Determining Optimal Load For a Constant-
Load Cycle Ergometer Test Relative to Isotonic
Leg Strength

by

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CHAPTER I

INTRODUCTION

Although extensive research has been conducted to identify the essential factors that determine aerobic performance, relatively little research has been directed towards identifying the essential factors that contribute to anaerobic performance. Anaerobic power has been described as short-term, high-intensity power. Muscular power is the product of force and velocity and is an essential component in activities involving short-term, high-intensity efforts. These activities include such sports as short distance sprints, swimming, and weight training. The essential factors that contribute to maximal power output include muscular strength and shortening velocity. It is likely that the amount of maximal power an athlete generates influences his/her success in short-term, high-intensity sports performance.

Tests of muscle power were initially developed over 70 years ago with L. W. Sargent being one of the pioneers in this area of interest (1921). Sargent developed the vertical jump test, which has been used as a field test of muscular power. Several other tests have been developed which also measure power, or the time required to perform a given amount of work. These tests include: the Margaria-Kalamen test, a stair climb test (1966); a cycle ergometer test (Bar-Or, Dotan, & Inbar, 1977); short distance sprints; and short distance treadmill tests (Cheetham, Boobis, Brooks, & Williams, 1986).

The cycle ergometer power test is one of the most common laboratory tests. Numerous researchers have used the cycle ergometer to measure power output in a short period of time ranging from 10 to 120 seconds (Sargeant, Hoinville, & Young, 1981; Jones, McCartney, Graham, Spriet, Kowalchuk, Heigenhauser, & Sutton, 1985; Reilly & Bayley, 1988; McCartney, Heigenhauser & Jones, 1983). Typically, the test is performed using a common cycle ergometer in which a certain resistance or standard braking force is applied. Power produced during cycling is a function of the applied force and the velocity of the flywheel. The subject's leg strength is largely responsible for the amount of power produced during cycling. To achieve optimal power, the applied force must be accurately determined and must be reflective of the subject's strength ability (Wilkie, 1960).

STATEMENT OF THE PROBLEM

The optimal load for the 15 sec cycle ergometer test is that which elicits the highest maximal power. The optimal load reflects the subject's muscular ability and therefore allows for adequate assessment of the subject's full power potential (Wilkie, 1960). Although previous research in optimal load determination has contributed considerably to developing accurate methods of testing short-term, high-intensity power, the essential factors that contribute to power output have not all been taken into consideration. These factors include muscle shortening velocity (hence, pedalling velocity), lean body mass, and more specifically, the leg strength that largely contributes to the peak power production (Sargent et al, 1981; Dotan and Bar-Or, 1983).

The relationship between the peak force and pedalling velocity during short-term, high intensity cycling has been described as inverse (Sargeant et al, 1981). Force production during cycling depends upon leg strength and lean muscle mass. The velocity of the flywheel is directly related to the speed of muscle contraction and relaxation during cycling. An optimal velocity during peak power output has been shown to be 110 rev/min (Sargeant et al, 1981). Therefore, a significantly higher or lower velocity would result in a decreased power output as shown by the curvilinear relationship between power output and crank velocity.

The friction-loaded cycle ergometer test functions with an applied load to the flywheel, resulting in resistance during cycling. The potential for power output depends upon the application of an appropriate load, one which closely represents the muscular ability of the subject. In developing an optimal load, for power output such factors as the strength of the leg muscles, lean muscle mass, and its distribution should be considered (Vanderwalle, Peres, Heller, & Monod, 1985; Bar-Or, 1987).

Several loading methods previously used to assess peak power include an absolute load, a load relative to body weight, and a load relative to lean body mass. Using an absolute load to assess peak power output with the cycle ergometer has been investigated in the studied by Weltman, Moffatt & Stamford (1978). The load chosen by the researchers is the same for all subjects. Some variations of this method have included the use of a set resistance for all subjects that has been increased at a steady rate upon successful completion of a previous setting on the cycle ergometer (Boulay, Lortie, Simoneau, Hamel, Leblanc, & Bouchard, 1985; Evans & Quinney 1981). The absolute loading method has the advantages of time efficiency and simplicity. Since all subjects can be assessed at the same loads, few equipment adjustments are necessary between subjects.

Furthermore, since no additional parameters are used such as anthropometric or strength measurements, to develop the load staff time and training requirements are kept to a minimum. A disadvantage of using an absolute load is that it may be biased towards certain individuals because body weight, leg strength, lean body mass, and its distribution are not considered. By not considering these factors maximal power may not be adequately assessed.

Another loading method used to assess power output with a cycle ergometer is a load relative to body weight. Loading relative to body weight during the Wingate test was investigated by Bar-Or and Dotan (1983) in their study of males and females. The Wingate test is a short-term, high-intensity cycle ergometer test used to assess power output. The loads used in this study were 0.086 and 0.087 kg per kg of body weight for females and males respectively (Bar-Or and Dotan, 1983). This method recognizes the relevance of body weight, yet is based on the assumption that the larger the individual, the higher the power output. Therefore, a higher load would be required. However, all individuals of the same weight may not produce equal power outputs. The lean muscle mass and its distribution are not considered, therefore two individuals of the same weight yet different body composition are tested at the same resistance/load. An individual who possesses a higher percent of muscle mass may require a higher load to reach maximum power output. Conversely, the individual with a higher percent body fat may require a lesser load. Each situation results in an inaccurate assessment of power output with the utilization of the total body weight method.

Determining a load relative to lean body mass is another method of loading for the cycle ergometer. This method is based on the assumption that subjects with a higher percent of muscle mass produce an increased amount of power during the short-term, high-intensity cycle test. The shortcoming in this method, however, is that it does not account for the distribution of the muscle mass. Two subjects with similar body compositions may vary significantly in leg muscle mass. These differences could substantially affect the power output abilities of each.

In considering the previous methods of load determination, a contributing factor of power output yet unconsidered is leg strength or the muscle mass in the legs. Leg strength is a main contributor to the production of power during short-term, high-intensity cycling. The primary group of muscles which contributes to power output during cycling is the knee extensors, namely the vastus lateralis and vastus medialis (Vaughan, 1989). The one repetition maximum (1RM) test assesses the strength of the leg extensors by measuring the amount of weight an individual can lift one time. Lean muscle mass is difficult and costly to be measured non-invasively, however, the amount of lean muscle mass is reflected in the amount of leg strength a subject possesses. Accordingly a correlation of r = 0.87 has been found between leg strength and peak power output (Wagner, 1991). Developing the load resistance using a percentage of the leg strength incorporates such essential factors as lean body mass and its distribution. This provides an optimal situation in which to attain a maximum power output. The main purpose of the current study was to determine an optimal load relative to isotonic leg strength for the constant-load cycle ergometer test.

SIGNIFICANCE OF THE STUDY

The current protocol consisted of five, 15 second short-term, high-intensity cycle ergometer tests using a load relative to isotonic leg strength. The 1RM leg strength test was performed and a percentage of the 1RM was used to determine the optimal load. Loads from six to ten percent 1RM were chosen as the resistance settings. The percent 1RM is a measurement that reflects the amount of muscle mass which produces the force throughout the cycle ergometer power test. As a result, this loading method appears to more accurately assess power output since loading is relative to individual leg strength and not total body mass or simply lean muscle mass which are less associated with power output.

Determining an optimal load is important due to the many activities which involve the production of short-term, high-intensity power. Results from these short-term, high-intensity cycle tests may aid in the development of effective training programs by identifying and assessing key components in short-term, high-intensity power production. Identification of these key components could also aid in the teaching of sport techniques to athletes. Knowing that, perhaps, an athlete's weakness lies within his/her endurance in a short-term, high-intensity activity, training programs can address the weakness and therefore enhance the athlete's performance. The usefulness of such tests, however, relies on their accuracy and validity. Therefore, accurate load determination is critical in these power tests.

RESEARCH HYPOTHESIS

The following is the null hypothesis to define the possible results of this study:

Ho: The following variables: peak power, power fatigue rate, time to peak power, average power, and power fatigue index are not a function of optimal loading relative to isotonic leg strength during the 15 second constant-load cycle ergometer test.

DELIMITATIONS

Below are stated the delimitations as established by the investigator:

1. The study was delimited to females between the ages of 18 and 38 years.
2. The study was delimited to college-aged females of varying exercise fitness levels averaging from 2 to 6 days, and consisting primarily of aerobic exercise, with a small percent being short-term, high-intensity, mainly weight training.
3. The power fatigue index, time to peak power, peak power, average power and power fatigue rate were measured as indications of power output.
4. A percentage (6-10) of the one repetition maximum of the leg extensors was used to determine the optimal load of the cycle ergometer.

LIMITATIONS

The following limitations were known to the investigator:

1. The results are applicable only to the population from which the subjects were pooled, mainly females between the ages of 18 and 38.
2. The use of a cycle ergometer power test may be biased towards those individuals who participate in cycling activities.

BASIC ASSUMPTIONS

The following assumptions were made by the investigator:

1. Maximal effort was exerted for the entire 15 seconds of the test by all subjects for all 5 tests performed.
2. The subjects were not pre-fatigued by activities within 24 hours of the cycle ergometer power test.
3. The power test results were not influenced by such external factors as: the subject's diet and amount of sleep during the night previous to testing.
4. The subjects in this study had no history of trauma, injury or surgery to the knee, hip or associated musculature.

DEFINITIONS AND SYMBOLS

Average Power (AP) (Watts) - the total power average produced every one half pedal revolution throughout the exercise bout.

One Repetition Maximum (1RM) (Kg) - the maximum amount of force exerted by the muscle in one given trial.

Optimal load - resistive force which elicits the highest peak power.

Peak Power (PP) (Watts) - the greatest power output attained during any one half pedal revolution throughout the exercise bout.

Power Fatigue Index (PFI) (%) - the percent at which the individual fatigues from the point of peak power to the end of exercise.

Power Fatigue Rate (PFR) (Watts/second) - the rate at which power declines from PP to the end of the test.

Time to Peak Power (TTPP) (seconds) - the elapsed time measured from the start of the exercise bout to the time of peak power.

SUMMARY

Short-term, high-intensity power is necessary in such sports as swimming, weight training and short-distance

sprints in track and field events. Power output is the function of force and velocity. Several tests such as the Margaria stair climb test, short distance sprints, the vertical jump test and various treadmill tests have been developed to assess short-term, high-intensity power. Few of these tests, however, examine the essential factors contributing to the production of short-term, high-intensity power. The power output during cycling is largely dependent upon the load applied to the flywheel. An excessive load inhibits power output by substantially reducing velocity; whereas, an insufficient load lessens the force applied to the wheel thus reducing the power produced.

Several methods have been employed in the selection of resistive loads including an absolute load, a load relative to body weight, and a load relative to muscle mass. These methods do not consider all of the important factors contributing to power output such as leg strength, muscle mass and muscle mass distribution. Applying a load relative to the isotonic leg strength used during short-term, high-intensity cycling should more accurately reflect the leg muscle mass and therefore potential for power output (Wilkie, 1960). Determining an optimal load for females during a constant-load cycle ergometer test was the purpose of this study. Loads were chosen as a percentage of the subjects' isotonic leg strength to account for the muscular abilities of the individuals tested.

CHAPTER II

REVIEW OF LITERATURE

This review of literature provides research information regarding the history of short-term, high-intensity power tests and the various loading methods used to assess maximal power output using the cycle ergometer. Additionally, this review compares the different load selection methods and introduces information for the use of a load relative to leg strength. The studies presented provide support necessary to demonstrate areas requiring further examination such as optimal load determination methods for the short-term, high-intensity cycle ergometer test.

SHORT-TERM, HIGH-INTENSITY POWER

Short-term, high-intensity power is the power used in activities less than two minutes in length (McArdle, Katch and Katch (1991). This type of power has also been referred to as anaerobic power by some authors. Since the creatine phosphate and the glycolytic pathway are responsible for energy production during these activities. Short-term, high-intensity exercise comprises much of man's daily activities. Compared to the amount of aerobic exercise research, a relatively small amount of research has been done in the area of short-term, high-intensity exercise

Power is the function of force and velocity. The force-velocity relationship has been described by several authors (Hill, 1922; Sargeant, Hoinville and Young, 1981; Fenn and Marsh, 1935). In general, as the force increases in a muscle, the velocity of shortening decreases. A similar inverse relationship has been shown to be curvilinear at moderate force and velocity using a cycle ergometer (Nadeau, Brassard, and Cuerrier 1983). The resistance placed against the flywheel is the force while the velocity is the measure of flywheel revolutions per second (Nadeau et al, 1983). Consequently, the power produced on a constant-load cycle ergometer is contingent upon the resistance or the force applied to the flywheel and the flywheel velocity achieved by the subject.

