects in the above mentioned training studies experienced, the present study supports the fact that anaerobic power can be increased by anaerobic training.

The results of the present study for Mean Power, a measure of anaerobic capacity, indicate that the basketball players significantly improved from T₁ (8.89 watts per kilogram) to T₃ (9.79 watts per kilogram), a 10.1% increase. No other study in the reviewed literature
examined the effects of a season of basketball on anaerobic capacity, although two similar studies were completed using athletes from similar but different sports. Green and Houston (1975) determined that as a result of a season of competition the anaerobic capacity, using the short exhaustive run technique of hockey players increased significantly from 64.3 seconds to 74.8 seconds, an increase of 16.3%. Withers (1978), in his study of female lacrosse players, concluded that three months of training significantly improved anaerobic capacity, also measured by the exhaustive run technique, from 42.5 seconds to 61.4 seconds, an increase of 42.5%. While the increase in anaerobic capacity in the present study is not as large as that of these other two studies, it does support the fact that anaerobic capacity does increase as a result of a season of competition. The very large percentage increase found in the Withers (1978) study could possibly be explained by the relatively low level of fitness of the subjects at the beginning of the season.

It has been well documented that anaerobic training significantly improves anaerobic capacity (Grodjinkovsky et al., 1980; Weltman et al., 1978; Houston & Thomson, 1977; Cunningham & Faulkner, 1969). As a season of basketball competition as well as the pre-season period of practice involves significant anaerobic training the results of the present study support the work done by these researchers.

Fatigue Index, which is a measure of anaerobic capacity indicating the percentage decline in power, in this study did not change over the three testing periods. The mean Fatigue Index for the
basketball players was 41% while the mean Fatigue Index for the control
group was 46%. These Fatigue Indices are very similar to those of
Jacobs et al. (1987) who found a Fatigue Index for their experimental
group of 41% and of 46.5% for the control group following six weeks of
training.

Low Power is a measure of anaerobic performance reflecting the
lowest five second power output during the 30 second test. The results
from the present study reveal that there is a significant difference in
mean Low Power between the basketball players (6.9 watts per kilogram)
and the control group (6.3 watts per kilogram). The basketball players
increased significantly in Low Power from $T_1$ (6.61 watts per kilogram)
to $T_3$ (7.34 watts per kilogram) and from $T_2$ (6.80 watts per kilogram)
to $T_3$. No other published literature has reported Low Power values but
as Low Power is in fact another measure of capacity the improvements
seen in the present study in the basketball players is supported by the
above mentioned research in the area of anaerobic capacity.

It is surprising to note that only one variable, Low Power, was
significantly different between the basketball players and control
group. As was discussed previously the explanation for this is
partially explained by the fact that these variables are expressed in
relation to body weight. Until further research is completed using
similar units of measure as the present study, it is not possible to
identify why the values are so similar. Examination of figures 1, 2,
and 4 show that Peak Power, Mean Power, and Low Power for the
basketball players demonstrates a general upward shift from $T_1$ to $T_3$. 
This same trend is not seen in the control group. The overall conclusions from these data is that basketball practices and games provide enough training stimulus to improve anaerobic power and capacity of college basketball players.
Chapter V

SUMMARY AND CONCLUSIONS

Summary

The purpose of this study was to investigate the effects of preseason practice and a season of competition on the anaerobic power and capacity of NCAA Division II basketball players as measured by the Wingate Anaerobic Test. Eleven basketball players made up the experimental group and 12 non-athletic college-age males comprised the control group. Three different testing dates were completed to be representative of the stages of a college basketball season. The first test for the basketball players was completed at the end of the pre-season training, October 13, 1987. The second test, November 16-18, 1987 was conducted at the conclusion of the pre-competitive practices. The last test was completed at the end of the basketball season, March 21, 1987. The three testing dates for the control group were: test one; October 29, 1987, test two; December 3 and 4, 1987, and test three; March 21, 1988.

Each subject completed at least one familiarization session prior to the actual testing session. Testing was conducted using a modified Monark bicycle ergometer with the flywheel resistance set at 75 grams per kilogram of body weight. Each testing session consisted of a 2 minute warm-up at a pace of 50 revolutions per minute and .5 kilograms of resistance. At the completion of the warm-up the test
instructor called "now" at which time the subject increased the pedal rate to a maximum level. During this time, the test instructor lowered the weight such that the full resistance was then placed on the flywheel belt. Once the weight had been lowered, the test began and was coincided by the starting of the video camera stopwatch. The pace of the test was all-out, each subject was to complete as many revolutions as possible during the 30 second test. Following the test the subject completed a very low intensity warm-down for approximately two minutes. The counting of pedal revolutions was recorded with the use of a video camera and recorder that was equipped with a stopwatch that was visible on the tv screen where the pedal revolutions were counted to the nearest fourth.