MEASUREMENT OF SHORT-TERM, HIGH-INTENSITY POWER

Tests to measure short-term, high-intensity power have been developed for over 70 years. L. W. Sargent served as a pioneer in this field with his development of the Sargent jump test (1921). Some researchers consider these anaerobic power tests; however, this may be a misnomer because some, albeit small amount of activity is still fueled by the aerobic power system and, thus, the power is note entirely derived from the anaerobic power systems. Additional short-term, high-intensity power tests used include: the Margaria-Kalamen stair climb test (1966); cycle ergometer tests (Bar-Or, Dotan, Inbar, Rothstein, Karlsson, and Tesch, 1980; Dotan and Bar-Or, 1983; McCartney, Heigenhauser, and Jones, 1983; Williams et al, 1988; Vanderwalle, Peres, Heller, and Monod, 1985;), short distance sprints (Tharp, Johnson, and Thorland, 1984); and short distance treadmill tests (Cheetham, Boobis, Brooks, and Williams, 1986).

Although several of the above mentioned tests, such as the vertical jump and stair climb test, are used quite frequently, the velocity and the force cannot be tightly controlled by the investigator (Margaria et al, 1966; Sargent, 1921). An example of an uncontrolled force occurs in the stair climb test. Since the total body mass of each subject acts as his/her force, the force differs from subject to subject and it cannot be controlled by the investigator. In addition, few of the above field tests evaluate specific components of power production such as total power and fatigue measurements.

Cycle Ergometer Tests

One mode of testing that does allow for the control of velocity and force is short-term, high-intensity cycling. Of the above mentioned short-term, high-intensity power tests, by far the most widely used assessment is the cycle ergometer test. Numerous researchers have used the cycle ergometer to measure power output over a short period of time ranging from 10 to 120 seconds (Sargeant, Hoinville, and Young, 1981; Jones, McCartney, Graham, Spriet, Kowalchuk, Heigenhauser, and Sutton, 1985; Reilly and Bayley, 1988). The ability to control the force and velocity throughout the test is an important advantage over the Sargent jump test, the stair climb test, and short distance sprints.

An inverse relationship exists between force and velocity. An excessive force applied will significantly reduce the level of attainable velocity thereby diminishing power output. Conversely, an insufficient force allows for an increased velocity, but the lack of resistance results in an overall reduction in power output. Based upon several cycle ergometer tests of varying velocities, Sargeant et al (1981) reported the optimal velocity during cycling to be 110 revolutions per minute during cycling. In researching optimal velocity, the resistive load remains constant while various velocities are tested. The velocity eliciting the highest peak power is reported to be the optimal velocity. Another factor contributing to power output is the resistive load or force applied to the wheel. An optimal load exists for each subject which reflects the subject's muscular ability, and therefore allows maximization of power output (Wilkie, 1960). The optimal combination of the applied force and velocity produced results in the attainment of peak power (Patton, Murphy and Frederick, 1985).

One of the most widely used cycle ergometer tests has been the Wingate Anaerobic test (WAnT). This test was designed to assess short-term, high-intensity power and was developed over fifteen years ago by Bar-Or, Dotan, and Inbar, 1977). The WAnT consisted of a 30 second maximal cycling power test in which the resistance was determined using 0.075 kg per kg of body weight. The resistance was applied after approximately three seconds (Bar-Or et al, 1980). The WAnT has evolved over the years with modified versions for arm ergometry, and for the swim bench (Patton and Duggan, 1987; Reilly and Bayley, 1988). Variables measured during the WAnT included peak power (after 5 seconds), average power (during the entire test), and a measure of fatigue referred to as power decrease (the difference between the highest and lowest values divided by time expired) (Bar-Or et al, 1980). The test-retest reliability of the WAnT has been found to be between 0.95 and 0.98 (as cited in Bar-Or et al, 1980; Evans and Quinney, 1981). Several advantages of the WAnt included: the ability of the researcher to determine the applied force, the velocity, and the seat height; the non-weight bearing nature of cycling; and the relative inexpense and availability of the necessary common laboratory equipment. Overall the test has been a simple and effective laboratory test of short-term, high-intensity power.

Another short-term, high-intensity power test recently developed by Williams et al uses a constant-load ergometer (1988). Throughout this test, a resistive force is applied continuously. The test lasts 15 seconds and the changes in power output are measured every one-half pedal revolution throughout the test. Measured variables included peak power (PP), time to peak power (TTPP), average power (AP), power fatigue rate (PFR), power fatigue index (PFI), and total work (TW) (Williams et al, 1988). These variables provide pertinent information for describing short-term power production and fatigue development per half pedal revolution instead of averaging peak power output over a period of seconds (Evans and Quinney, 1981; Bar-Or et al, 1980; Tharp et al, 1984). By measuring the variables every half-pedal revolution, the contraction-relaxation cycle of the muscles are accounted for as are the transient shifts in power output (Williams et al, 1988). The test-retest reliability reported for all variables was high [R=0.91 - 0.97] for both sets of tests with varying rest times (Williams et al, 1988).

The cycle ergometer test was performed using a modified Monark cycle ergometer equipped to electronically count the half-pedal revolutions and feed the information into a microcomputer which further analyzed the results (Williams et al, 1988). A preset load of 111.8N was used for all participants who completed the 15 sec tests. Tests were administered with a minimum of 15 minutes and two days between tests (Williams et al, 1988). The results were displayed in a power curve, which upon further analysis provided a more detailed report of the contributing factors in short-term, high-intensity power output.

OPTIMAL LOADING

The determination of an optimal resistive force or load during short-term, high-intensity cycling is crucial to obtaining accurate power output assessments. An optimal force, as mentioned previously, is defined as one that is reflective of the subject's muscular ability allowing an accurate assessment of power output (Wilkie, 1960). If an excessive load is used, a reduced power output occurs whereas an insufficient load also results in a reduced output. Several factors greatly contribute to the load determination method including physical condition, strength of leg muscles (namely the leg extensors), lean body mass and lean body mass distribution (Vanderwalle et al, 1985; Bar-Or, 1987). An additional factor such as training experience in short-term, high-intensity events may also influence the loading requirements. Clearly, a need is present to identify a method which considers these additional factors in optimal load determination (Bar-Or, 1987).

Several different types of load resistances have been used in assessing short-term, high-intensity power using a cycle ergometer including an absolute load, a load relative to body weight, and a load relative to lean body mass. Using an absolute load to assess peak power output in males has been investigated in a study by Evans and Quinney (1981). All subjects were tested at set resistances beginning at 4 kilopond (kp) to 10.0 kp (Evans and Quinney, 1981). The subjects began to pedal at 4 kp and the resistance was increased by 1 kp until a decline in power occurred. The maximal power output was measured for 30 seconds and then compared to the subjects performance during the Wingate test. Significant differences ($p < 0.05$) were found between the two tests. The power output was significantly higher during the test using increasing resistances as opposed to the load relative to body weight used during the Wingate test (Evans and Quinney, 1981). Additionally, a test-retest reliability of the maximal power output test used in this study was reported at $r = 0.96$ (Evans and Quinney, 1981)

Absolute loading has advantages such as time efficiency and simplicity. Since all subjects can be assessed at the same loads, little equipment changes are necessary between subjects. Additionally, since no other parameters are used to develop the load, such as anthropometric or strength measurements, staff time and education requirements are kept to a minimum. On the other hand, absolute loading may produce inaccurate results for many subjects since important factors such as leg strength, muscle mass, and its distribution are not considered. Optimal power cannot be adequately assessed when these factors are not considered in the load determination process.

Another loading method used to assess power output using a cycle ergometer is a load relative to body weight. Loading relative to body weight during the Wingate test was investigated by Bar-Or and Dotan (1983) in their study of males and females. Initially, the standard method of determining the resistance for the WAnT involved young male subjects and was reported to be 0.075 kg per kg of body mass. Upon further investigation, however, this load was deemed insufficient and an optimal resistance was determined at 0.086 to 0.087 (kg per kg of body weight) for females and males respectively using the WAnT (Dotan and Bar-Or, 1983).

Another study examining the use of a load relative to body weight was performed by Davy et al (1990). The study examined 10 college aged males to determine an optimal load for the 15 second power test developed by Williams et al rather than utilizing the Wingate Anaerobic Test (1988). Resistance loads between 0.10 to 0.15 kg per kg of body weight were applied (Davy et al, 1990). Six tests were performed by all subjects with a rest of at least 20 minutes between tests. No more than three tests were done per day. An optimal resistance relative to body weight (between 0.12 to 0.15 kg per kg per kg of body weight) was found appropriate for the group of male subjects during the 15 second power test (Davy et al, 1990).

Determining an optimal load relative to body weight is based on the assumption that the larger the individual, the higher the power output. Because lean muscle mass and its distribution are not considered, two individuals of the same weight yet different body composition are tested at the same resistance/load. If an individual has a higher percent of lean muscle mass he/she may require a higher load. On the contrary, an individual with a higher percent body fat may require a lesser load. Each situation results in an inaccurate assessment of power output. This failure to account for differences in muscular composition is the weakness of the load relative to total body weight method.

Determining a load relative to muscle mass is another loading method. A load relative to muscle mass results in a load reflecting the subject's body composition and therefore muscular ability. This method is based on the assumption that subjects with a higher percent of lean muscle mass will produce an increased amount of power during the short-term, high-intensity cycle test. A shortcoming of this method; however, is that it does not account for the distribution of the lean muscle mass. Two subjects with similar body compositions but varying muscle mass in the legs would not be accurately assessed during a cycle test. These variances in leg muscle mass, and therefore leg strength, affect power output. Additionally, other disadvantages include the fact that estimating body composition accurately requires trained personnel and more time per subject.

Short-term, high-intensity cycle power tests are designed to be relatively simple to execute with a minimal amount of training and equipment required. Therefore determining a load relative to lean body mass is an inefficient method.

A contributing factor of power output yet unconsidered by the previous methods is leg strength or the muscle mass in the legs. Leg strength is a major contributor to power production during short-term, high-intensity cycling. The primary group of muscles which contribute to power output during cycling is the knee extensors, namely the vastus lateralis and vastus medialis (Vaughan, 1989). Lean muscle mass cannot be measured non-invasively, but, the amount of lean muscle mass is reflected in the amount of leg strength a subject possesses. This concept is supported by the fact that muscular force is equal to three to four kg/cm2. A correlation of r = 0.87 has been found between leg strength and peak power output (Wagner, 1991). Additionally, peak isometric torque of the knee extensors has been correlated strongly (r = 0.89) with the peak power produced on the cycle ergometer during short-term, high-intensity tests (Wagner, 1991). By developing a resistance relative to the leg strength the loading will appropriately reflect the muscular ability of the subject, and therefore, more accurately assess his/her power output.

Many activities involve the production of short-term, high-intensity power. Results from these tests can aid in the development of effective training programs by identifying key components in short-term, high-intensity power activities. Therefore, it is important to have the ability to accurately assess power output.

MEASUREMENT OF LEG STRENGTH

The knee extensor muscles, the vastus lateralis and vastus medialis, are the primary contributors to power output in cycling (Vaughan, 1989). Since cycling is an isotonic muscle contraction, an assessment of the isotonic leg strength identifies the main contributing force in power production. The common method of assessing isotonic knee extensor strength is the one repetition-maximum (1RM) test using Nautilus or Universal equipment (McArdle et al, 1991). The 1RM test is easily administered and involves the use of both legs as in the cycling activity.

SUMMARY

The main purpose of the present literature review has been to present related research of short-term, high-intensity power output tests in addition to load determination methods for these tests. Short-term, high-intensity power is used during many daily activities where short maximal exercise bouts are interspersed with periods of rest. Previous research of power output tests have been performed using either an absolute load, a load relative to body weight or a load relative to muscle mass. These methods, however, do not account for the large component of power, isotonic leg strength. Using leg strength to determine the applied load takes the muscle mass of the legs into consideration. Consequently, the result may be a more accurate assessment of power output. The main purpose of the current study was to determine an optimal load for a constant-load cycle ergometer test relative to isotonic leg strength.

Chapter III

JOURNAL MANUSCRIPT

DETERMINING AN OPTIMAL LOAD FOR A CONSTANT-LOAD ERGOMETER RELATIVE TO ISOTONIC LEG STRENGTH

(ABSTRACT)

Holly A. Wagner

This study investigated the determination of an optimal resistive force for use during a short-term, high-intensity cycling power test. Twenty-four college females 22.0 ±0.50 y; 60.3 ± 1.46 kg (x±SE) gave consent and participated in a 1 repetition maximum (1RM) test of the knee extensors and 5 maximal 15 s cycling tests. The 1 RM test was performed using a Nautilus leg extensor machine. Even increments between 6 - 10 % 1RM test were utilized to determine the resistive force applied to the flywheel. The 5 tests were divided into a 2 testing sessions occurring at least 48 h apart. Each subject warmed-up at 50 - 60 rpms for 2 - 5 minutes without resistance prior to testing. Each test consisted of a maximal cycling bout of 15 s with 20 minutes rest between tests. The variables measured included peak power (PP), time to peak power (TTPP), power fatigue rate (PFR), power fatigue index (PFI), and average power (AP). These values were collected by a microcomputer interfaced with the cycle ergometer. In general, PP was lower at

resistances greater and less than 9 % 1RM. The average reported PP values were 363±15, 413±19, 465±19, 520±21, and 460±41 for loads 6 - 10 % 1RM respectively. The differences in PP for loads between 8 - 10 % 1RM were statistically different. Similar results were reported for AP. Results show that PP varies based on loads of % 1 RM and the optimal range is between 8 -10 % 1RM.

INTRODUCTION

Although extensive research has been conducted to identify the essential factors that determine aerobic performance, relatively little research has been directed towards identifying the essential factors that contribute to anaerobic performance. Muscular power is the product of force and velocity and is crucial to activities involving short-term, high-intensity efforts. These activities include such sports as short distance sprints, swimming and weight training. Often the amount of maximal power an athlete generates affects his/her success in sport performance. The essential factors that contribute to optimal power output include muscular strength and shortening velocity.

Tests of muscle power were initially developed over 70 years ago with L. W. Sargent being one of the pioneers in this area of interest (1921). Sargent developed the vertical jump test, which has been used as a field test of muscular power. Other tests which also measure power, or the time required to perform a given amount of work, include: the Margaria-Kalamen test, a stair climb test (1966); a cycle ergometer test (Bar-Or, Dotan, & Inbar, 1977); short distance sprints; and short distance treadmill tests (Cheetham, Boobis, Brooks, & Williams, 1986).

The cycle ergometer power test is one of the most common laboratory tests. Numerous researchers have used the cycle ergometer to measure power output in a short period of time ranging from 10 to 120 seconds (Sargeant, Hoinville, & Young, 1981; Jones, McCartney, Graham, Spriet, Kowalchuk, Heigenhauser, & Sutton, 1985; Reilly & Bayley, 1988; McCartney, Heigenhauser & Jones, 1983). Typically, the test is performed using a common cycle ergometer in which a standard resistance or braking force is applied. Power produced during cycling is a function of the applied force and the velocity of the flywheel. The subject's leg strength largely determines the amount of power produced during cycling. To produce optimal power, the applied force must be appropriate, reflecting of the subject's muscular ability (Wilkie, 1960).

The optimal load for the 15 sec cycle ergometer test is a resistance which reflects the subject's muscular ability and therefore allows for an accurate assessment of the subject's true power output (Wilkie, 1960). Although previous research in optimal load determination has contributed considerably to the development of accurate methods of testing short-term, high-intensity power, not all of the essential factors contributing to power output have been considered. These factors include shortening (or crank) velocity, lean body mass, and more specifically leg strength which largely contributes to peak power production (Sargent et al., 1981; Dotan & Bar-Or, 1983).

Several loading methods previously used to assess peak power include an absolute load, a load relative to body weight, and a load relative to lean body mass. In considering the previous methods of load determination, a contributing factor of power output yet unconsidered is leg strength. Muscle mass cannot be easily measured non-invasively, however, a 1RM test can be performed to assess the isotonic leg strength. The amount of lean muscle mass is reflected in the amount of leg strength that the subject possesses. A linear relationship of $r = 0.87$ has been found between leg strength and peak power output (Wagner, 1991). By using a percentage of the leg strength to select the load resistance, such essential factors as lean body mass and its distribution have been taken into account. The resulting load allows for a more accurate assessment of power output. The purpose of the current study was to determine an optimal load relative to isotonic leg strength for the constant-load cycle ergometer.

METHODS

Subjects

Twenty-four college females, (22.0 ±.50 y) participated. These female subjects were recruited from a college population with varying fitness levels. The students attended a brief orientation session in which the procedures of the study, the risks and benefits of the study, and the informed consent form were explained. Following the discussion, the students were given the opportunity to ask questions. All the questions were answered to the students' complete satisfaction. Before participating in the study, all subjects completed the informed consent form which included the protocol, risks and benefits of the study.

Percent of 1RM Test

One repetition maximum (1RM) were measured using the leg extensor weight machine. To perform the 1RM isotonic test of the knee extensors, each subject was seated on the machine and straps were secured across the subject's hips. By proceeding through approximately three to six resistance settings towards maximum, the test administrator assessed the 1RM as the highest load lifted.

Development of a range of loads for this test was based on pilot research in optimal load determination. Although the present study examined a load relative to leg strength, the findings of a load relative to total body weight reported by Davy, Williams, Ward, Smith & Franke were used as a guide (1990). Determining an optimal load for the cycle ergometer test was the purpose of the study. The protocol utilized by Davy et al involved determination of the loads relative to a percentage of total body weight (0.10 to 0.15 kg per kg BW) (1990). Davy, et al, demonstrated that the optimal load for males during the 15 s cycle ergometer test was between 6.8 to 9.0 kg or approximately 8.5 to 11.3 % of the average (80kg) body mass of the subjects. Because females tended to weigh less (average 57 kg), values closer to the lower end of the males' were chosen [6-10% of body mass] for the testing protocol. In addition, females tend to possess less lean muscle mass and therefore may require a lesser load to attain peak power.

Power Output Assessment

To assess power output during the short-term, high-intensity power test, a front loading modified 818 Monark ergometer was utilized. The device and test protocol set-up model utilized by Williams, Barnes & Signorile (1988) was also used in this experiment including the cycle ergometer, power test protocol, microcomputer, and software. Interfaced with the cycle ergometer was an IBM microcomputer which collected and processed the subjects' data (Williams et al, 1988). Attached to the ergometer frame was a magnetic reed switch that was activated from the two rotating magnets attached to the cycle sprocket at 0 and 180 degrees. Revolutions were determined by the magnetic reed switch at a 200 hertz frequency (Williams et al, 1988). The start of the subjects' pedal revolution began the data collection via the microcomputer.

Data collected to compute velocity included elapsed time, the number of half pedal revolutions, and the flywheel distance per half revolution. Attached to the load basket, and mounted between the friction belt and cycle ergometer frame was an inline Genisco, Astro-Weigh GAU-250 force transducer, which measured force in newtons (Williams et al, 1988). A MOD-x amplifier (3mV/5VDC) amplified the analog transducer signal. The information from the reed switch and transducer signal were connected into a Metra-Byte 16-bit analog to digital converter prior to assembly with the microcomputer (Williams et al, 1988). The dependent variables measured included power fatigue index (PFI), time to peak power (TTPP), peak power (PP), and power fatigue rate (PFR). These variables were computed via the basic power program software, and the power versus time graphs were plotted.

Protocol

Five different percentages (six to ten percent of the 1 RM) were used as the load for the five tests. The different loads were assigned to each subject in a randomly chosen sequence. All subjects participated in 5 short-term, high-intensity power tests on the cycle ergometer in the Muscle Function Laboratory. The 5 tests were conducted in a sets of 2 and 3; the sets of tests were performed at least 48 hours apart.

The subjects warmed up on the cycle for approximately 2-5 minutes (50 W, 60 rpms). The duration of the power test was 15 seconds, after which the subject cooled down with no resistance on the cycle ergometer. After approximately 20 minutes, the second test was performed following the same procedure as the first. The procedure for the third test was the same as previous tests. Prior to testing, the appropriate seat was set for each subject.

The subjects participated in 3 tests on 1 day and 2 on another at least 48 hours apart, to allow for muscle recovery. Previous work has shown high test-retest reliability for tests separated by 20 minutes or when sets of tests are separated by 48 h (Williams et al., 1988). Then, the test administrator gave brief instructions regarding the power test. Subjects were instructed to place the dominant leg forward in the pedals, to place the pedals parallel to the ground, to remain seated during the entire test, to give a maximal effort, and to continue pedaling upon completion of the test to prevent blood from pooling in the lower extremities. The subjects were also informed that the test began when she first moved her dominant pedalling foot forward. The test administrator gave verbal encouragement throughout the test. The test administrator signaled the test termination upon completion of the 15 s power test.

Statistical Procedures

Descriptive statistics of the subjects' data were generated. In addition, a one way ANOVA with repeated measures, and Duncan's Post Hoc test were used to analyze the collected data. The variables that were examined included: % 1RM, PP, AP, PFI, PFR, and TTPP.

RESULTS

The results indicate that the PP, AP and PFI were sensitive to loading conditions whereas the others were not (Figures 1 - 5). In examining the results of PP values for different loads, a load of 9% appears to be in the optimal range (between 8 - 10%) and resulted in the highest power output (Figure 1). Average power responded similar to PP with the highest AP being reported at 9 % 1RM. The ANOVA revealed significant differences in PFI vs. % 1RM between a load of 6 % and 7-10 % suggesting that a lighter load results in possibly greater fatigue. The TTPP tended to increase non-significantly as % 1RM increased until 9% at which a decline in TTPP occurred (Figure 5). Lastly, the PFR was not statistically different between loads (Figure 3).

Correlations (Pearson's Coefficient) were computed between total body weight and load utilized to attain highest peak power to result in r = .497 (Figure 6). In addition, the linear relationship between 1RM and load utilized to attain highest PP and was reported at r = .854 (Figure 7). These correlations indicate the stronger relationship between 1RM and load of highest PP. The higher correlation suggests that a load relative to the 1RM accounts for a greater percent of the contributing factors for power output whereas the load relative to total body weight does not. Also, the assumption that larger individuals require a heavier load for maximal power is not supported with the lower correlation.

DISCUSSION

The two main findings from the present study include the following. Loading relative to isotonic leg strength is preferable to loading relative to total body weight. This is supported by Figures 6 and 7. Also the optimal range necessary for attaining the highest peak power (i.e. optimal load) is between 8 and 10 % 1RM for college-age females. This is evident in Figure 1.

Optimal Load Determination

It appears to be preferable to choose the optimal load relative to leg strength as opposed to body weight as shown in Figures 6 and 7. Based on leg strength, the optimal load appears to be between 8 and 10 % 1RM. Past research has suggested methods of load determination such as an absolute load and a load relative to body weight (Evans & Quinney, 1981; Weltman, Moffatt & Stamford, 1978; Dotan & Bar-Or, 1983). These methods fail to account for muscle mass and its distribution. An additional method is to develop a load relative to lean body mass; however, again this method does not account for muscle mass and its distribution. By using a load relative to leg strength, the muscle mass and its distribution are taken into account therefore allowing a more accurate power output assessment.

Of the above methods for load determination, the most commonly used is that relative to total body weight. Unfortunately, as stated above, the load relative to total body weight does not consider muscle mass and its distribution. By using the previously mentioned method of a loading based upon 0.10 (kg) of total body weight (kg) developed by Dotan and Bar-Or (1983), the actual load for the subjects in the present study would have been approximately 7 to 8 % 1RM and therefore insufficient for optimal loading conditions. A more effective method would be lean body mass estimation (Bar-Or, 1987); however, this method is often impractical and fails to account for the specific muscle mass actively used in cycling. Additional technical considerations including the need for more time per subject and higher trained personnel may also make this method undesirable.

Developing a load relative to the muscle mass in the legs is essential to adequately assess power output. Without the consideration of the leg muscle mass, one of the most important factors of power output is not considered. Vaughan (1989) stated that the main contributing muscles used for cycling are the vastus lateralis and vastus medialis or the extensor muscles. Unfortunately, it is extremely difficult to measure lean muscle mass. In lieu of the lean muscle mass assessment, the muscular force produced may be measured as it is related to the cross sectional area of the muscle. Therefore, measuring the force of contraction of the quadriceps should more accurately reflect the muscle mass involved and be a sound basis for selecting the optimal load for power output. This concept is shown in Figures 6 and 7, with a far higher correlation found between the optimal load and leg strength as opposed to optimal load and body weight.