The statistical analyses included a 2x3 factorial design for the calculations of an ANOVA with repeated measures across time and group for the following variables; Peak Power, Mean Power, Fatigue Index and Low Power. The statistical analyses indicated that for Peak Power no significant differences existed between the two groups. However, there was a significant improvement in the group mean for Peak Power from \( T_1 \) to \( T_3 \). No significant difference was found between the basketball players and control group for Mean Power. A significant group by time interaction was determined for Mean Power. The basketball players improved significantly in Mean Power from \( T_1 \) to \( T_3 \) and from \( T_2 \) to \( T_3 \), while the control group did not demonstrate any significant changes over the three testing periods. A significant difference existed between the basketball players and control group for
mean Low Power. The basketball players exerted a higher mean Low Power than did the control group and also improved significantly from T1 to T3. No significant differences were found between the basketball players and control group for the Fatigue Index.

Conclusions

Within the limitations of this study the following conclusions can be made pertaining to how a basketball season affects the anaerobic power and capacity of college basketball players. The results of the study indicate that there are no significant differences between college basketball players and non-athletic college-age males for anaerobic power, which is the ability to generate a large amount of force in a short period of time, when expressed relative to body weight. The combined average of the basketball players and non-athletic males for anaerobic power improved significantly from the end of the pre-season practice to the conclusion of the basketball season. A close examination of Figure 2 reveals that the improvement in anaerobic power is due to the increase in the anaerobic power of the basketball players. No significant differences were determined for anaerobic capacity, the total amount of work generated in 30 seconds, between the basketball players and non-athletic college-age males, again when expressed relative to body weight. It was found that the anaerobic capacity of the basketball players improved significantly from the end of the pre-season practice to the conclusion of the
season. The anaerobic capacity of the college-age non-athletic males did not improve significantly during this time. It appears that the decline in force production during the 30 second test, Fatigue Index, is not affected by preseason practice and/or a season of competition.

Recommendations for Further Study

The present study indicated that as a result of a season of competition, basketball players significantly improved Mean and Low Power, both of which are measures of anaerobic capacity. During the season it was not possible to keep the total amount of work equal for each player. For this reason, additional research comparing the total amount of work with anaerobic capacity measures could be pursued. It is not known how diet, amount of sleep or emotional state of the individual affects anaerobic testing. Research could be undertaken to determine how one or all of these variables affects anaerobic testing. Lastly, unpublished research has indicated that the recommended body weight resistance of the Wingate Anaerobic Test of 75 grams per kilogram of body weight might not be enough resistance to elicit a maximal test of anaerobic performance in adult males. Research using resistance settings ranging from 85 grams to 95 grams per kilogram of body weight might produce higher measures of anaerobic performance.
BIBLIOGRAPHY


APPENDIX A

EFFECTS OF A SEASON OF COMPETITION ON ANAEROBIC PERFORMANCE OF MALE COLLEGIATE BASKETBALL PLAYERS

INFORMED CONSENT FORM

I, ____________________________, state that I am at least eighteen years of age and wish to participate in a program of research being conducted by Marc Peterson.

The purpose of the research is to investigate the effects of a basketball preseason practice and a season of competition on the anaerobic power and anaerobic capacity of NCAA Division II basketball players.

The study involves three testing dates; Oct. 13, 1987, Nov. 16, 1987 and at the conclusion of the basketball season. The subject will perform an all-out maximal 30 second anaerobic bicycle ergometer test. The test will be conducted on a modified Monark bicycle ergometer. The calibration settings for the flywheel resistance will be based on the subject's weight and will range from 1.0 to 10.0 kiloponds (Wingate Protocol; \( L = 0.075 \text{ kg} / \text{kg body weight} \)). A two minute warm-up of light pedaling will precede the test. At the conclusion of the warm-up, the subject will begin an all-out pedaling rate at which time the correct flywheel resistance will be applied and the 30 second test will begin. The subject's feet will be videotaped for counting pedal revolutions.