Selection of Optimal Load

Statistical analysis showed that the optimal load for PP and AP fell between 8 and 10 % 1RM (Figure 1 and 2). Loads less than this range elicited significantly less PP output and there was a tendency for peak power to decrease as the loads increased above 9 %. This response is expected based on the force-velocity and power relationship of the muscle. Thus, it is probable that PP would have continued to decrease with loads greater that 10 % 1RM. Unfortunately, the use of high loading conditions is not without liability since a number of subjects are unable to accelerate the loads from rest. A similar parabolic relationship between resistive loads and PP has been reported by Davy et al. (1990) in the study of males and optimal loading for the 15 second short-term, high-intensity cycle power test.

A study by Lowensteyn, Signorile, Schlaff & Perry (1991) examined load determination methods for the constant load ergometer test. The maximum voluntary contraction (MVC) of the quadriceps femoris was measured and a percentage used to determine the load for the cycle ergometer test. All subjects (males and females) performed tests at 4 through 7 % MVC (Lowensteyn et al, 1991). Correlations between power output and % MVC utilized were performed; the highest r (.98-.99) was found between 5 %MVC and PP) (Lowensteyn et al, 1991). These authors suggest loading based on leg strength, however, detailed comparisons with the present study are difficult owing to different statistical procedures and measurements of leg strength. Additionally, using a % MVC for load determination necessitates additionally equipment and trained personnel which complicates this rather simple, effective and practical laymen's test of short-term, high-intensity power using the cycle ergometer.

Lowensteyn et al. (1991) examined a measurement of force production and developed a relative optimal load which indirectly accounted for the leg muscle mass involved in cycling. The isometric force was measured at a single angle by the load cell as opposed to isotonic force which is used during cycling. A 1 RM measurement as used in the present study, assesses isotonic force and therefore reflects the muscular activity during cycling.

Although the optimal range found in this study was 8 to 10 % 1RM, it is possible that this may not be an adequate range for all populations including the highly trained athlete. For example, highly trained sprinters may attain the highest peak power with loads higher than those stated in this study. These individuals are trained in short-term, high-intensity activities therefore one may expect a higher power output during the 15 second short-term, high-intensity cycle test. Such a relationship between training and power performance was shown in study of sprint performance and power output done by Shorten (1991). Results of the study demonstrated that a higher correlation existed between faster sprint performances and power output.

Conclusion

The present study suggests that the optimal loading range for the short-term, high-intensity cycle test is between 8 to 10 % 1RM. By using a load relative to leg strength as opposed to total body weight, the leg muscle mass used in the cycling activity is taken into consideration. Therefore, this method should provide for a more accurate assessment of short-term, high-intensity power output. Assessments of power output may be used to identify those better suited to perform in activities necessitating short-term, high-intensity power such as short-distance sprints, swimming sprints and basketball. In addition, power output test results may be used to predict performance in an activity such as short-distance sprints. By examining the components of power output, the effects of fatigue on performance may also be shown.

REFERENCES

Bar-Or, O., Dotan, R., and Inbar, O. (1977). A 30 second all-out ergometer test: its reliability and validity for anaerobic capacity. Israel Journal of Medical Science, 13(3), 126-127.

Cheetham, M., Boobis, L., Brooks, S., & Williams, C. (1986). Human muscle metabolism during sprint running. Journal of Applied Physiology, 61, 54-60.

Davy, K., Williams, J., Ward, C., Smith, S., and Franke, W. (1990). Optimal loading conditions for a constant load cycle ergometer test. Medicine and Science in Sports and Exercise, 22 (Supplement), S65.

Dotan, R. and Bar-Or, O. (1983). Load optimization for the Wingate anaerobic test. European Journal of Applied Physiology, 51, 409-417.

Evans, J.A. and Quinney, H.A. (1981). Determination of resistance settings for anaerobic power testing. Canadian Journal of Applied Sport Science. 65, 53-56.

Jones, N., McCartney, N., Graham, T., Spriet, L., Kowalchuk, J., Heigenhauser, G., and Sutton, J. (1985) Muscle performance and metabolism in maximal isokinetic cycling at slow and fast speeds. Journal of Applied Physiology, 59(1), 132-136.

Lowensteyn, I., Signorile, J., Schlaff, D., Perry, A. (1991). A comparison of various loading techniques for bicycle power ergometry. Medicine and Science in Sports and Exercise, Supplement 23 (4), S66.

Margaria, R., Aghemo, P., and Rovelli, E. (1966). Measurement of muscle power (anaerobic) in man. Journal of Applied hysiology, 21(5), 1662-1664.

Mccartney, N., Heigenhauser, G., and Jones, N. (1983). Power output and fatigue of human muscle in maximal cycling exercise. Journal of Applied Physiology, 55(1), 218-224.

Reilly, T., and Bayley, K. (1988). The relation between short-term, power output and sprint performance of young female swimmers. Journal of Human Movement Studies, 14, 19-29.

Sargant, L.W. (1921). The physical test of man. American Physical Education Review, 26, 188-194.

Sargeant, A., Hoinville, E., and Young, A. (1981). Maximum leg force and power output during short-term dynamic exercise. Journal of Applied Physiology, 51(5), 1175-1182.

Shorten, J. (1991). Relationships between sprint performance, power output, and fatigue. Unpublished master's thesis, Virginia Polytechnic and State University, Blacksburg, VA.

Vaughan, C. (1989). Biomechanics of Sport. Florida: RC Press.

Wagner, H. (1991). [Power testing using the 15 second constant-load cycle ergometer test]. Unpublished raw data.

Weltman, A., Moffatt, R., and Stamford, B. (1978). Supramaximal training in females: Effects on anaerobic power output, anaerobic capacity, and aerobic power. Journal of Sports Medicine, 18, 237-244.

Wilkie, D. (1960). Man as a source of mechanical power. Ergonomics, 3, 1-8.

Williams, J., Barnes, W., and Signorile, J. (1988). A constant load ergometer for measuring peak power output and fatigue. Journal of Applied Physiology, 65(5), 2343-2348.

LIST OF TABLES

Table

Table 1

Mean and Standard Error for Age, Height, Weight and 1 Rep Maximum of the Knee Extensors.

Variable	Mean	Standard Error
Age (yrs.)	22.0	0.50
Height (cm)	165.6	2.13
Weight (kg)	60.3	1.46
One Rep Maximum	75.4	3.22

FIGURE CAPTIONS

Figure

1 Peak Power vs. % 1RM
Legend: Means with similar letters are not significantly different at $p < 0.05$.

2 Average Power vs. % 1RM
Legend: Means with similar letters are not significantly different at $p < 0.05$.

3 Power Fatigue Rate vs. % 1RM
Legend: Means with similar letters are not significantly different at $p < 0.05$.

4 Power Fatigue Index vs. % 1RM
Legend: Means with similar letters are not significantly different at $p < 0.05$.

5 Time to Peak Power vs. % 1RM
Legend: Means with similar letters are not significantly different at $p < 0.05$.

6 Total Body Weight vs. Resistance Used to Attain Peak Power

7 1RM vs. Resistance Used to Attain Peak Power

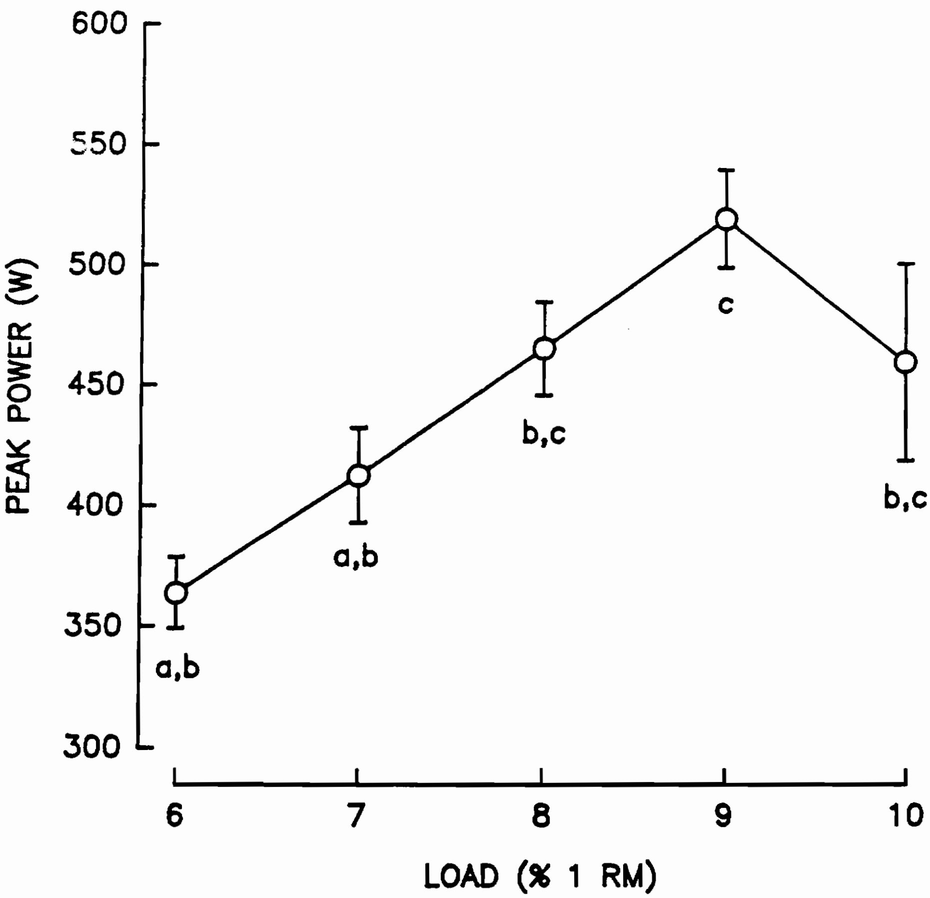

600
550
500
450
400
350
300
PEAK POWER (W)
a,b
a,b
b,c
c
b,c
6
7
8
9
10
LOAD (% 1 RM)

Figure 1

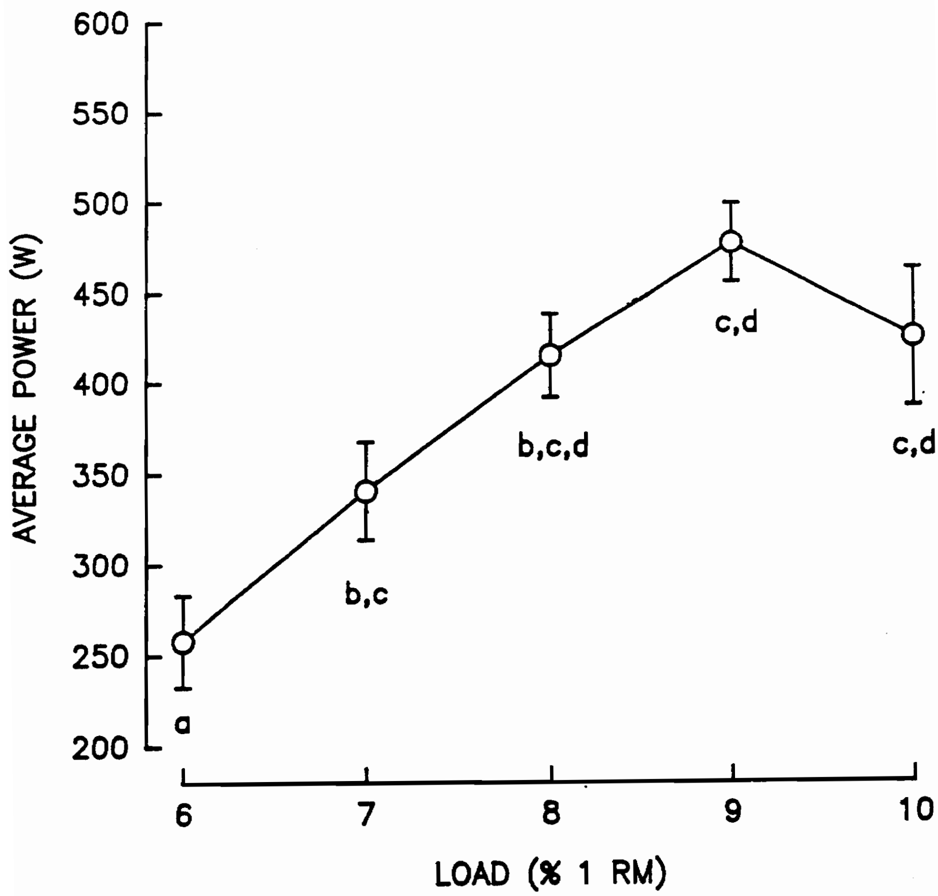
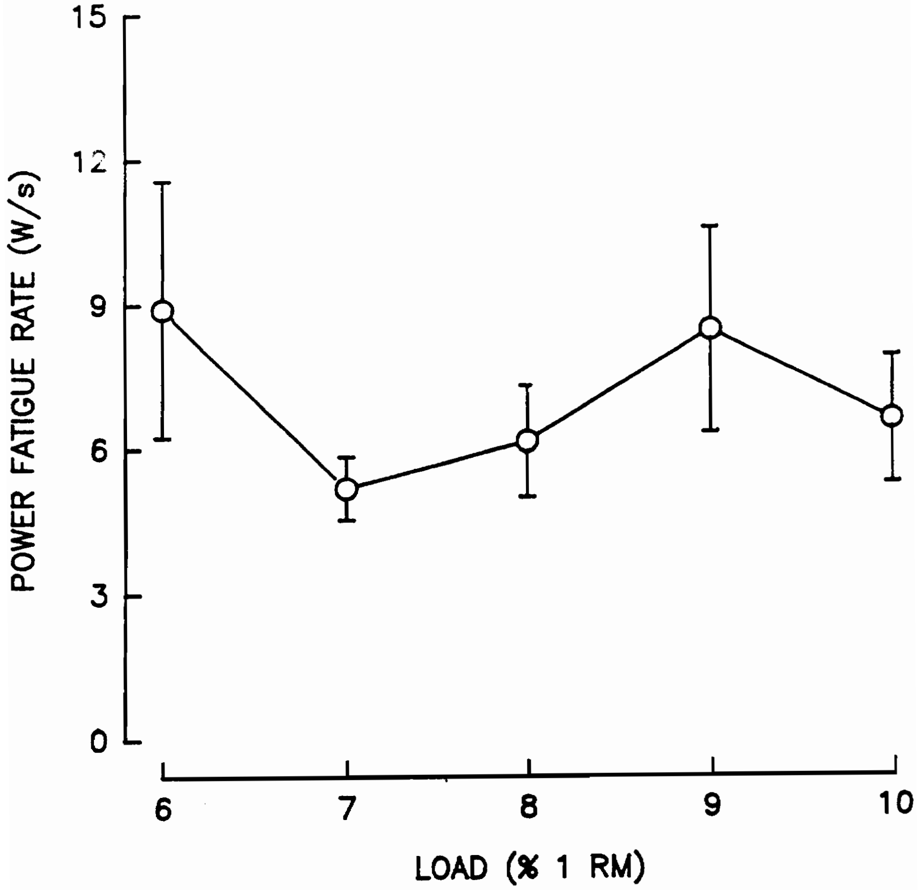

600
550
500
450
400
350
300
250
200
AVERAGE POWER (W)
a
b,c
b,c,d
c,d
c,d
6
7
8
9
10
LOAD (% 1 RM)

Figure 2



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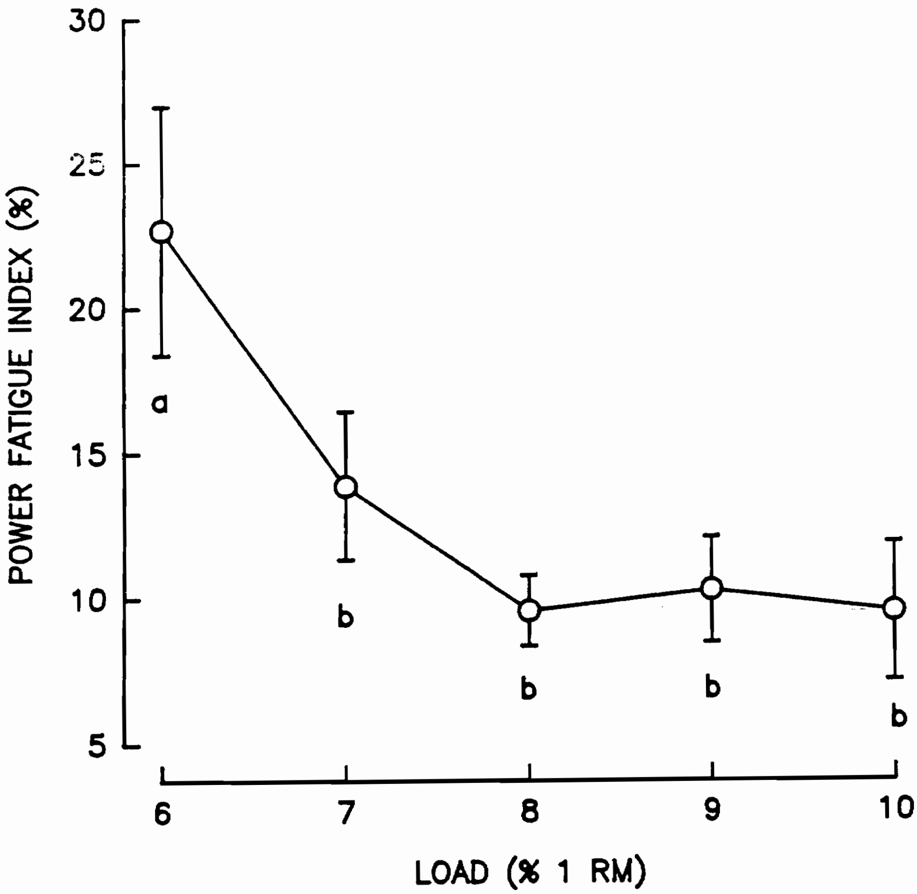

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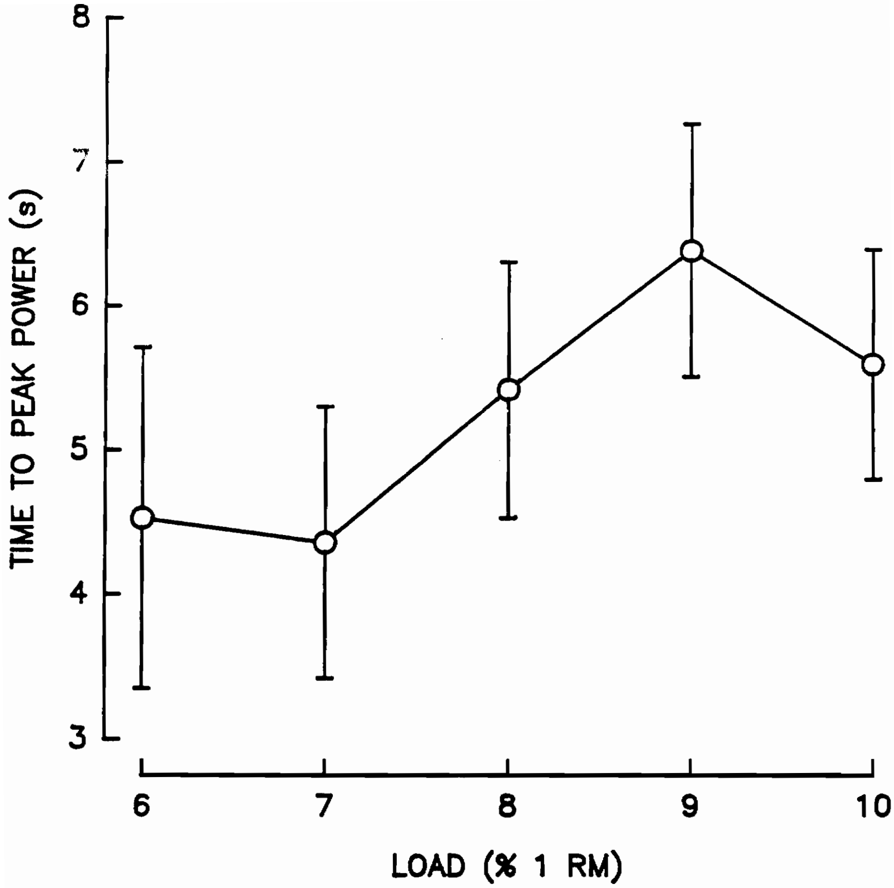
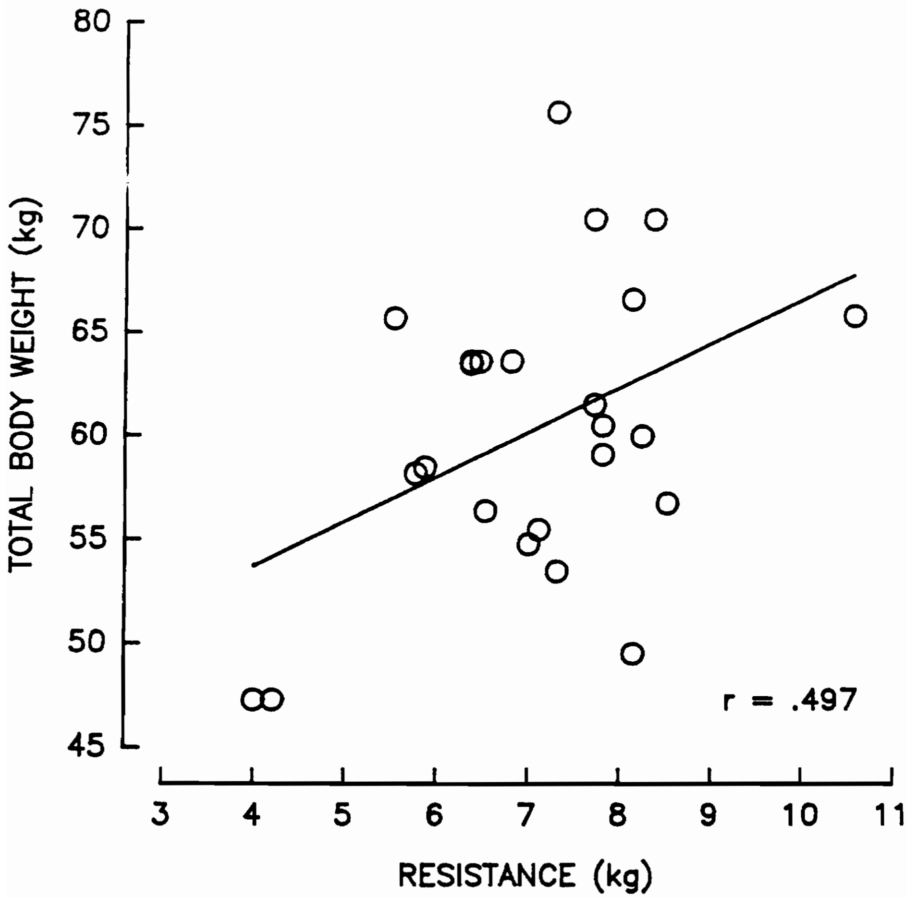
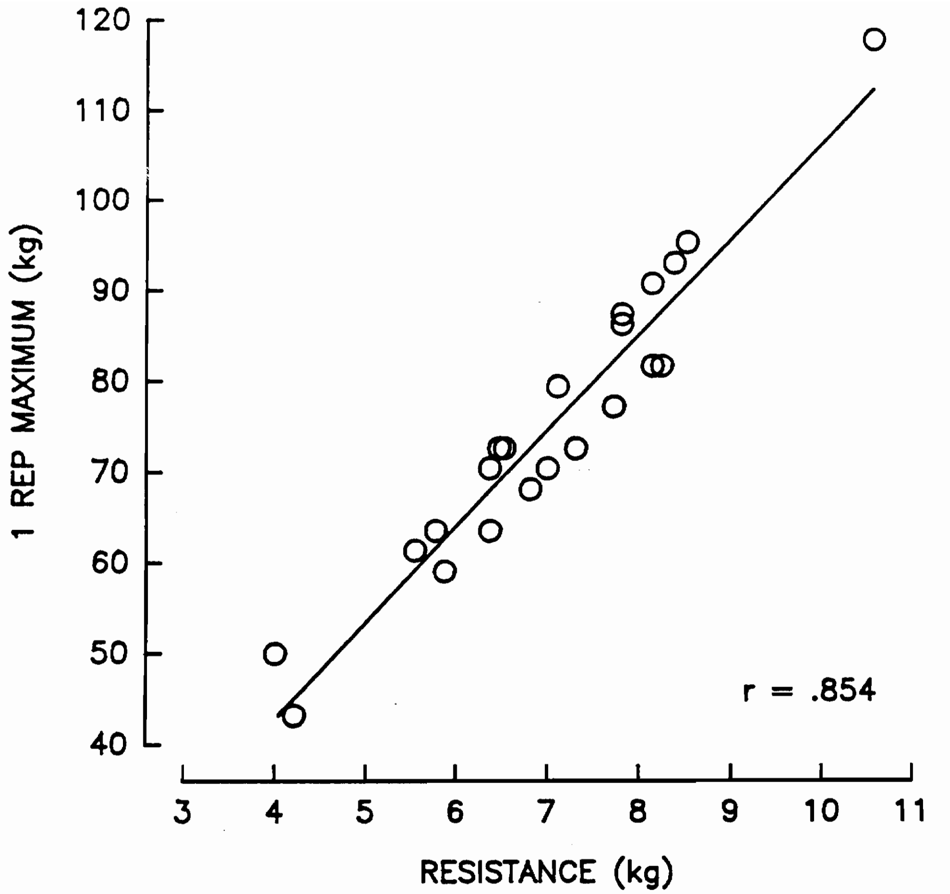