The benefit from participating in this study is that the subject will become aware of his anaerobic power and anaerobic capacity and how his results compare to the experimental and control groups.

Although the chance of injury with this test is extremely low, the possible risks include nausea, leg and ankle injuries, and circulatory system complications i.e. heart attack and stroke. Every effort has been made to reduce these risks.

I acknowledge that I have been informed that I may obtain information about my weight upon request. In addition, I understand that upon request I will be informed of how my test results compare to both group's results.

I acknowledge that Marc Peterson has fully explained to me the procedures and possible risks; has informed me that I may withdraw at any time, and has offered to answer any questions I may have concerning the procedures to be followed. I freely and voluntarily consent to participate in this research project.

_______________________________
(signature of volunteer)

_______________________________
(signature of staff member)

_______________________________
(date)
**APPENDIX B**

**SDSU MEN'S BASKETBALL**

**1987-88 PRESEASON CONDITIONING**

<table>
<thead>
<tr>
<th>Day</th>
<th>Date</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mon.</td>
<td>Sept. 14</td>
<td>Anaerobic Bike Test</td>
</tr>
<tr>
<td>Tues.</td>
<td>Sept. 15</td>
<td>Weights</td>
</tr>
<tr>
<td>Wed.</td>
<td>Sept. 16</td>
<td>IM Fields&lt;br&gt;1 warm-up lap around intramural FB fields&lt;br&gt;Stretching&lt;br&gt;Form Running - high knees, butt kicks, form run, pickups&lt;br&gt;Intervals - 6 reps 200m (along College Dr.)</td>
</tr>
<tr>
<td>Thurs.</td>
<td>Sept. 17</td>
<td></td>
</tr>
<tr>
<td>Fri.</td>
<td>Sept. 18</td>
<td>Shooting Workout</td>
</tr>
<tr>
<td>Sat.-Sun.</td>
<td>Sept. 19-20</td>
<td>Distance Running, Weights</td>
</tr>
<tr>
<td>Mon.</td>
<td>Sept. 21</td>
<td>I.M. Fields&lt;br&gt;1 warm-up lap around I.M. FB fields&lt;br&gt;Stretching&lt;br&gt;Form Running&lt;br&gt;Hollow Sprints 8 laps</td>
</tr>
<tr>
<td>Tues.</td>
<td>Sept. 22</td>
<td>Weights</td>
</tr>
</tbody>
</table>
1987-88 Preseason Conditioning Cont’d

Thurs.
Sept. 24     Weights

Fri.
Sept. 25     Shooting Workout

Sat.-Sun.
Sept. 26-27  Distance Running, Weights

Mon.
Sept. 28     Outdoor Track
              1 lap warm-up
              Stretching
              Form Running
              Intervals - 2 reps. 400m
              4 reps. 200m

Tues.
Sept. 29     Weights

Wed.
Sept. 30     I.M. Fields
              1 warm-up lap around I.M. FB fields
              Stretching
              Form Running
              Fartlek - 4 laps

Thurs.
Oct. 1       Weights

Fri.
Oct. 2       Shooting Workout

Sat.-Sun.
Oct. 3-4     Distance Running, Weights

Mon.
Oct. 5       I.M. Fields
              1 warm-up lap around I.M. FB fields
              Stretching
              Form Running
              Hollow Sprints 8 - 10 laps

Tues.
Oct. 6       Weights
1987-88 Preseason Conditioning Cont’d

Wed.
Oct. 7    I.M. Fields
          200 meter sprints (10 reps)

Thurs.
Oct. 8    Weights

Fri.
Oct. 9    Shooting Workout

Sat.-Sun.
Oct. 10-11 Distance Running, Weights

Tues.
Oct. 13   Anaerobic Bike Post - Test

Bad weather running workouts

Indoor Track - 1. Hollow Sprints
              2. Line Drills on the minute
## Name sample

<table>
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<th>Est. 1 rep max</th>
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<th>80%</th>
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<td>8</td>
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<td>Military</td>
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<td>8</td>
<td>6</td>
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<td>Pulldowns</td>
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<td>Sit-ups</td>
<td>AMAP</td>
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### Practice No. 14 | Date Nov. 2, 1987

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<td></td>
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<td>backdoor</td>
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<tr>
<td></td>
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<td>5:15</td>
<td>10</td>
<td>zone blockout and fastbreak</td>
<td>3 groups</td>
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<td>4 on 4 shell drill</td>
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