Figure 5



TOTAL BODY WEIGHT (kg)
80
75
70
65
60
55
50
45
r = .497
3
4
5
6
7
8
9
10
11
RESISTANCE (kg)

Figure 6



120
110
100
90
80
70
60
50
40
1 REP MAXIMUM (kg)
r = .854
3
4
5
6
7
8
9
10
11
RESISTANCE (kg)

Figure 7

CHAPTER IV

SUMMARY

A majority of man's daily activities involve short-term, high-intensity bouts of energy, yet a majority of the research in power performance has been done with aerobic activities. Several factors contribute to the production of short-term, high-intensity power including leg extensors strength, body mass, physical training, lean body mass, and lean body mass distribution (Vanderwalle, Peres, Heller, & Monod, 1985; Bar-Or, 1987). Although a few tests of short-term, high-intensity power have been developed in the last 15 years, few of these address the main contributing factors of power output.

One of the most common tests designed to assess short-term, high-intensity power is the cycle ergometer test. Determining an optimal load relative to isotonic leg strength for the 15 sec cycle ergometer test was the main purpose of this study. Because leg strength is a large contributor to the amount of power produced during cycling, using a percentage of it may result in an more accurate assessment of power output. Twenty-four collegiate females gave informed consent and participated in five, fifteen seconds all-out maximal cycling tests using a constant-load ergometer (Appendices A, C, E and H). Prior to participating in the study all subjects completed a medical and health questionnaire (Appendix G). Since leg strength was one of the main contributors in power production the subjects participated in a one-repetition maximum (RM) test of the leg extensors to assess leg strength (Appendix A). The loads used for the 5 exercise bouts were relative to a percent of each subject's 1RM (6 to 10 %) and administered in random sequence (Appendix F). The cycle ergometer tests were performed at least 20 minutes apart, with a maximum of 3 per day. Each subject had at least 48 hours between the sets of cycle tests.

The following response variables were measured including peak power (PP), time to peak power (TTPP), power fatigue rate (PFR). power fatigue index (PFI), average power (AP), and total work (TW) (Appendix F). Further details of the methodology were included in Appendix A. The relationships between individual variables and % 1RM are shown in Figures 1 through 5. The results indicate that the PP and AP are sensitive to loading conditions. In examining the results of PP values for different loads, a significant difference was seen between the load of 6 % 1RM and 7 to 10 % 1RM; however, a load of 9% appears to be in the optimal range and resulted in the highest power output (Appendix D).

Average power responded similar to PP with the highest AP being reported at 9 % 1RM (Appendix E).

The ANOVA revealed significant differences in PFI vs. % 1RM between a load of 6 % and 7-10 % suggesting that a lighter load results in possibly greater fatigue (Appendix D). The TTPP tended to increase as % 1RM increased until 9% at which a decline in TTPP occurred. Lastly, the PFR was not statistically different between loads (Appendix D).

DISCUSSION

The two main conclusions drawn from the present results include the following: Loading relative to isotonic leg strength is preferable to loading relative to total body weight. This is supported by Figures 6 & 7. Also the optimal range necessary for attaining the highest peak power (i.e. optimal load) is between 8 and 10 % 1RM. This is evident in Figure 1.

Optimal Load Determination

It appears to be preferable to choose the optimal load relative to leg strength as opposed to body weight as shown in Figures 6 and 7. Based on leg strength, the optimal load appears to be between 8 and 10 % 1RM. Past research has suggested methods of load determination such as an absolute load and a load relative to body weight (Evans & Quinney, 1981; Weltman, Moffatt & Stamford, 1978; Dotan & Bar-Or, 1983). These methods fail to account for muscle mass and its distribution. An additional method is to develop a load relative to lean body mass; however, again this method does not account for muscle mass and its distribution. By using a load relative to leg strength, the muscle mass and its distribution are taken into account therefore allowing a more accurate power output assessment.

Of the above methods for load determination, the most commonly used is that relative to total body weight. Unfortunately, as stated above, the load relative to total body weight does not consider muscle mass and its distribution. By using the previously mentioned method of a loading based upon 0.10 (kg) of total body weight (kg) developed by Dotan & Bar-Or, the actual load for the subjects in the present study would have been approximately 7 to 8 % 1RM and therefore insufficient for optimal loading conditions (1983). A more effective method would be lean body mass estimation (Bar-Or, 1987); however, this method is often impractical and fails to account for the specific muscle mass actively used in cycling. Additional technical considerations including the need for more time per subject and higher trained personnel may also make this method undesirable.

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Selection of Optimal Load

Statistical analysis showed that the optimal load for PP and AP fell between 8 and 10 % 1RM (Figure 1 and 2). Loads less than this range elicited significantly less PP output and there was a tendency for peak power to decrease as the loads increased above 9 %. This response is expected based on the force-velocity and power relationship of the muscle. Thus, it is probable that PP would have continued to decrease with loads greater that 10 % 1RM. Unfortunately, the use of high loading conditions is not without liability since a number of subjects are unable to accelerate the loads from rest. A similar parabolic relationship between resistive loads and PP has been reported by Davy et al in the study of males and optimal loading for the 15 second short-term, high-intensity cycle power test (1990).

A study by Lowensteyn, Signorile, Schlaff & Perry examined load determination methods for the constant load ergometer test (1991). The maximum voluntary contraction (MVC) of the quadriceps femoris was measured and a percentage used to determine the load for the cycle ergometer test. All subjects (males and females) performed tests at 4 through 7 % MVC (Lowensteyn et al., 1991). Correlations between power output and % MVC utilized were performed; the highest r (.98-.99) was found between 5 %MVC and PP) (Lowensteyn et al., 1991). These authors suggest loading based on leg strength, however, detailed comparisons with the present study are difficult owing to different statistical procedures and measurements of leg strength. Additionally, using a % MVC for load determination necessitates additionally equipment and trained personnel which complicates this rather simple, effective and practical laymen's test of short-term, high-intensity power using the cycle ergometer.

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Although the optimal range found in this study was 8 to 10 % 1RM, it is possible that this may not be an adequate range for all populations including the highly trained athlete. For example, highly trained sprinters may attain the highest peak power with loads higher than those stated in this study. These individuals are trained in short-term, high-intensity activities therefore one may expect a higher power output during the 15 second short-term, high-intensity cycle test. Such a relationship between training and power performance was shown in study of sprint performance and power output done by Shorten (1991). Results of the study demonstrated that a higher correlation existed between faster sprint performances and power output.

RESEARCH IMPLICATIONS

The main purpose of this study was to determine an optimal load relative to isotonic leg strength for the constant-load cycle ergometer test. The results of the current study suggest an optimal loading range between 8 and 10 % 1RM. Using this method of loading for the cycle ergometer test may result in a more accurate assessment of power output because the essential factor of leg strength was taken into account. Results of this power output test may be used in studying the effects of fatigue on sprint performance, and in simply assessing the power used in short-term, high-intensity activities such as swimming sprints, short distance track events, basketball and football.

Additionally, power output tests may help predict performance in sprinting events as was done in the study by Shorten (1991). If a weakness is shown in a particular power output variable, specific training programs may be designed which may increase performance. Also the results of the power output test may be used to assess which individuals have a higher power capacity and therefore may be better suited for particular sports involving short-term, high-intensity power.

RECOMMENDATIONS FOR FURTHER RESEARCH

Below are recommendations for further research in the areas of short-term, high-intensity power, optimal load determination and cycle tests.

1. Using different populations of male and female students with different levels of aerobic and anaerobic fitness to examine the effects of specific training programs on optimal load determination.
2. Developing a study to examine the effects of various interventions such as training, diet, drug use and psychological motivation on the optimal loading method.
3. Devising a test protocol of 8 to 12 % 1RM may provide further information to support the suggested optimal range of 8 to 10 % 1RM. It is possible that a few subjects may have attained PP at loads higher than 10 % 1RM.
4. Observe the relationships between force production and different muscles used in cycling and peak power output.

5. Comparing loads relative to different muscular force assessment tests including isometric, isotonic, and isokinetic force.

REFERENCES

Bar-Or, O. (1987). The Wingate Anaerobic Test-An update on methodology, reliability, and validity. Sports Medicine, 4, 381-394.

Bar-Or, O., Dotan, R., and Inbar, O. (1977). A 30 second all-out ergometer test: its reliability and validity for anaerobic capacity. Israel Journal of Medical Science, 13(3), 126-127.

Bar-Or, O., Dotan, R., Inbar, O., Rothstein, A., Karlsson, J., and Tesch, P. (1980). Anaerobic capacity and fiber type distribution in man. International Journal of Sports Medicine 1, 82-85.

Boulay, M., Lortie, G., Simoneau, J., Hamel, P., Leblanc, C., and Bouchard, C. (1985). Specificity of aerobic and anaerobic work capacities and powers. International Journal of Sports Medicine, 6, 325-328.

Cheetham, M., Boobis, L., Brooks, S., & Williams, C. (1986). Human muscle metabolism during sprint running. Journal of Applied Physiology, 61, 54-60.

Davy, K., Williams, J., Ward, C., Smith, S., and Franke, W. (1990). Optimal loading conditions for a constant load cycle ergometer test. Medicine and Science in Sports and Exercise, 22 (Supplement), S65.

Dotan, R. and Bar-Or, O. (1983). Load optimization for the Wingate anaerobic test. European Journal of Applied Physiology, 51, 409-417.

Evans, J.A. and Quinney, H.A. (1981). Determination of resistance settings for anaerobic power testing. Canadian Journal of Applied Sport Science. 6, 53-56.

Fenn, W., and Marsh, B. (1935). Muscular force at different speeds of shortening. Journal of Physiology, 85, 277-297.

Hill, A. (1922). The maximum work and mechanical efficiency of human muscles, and their most economical speed. Journal of Physiology, 56, 19-41.

Jones, N., McCartney, N., Graham, T., Spriet, L., Kowalchuk, J., Heigenhauser, G., and Sutton, J. (1985). Muscle performance and metabolism in maximal isokinetic cycling at slow and fast speeds. Journal of Applied Physiology, 59(1), 132-136.

Lowensteyn, I., Signorile, J., Schlaff, D., Perry, A. (1991). A comparison of various loading techniques for bicycle power ergometry. Medicine and Science in Sports and Exercise, Supplement 23 (4), S66.

Margaria, R., Aghemo, P., and Rovelli, E. (1966). Measurement of muscle power (anaerobic) in man. Journal of Applied Physiology, 21(5), 1662-1664.

McArdle, W., Katch, F., and Katch, V. (1991). Exercise Physiology, Energy, Nutrition, and Human Performance. Philadelphia: Lea and Febiger.

McCartney, N., Heigenhauser, G., and Jones, N. (1983). Power output and fatigue of human muscle in maximal cycling exercise. Journal of Applied Physiology, 55(1), 218-224.

Nadeau, M. and Brassard, A. (1983). The bicycle ergometer for muscle power testing. Canadian Journal of Applied Sport and Science, 8(1), 41-46.

Patton, J., and Duggan, A. (1987). Upper and lower body anaerobic power: comparison between biathletes and control subjects. International Journal of Sports Medicine, 8, 94-98.

Patton, J., Murphy, M., and Frederick, F. (1985). Maximal power outputs during the Wingate anaerobic test. International Journal of Sports Medicine, 6, 82-85.

Reilly, T., and Bayley, K. (1988). The relation between short-term, power output and sprint performance of young female swimmers. Journal of Human Movement Studies, 14, 19-29.

Sargent, D.A. (1921). The physical test of man. American Physical Education Review, 26, 188-194.

Sargeant, A., Hoinville, E., and Young, A. (1981). Maximum leg force and power output during short-term dynamic exercise. Journal of Applied Physiology, 51(5), 1175-1182.

Shorten, J. (1991). Relationships between sprint performance, power output, and fatigue. Unpublished master's thesis, Virginia Polytechnic and State University, Blacksburg, VA.

Smith, S. (1990). Effect of rapid dehydration repeated bouts of short-term, high intensity cycling exercise in college wrestlers. Unpublished master's thesis, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Tharp, G., Johnson, G., and Thorland, W. (1984). Measurement of anaerobic power and capacity in elite young track athletes using the Wingate test. Journal of Sports Medicine, 24, 100-105.

Vanderwalle, H., Peres, G., Heller. J., and Monod, H. (1985). All out anaerobic capacity tests on cycle ergometers. European Journal of Physiology, 54, 222-229.

Vaughan, C. (1989). Biomechanics of Sport. Florida: CRC Press.

Wagner, H. (1991). [Power testing using the 15 second constant-load cycle ergometer test]. Unpublished raw data.

Weltman, A., Moffatt, R., and Stamford, B. (1978). Supramaximal training in females: Effects on anaerobic power output, anaerobic capacity, and aerobic power. Journal of Sports Medicine, 18, 237-244.

Wilkie, D. (1960). Man as a source of mechanical power. Ergonomics, 3, 1-8.

Williams, J., Barnes, W., and Signorile, J. (1988). A constant load ergometer for measuring peak power output and fatigue. Journal of Applied Physiology, 65(5), 2343-2348.

Appendix A

METHODOLOGY

METHODOLOGY

SUBJECTS

A power analysis of the experimental design resulted in approximately 25 subjects. Subjects were pooled from the female college population with varying fitness levels. Students attended a brief orientation session in which the procedures of the study, the risks and benefits of the study, and the informed consent form were explained. Following the discussion concerning procedures, the students were given the opportunity to ask any questions and the questions were answered to the students' complete satisfaction. Before participating in the study, all subjects completed an informed consent (Appendix H) which included the protocol, risks and benefits of the study.

Twenty-four college females, [age (yrs) 22.0 $\pm$0.50 and weight (kg) 60.3$\pm$1.46 participated in this study of determining optimal load based upon isotonic leg strength.

ONE REPETITION MAXIMUM TEST

To perform the one repetition maximum (1RM) test of the leg extensors, the subject was seated on the Nautilus machine. Straps were placed across the hips. By proceeding through approximately three to six resistance settings towards maximum, the test administrator assessed the one RM. The following calculations were used to develop a range of loads for this test. The optimal load for males was between 6.8 to 9.0 kg (Davy et al, 1990). This was approximately 8.5 to 11.3 % of an average (80kg) body mass. Because females tended to weigh less (average-57 kg), values closer to the lower end of the males' were chosen [6-10%].

POWER OUTPUT ASSESSMENT

To assess power output during the short-term, high-intensity power test, a front loading modified 818 Monark ergometer was utilized by the investigator. Interfaced with the cycle ergometer was an IBM microcomputer which collected and processed the subjects' data. Attached to the ergometer frame was a magnetic reed switch that was activated from the two rotating magnets attached to the cycle sprocket at 0 and 180 degrees. Revolutions were counted by the magnetic reed switch at a 200 hertz frequency. The start of the subjects' pedal revolution began the data collection via of the microcomputer.

Data collected to compute velocity by the microcomputer included the time, half pedal revolutions, and the flywheel distance per half revolution. Attached to the load basket, and mounted between the friction belt and cycle ergometer frame was an inline Genisco, Astro-Weigh GAU-250 force transducer, which measured force in newtons. A MOD-x amplifier (3mV/5VDC) amplified the analog transducer signal. The information from the reed switch and transducer signal were connected into a Metro Bit 16 analog to a computerized converter prior to assembly with the microcomputer. The set-up model utilized by Williams, Barnes and Signorile (1988) was the model used in this experiment including the cycle ergometer, power test protocol, microcomputer, and software.

The dependent variables measured included power fatigue index (PFI), time to peak power (TTPP), peak power (PP), and power fatigue rate (PFR). These variables were computed via the basic power program software and the power versus time graphs were plotted.

PROTOCOL

Five different percentages (six to ten %) of the one RM were used to determine the load for the five tests. The different loads were assigned randomly. All subjects participated in five (5) short-term, high-intensity power tests on the cycle ergometer in the Muscle Function Laboratory. The 5 tests were divided into a set of 2 and 3; the sets of tests were performed at least 48 hours apart.

The subjects warmed up on the cycle for approximately 2-5 minutes at 50 W to 60 rpms. The duration of the power test was 15 seconds, after which the subject cooled down with no resistance on the cycle ergometer. After approximately 20 minutes, the second test was performed following the same procedure of the first. The procedure for the third test was the same as previous tests.

Prior to testing, the test administrator gave a brief instruction regarding the power test. These instructions included to place the dominant leg forward in the pedals, to place the pedals parallel to the ground, to remain seated during the entire test, to give a maximal effort, and to continue pedaling upon completion of the test to prevent blood from pooling in the lower extremities. The subject was also instructed that the test began when he/she first moved her dominant foot in the pedal forward. The test administrator gave verbal encouragement throughout the test. Prior to testing, the appropriate seat was set for each subject. Upon completion of data collection after the 15 second power test, the test administrator signaled to the subject of the test termination. The subjects participated in 3 tests on 1 day and 2 on another at least 48 hours apart, to allow for muscle recovery.

STATISTICAL PROCEDURES

Descriptive statistics and a one way ANOVA were used to analyze the data. The variables that were examined included: percent of one RM of leg extensors, peak power, power fatigue rate, time to peak power, power fatigue index, and the percent of one RM for loading during the power output test.

Appendix B

PILOT STUDY

DETERMINATION OF AN OPTIMAL LOAD RELATIVE TO ISOTONIC LEG STRENGTH FOR THE CONSTANT-LOAD CYCLE ERGOMETER

Holly Wagner

INTRODUCTION

One of the most common modes of assessing short-term, high-intensity power is the cycle ergometer. One of the essential components that should be considered in optimal load determination is leg strength or the active muscle mass. A common method of load determination is one relative to total body weight which does not take into consideration the leg muscle mass. The purpose of this study was to determine an optimal load for the constant-load cycle ergometer relative to isotonic leg strength.

METHODS

Three college aged females participated in the present study. Each subject performed a one repetition maximum (1RM) muscular strength test of the quadriceps using the Nautilus leg extensor machine. A percentage of this 1RM (even increments between 6 and 10 %) was used to load the modified Monark cycle ergometer interfaced with a microcomputer for data collection. Prior to testing, the subjects warmed-up on the cycle ergometer for 2-5 minutes, at approximately 50-60 W. Five, fifteen second maximal cycling bouts divided into sets of two and three were performed by all subjects. The subjects rested at least 20 minutes between tests with a 48 hour period between the sets of tests. All subjects began with the pedals parallel to the floor with the dominant leg forward.

The dependent variables included: peak power [PP], average power [AP], power fatigue rate [PFR], power fatigue index [PFI], and time to peak power [TTPP].

RESULTS

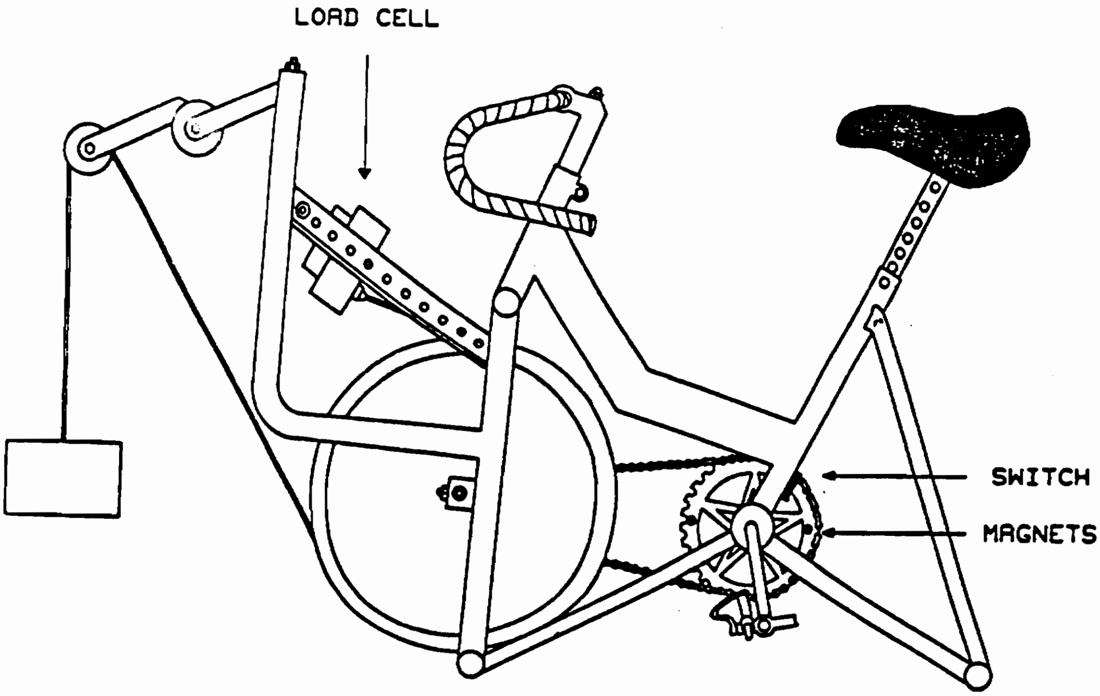
PP decreased with loads greater than 8 % 1RM on the average. AP responded similarly, however, due to a small sample size, various changes occurred in PFR, PFI and TTPP.

DISCUSSION

The results of the PP suggest that the optimal load range is between 8 and 9 % 1RM. Had the common method of using 0.10 kg per kg of total body weight been used, the range would have fell below 8 % 1RM which would not have provided sufficient resistance in which to assess maximum power output. By determining an optimal load relative to leg strength, the muscle mass of the legs is taken into consideration which results in a more accurate power output measurement. Results from the short-term, high-intensity cycle test may be used to further examine the indices of power output as it responds to appropriate loading conditions.

Appendix C

ERGOMETER DESIGN



SOURCE: Williams et al, 1988

Appendix D

RESULTS OF THE ONE WAY ANOVA AND POST HOC TESTS

Table 2.

Results of the ANOVA Between 6 Through 10 % of 1 RM for All Subjects.

Response Variable : **PEAK POWER (PP)**

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F
A(%1RM)	4	332866.6	83216.65	5.66	p<.05
ERROR	115	1690794	14702.56		
TOTAL	119	2023661			

Response Variable : **AVERAGE POWER (AP)**

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F
A(%1RM)	4	708004.7	177001.2	9.58	p<.05
ERROR	115	2124719	18475.81		
TOTAL	119	2832723			

Response Variable : **POWER FATIGUE RATE (PFR)**

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F
A(%1RM)	4	235.5939	58.89848	0.82	N.S.
ERROR	115	8302.174	72.19281		
TOTAL	119	8537.768			

Response Variable : **POWER FATIGUE INDEX (PFI)**

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F
A(%1RM)	4	3001.998	750.4995	4.41	p<.05
ERROR	115	19576.17	170.2275		
TOTAL	119	22578.16			

Response Variable : **TIME TO PEAK POWER (TTPP)**

Source	DF	Sum-Squares	Mean Square	F-Ratio	Prob>F
A(%1rm)	4	66.28073	16.57018	0.77	N.S.
ERROR	115	2477.397	21.54258		
TOTAL	119	2543.678			

Appendix E

RESULTS OF THE DESCRIPTIVE STATISTICAL TESTS

Table 1

Mean and Standard Error for Age, Height, Weight and 1 Rep Maximum of the Knee Extensors.

Variable	Mean	Standard Error
Age (yrs.)	22.0	0.50
Height (cm)	165.6	2.13
Weight (kg)	60.3	1.46
One Rep Maximum	75.4	3.22

Table 3

Mean and Standard Error for the Dependent Variables.

Variable	% 1 RM	Mean	Standard Error
PP (W)	6	363.8	±14.8
	7	412.5	±19.4
	8	465.0	±19.4
	9	519.7	±20.5
	10	460.4	±40.9
AP (W)	6	257.8	±25.2
	7	340.8	±26.9
	8	415.4	±23.0
	9	478.4	±21.8
	10	426.6	±38.5
PFR (W/s)	6	8.90	± 2.66
	7	5.20	± 0.65
	8	6.16	± 1.14
	9	8.47	± 2.12
	10	6.64	± 1.32
PFI (%)	6	22.69	± 4.29
	7	13.91	± 2.55
	8	9.59	± 1.22
	9	10.31	± 1.82
	10	9.57	± 2.39
TTPP (s)	6	4.53	± 1.18
	7	4.36	± 0.94
	8	5.42	± 0.89
	9	6.39	± 0.88
	10	5.60	± 0.80

Appendix F

RAW DATA

RAW DATA

Legend:
Sbj = Subject Number
1RM = One Repetition Maximum of Leg Extensors (kg)
%1 RM = Percentage of 1 repetition maximum used for load
PP = Peak Power (W)
AP = Average Power (W)
TTPP = Time to Peak Power (sec)
PFR = Power Fatigue Rate (W/sec)
PFI = Power Fatigue Index (%)
TW = Total Work (J)
---- = denotes the subject could not complete this load

Sbj	WT (kg)	AGE	1RM	%1R	MPP	TTPP	PFR	PFI	AP	TW
1	60.0	20	81.8	6	417.99	0.84	5.27	17.85	294.61	4.42
				7	449.17	11.90	2.59	1.79	379.99	5.70
				8	530.77	1.17	0.44	1.16	501.21	7.52
				9	628.83	8.86	1.86	1.81	602.93	9.04
				10	750.84	11.55	9.65	4.44	710.59	10.66
2	63.6	22	68.2	6	348.39	0.40	5.55	23.26	196.24	2.94
				7	392.12	0.57	1.67	6.15	323.09	4.85
				8	437.48	13.77	8.98	2.52	401.65	6.02
				9	503.57	12.29	17.36	9.35	475.15	7.13
				10	543.81	1.28	2.09	5.26	521.61	7.82
3	55.5	24	79.5	6	357.87	0.45	0.45	1.83	275.84	4.14
				7	434.58	14.00	7.36	1.69	388.82	5.83
				8	499.07	7.01	4.03	6.45	467.71	7.02
				9	577.34	7.29	7.31	9.76	541.30	8.12
				10	------	----	----	----	------	---
4	65.9	22	118.2	6	587.09	1.12	2.61	6.18	558.46	8.38
				7	671.17	4.10	4.61	7.49	636.88	9.55
				8	696.95	5.82	7.64	10.07	665.01	9.98
				9	753.21	5.29	14.87	19.18	711.58	10.67
				10	712.12	4.65	9.31	13.54	646.96	9.70
5	75.7	20	72.7	6	355.41	0.40	6.58	27.04	209.58	3.14
				7	344.48	0.38	1.69	7.16	275.22	4.13
				8	428.97	13.81	27.49	7.63	381.53	5.72
				9	538.54	9.60	0.23	0.23	510.35	7.66
				10	603.55	5.34	3.09	4.95	577.68	8.67
6	53.5	22	72.7	6	386.86	.43	8.88	33.46	232.26	3.48
				7	395.11	0.85	4.38	15.67	288.11	4.32

RAW DATA CONTINUED

				8	457.31	0.89	2.36	7.29	398.63	5.98
				9	534.52	14.04	50.12	8.96	488.97	7.33
				10	573.92	8.57	7.22	8.08	542.99	8.14
7	49.5	21	81.8	6	394.59	13.00	1.11	0.56	358.75	5.38
				7	483.85	8.46	7.79	10.52	449.88	6.75
				8	543.29	6.63	5.00	7.71	508.90	7.63
				9	455.84	11.45	2.07	1.61	431.20	6.47
				10	486.39	8.90	3.62	4.54	469.42	7.04
8	63.5	24	63.6	6	288.77	0.36	9.53	48.31	95.94	1.44
				7	318.07	0.25	5.23	24.24	132.88	1.99
				8	396.78	0.35	5.62	20.74	254.79	3.82
				9	471.58	0.36	4.38	13.58	379.68	5.70
				10	523.11	13.90	22.40	4.69	458.09	6.87
9	65.7	20	61.4	6	300.25	0.37	12.68	61.76	77.85	1.17
				7	298.91	0.37	4.65	22.74	140.75	2.11
				8	339.07	0.46	2.06	8.83	21.20	3.17
				9	457.69	11.71	9.63	6.93	394.53	5.92
				10	457.37	12.19	15.74	9.67	400.79	6.01
10	59.1	22	87.5	6	403.51	14.36	67.00	10.56	362.60	5.44
				7	316.91	2.68	4.76	18.5	292.61	4.39
				8	356.40	6.68	7.99	18.65	317.02	4.76
				9	500.78	2.80	11.33	27.62	453.69	6.81
				10	100.28	2.05	-----	-----	100.28	1.50
11	63.6	20	72.7	6	360.99	14.76	-----	-----	293.88	4.41
				7	418.25	12.31	2.43	1.56	390.53	5.86
				8	442.27	8.01	3.19	5.04	422.54	6.34
				9	532.59	2.67	3.00	6.94	505.34	7.58
				10	510.37	5.59	7.96	14.68	481.46	7.22
12	56.4	23	72.7	6	415.11	3.88	13.67	36.60	350.96	5.26
				7	482.08	3.77	13.27	30.92	407.63	6.11
				8	448.53	9.05	4.44	5.89	421.44	6.32
				9	494.12	6.05	22.16	40.13	422.72	6.34
				10	484.19	3.38	24.15	57.94	405.21	6.08
13	58.2	21	63.6	6	330.62	0.45	3.56	15.65	223.45	3.35
				7	372.46	13.61	10.54	3.95	334.96	5.02
				8	401.15	10.03	6.46	8.01	375.31	5.63
				9	482.76	2.84	4.14	10.43	454.79	6.82
				10	470.59	6.99	5.21	8.87	443.41	6.65
14	63.6	21	70.5	6	320.42	0.55	8.53	38.46	210.08	3.15
				7	406.93	1.40	5.05	16.89	348.75	5.23
				8	424.99	1.39	2.18	6.99	378.43	5.68
				9	520.42	5.17	2.30	4.34	495.13	7.43
				10	512.11	3.58	2.43	5.42	483.46	7.25
15	60.5	22	86.4	6	401.05	1.45	3.04	10.27	353.02	5.30
				7	480.78	3.31	1.73	4.22	450.58	6.76
				8	559.79	5.97	8.47	13.67	519.13	7.79
				9	590.92	5.14	8.36	13.95	553.21	8.30
				10	494.61	7.83	5.19	7.50	464.80	6.97

RAW DATA CONTINUED

16	47.3	22	43.2	6	251.09	0.41	12.63	7.35	61.61	0.92
				7	298.24	0.44	10.94	53.41	69.14	1.04
				8	313.03	0.41	4.30	20.06	219.38	3.29
				9	342.59	0.48	1.91	8.11	267.02	4 . 0
				10	362.12	0.53	4.23	16.91	294.33	4.41
17	61.5	22	77.3	6	360.10	14.23	4.61	0.99	264.61	3.97
				7	426.57	1.62	2.24	7.03	398.68	5.98
				8	478.44	12.46	11.40	6.05	458.70	6.88
				9	530.77	5.37	3.10	5.63	510.68	7.66
				10	579.07	6.50	7.87	11.56	544.53	8.17
18	66.6	18	90.9	6	429.58	12.47	8.65	5.09	395.23	5.90
				7	518.14	4.21	4.98	10.36	486.61	7.30
				8	546.03	3.38	8.63	18.36	507.88	7 . 6
				9	575.04	2.43	5.48	11.98	537.35	8.06
				10	539.20	3.13	3.40	7.49	498.30	7.47
19	58.5	22	59.1	6	281.06	0.42	10.60	54.97	55.66	0.83
				7	301.45	0.34	7.52	36.57	183.02	2.75
				8	410.44	1.37	3.07	10.21	343.34	5.15
				9	424.89	11.96	7.95	5.68	378.52	5.68
				10	469.34	2.20	2.22	6.05	444.52	6.67
20	54.8	21	70.5	6	307.98	0.35	6.36	30.25	158.74	2.38
				7	335.85	0.89	1.62	6.79	249.41	3.74
				8	398.99	0.34	2.62	9.61	329.11	4.94
				9	431.99	1.33	2.61	8.26	394.72	5.92
				10	449.96	5.81	4.18	8.55	428.74	6.43
21	56.8	21	95.5	6	424.45	11.38	10.38	8.86	391.02	5.87
				7	497.68	6.32	3.64	6.35	474.81	7.12
				8	616.37	5.46	6.54	10.11	583.59	8.75
				9	669.91	3.88	6.14	10.20	636.45	9.50
				10	------	----	----	-----	------	---
22	70.5	21	77.3	6	370.01	0.35	7.58	30.02	168.68	2.53
				7	433.27	0.83	4.45	14.56	323.97	4.86
				8	503.90	1.54	0.54	1.44	458.47	6.88
				9	518.35	3.74	2.03	4.41	497.62	7.46
				10	650.53	10.93	6.94	4.35	617.44	9.26
23	70.5	25	93.2	6	400.59	4.68	2.67	6.87	379.93	5.70
				7	546.08	4.00	8.34	16.79	503.60	7.55
				8	590.08	5.57	12.45	19.89	534.10	8.01
				9	646.50	4.35	10.38	17.11	592.00	8.88
				10	602.84	3.35	12.08	23.35	548.43	8.23
24	47.3	31	50.0	6	236.96	11.68	1.65	2.31	218.24	3.27
				7	277.25	7.92	3.36	8.59	248.09	3.72
				8	340.15	8.55	1.96	3.71	303.37	4.55
				9	290.27	14.24	4.62	1.20	247.73	3.72
				10	172.24	6.08	0.38	1.94	155.98	2.34

Appendix G

MEDICAL AND HEALTH QUESTIONNAIRE

QUESTIONNAIRE FOR SUBJECTS
IN THE POWER OUTPUT STUDY
by HOLLY WAGNER
MUSCLE FUNCTION LABORATORY, VA. TECH
1991

NAME________________________________Date_________________
please print

NAME____
signature

Before participating in the thesis research by Holly Wagner in determining optimal loading for the cycle ergometer test, you are to read and answer the following questionnaire. It includes questions on different health, fitness and other components to provide more information for the investigator. This is a screening process, and ALL INFORMATION PROVIDED ON THIS FORM WILL REMAIN CONFIDENTIAL AND BE USED FOR RESEARCH PURPOSES ONLY. ANSWERS ARE ON A VOLUNTEER BASIS. It is important you answer honestly, and to the best of your knowledge.

If you have ANY questions at any time, please ask them. This survey is NOT <u>IN LIEU OF</u> a physician's exam, and intended to be used by apparently healthy adults only.

(An apparently healthy adult, as stated in the American College of Sports Medicine Guidelines for Exercise Testing and Prescription, is one who is "...asymptomatic and apparently healthy with no more than one major coronary risk factor." (Risk factors include: diagnosed hypertension, cholesterol > or = to 240 mg/dl, cigarette smoking, diabetes mellitus, or family history of coronary heart disease (ACSM, 1991).) (Additional sources listed below.)

PLEASE VOLUNTEER YOUR RESPONSES FOR EACH QUESTION. THANK YOU FOR YOUR TIME AND EFFORT!

Age__________________ Date of Birth_______________________

Year in school __________________

Address
(local)____

____

Telephone number ____

(w) ____

Do you have any of the following conditions? Check if YES.

______Extra/Skipped or Rapid Heart Beats/Palpitations, or other Cardiac Findings.
______Chest Pain; especially with exertion.
______Asthma
______Pregnancy
______Epilepsy

______Diagnosed high blood pressure
______Back Pain

______Leg Cramps, during exercise
______Diabetes

______Dizziness/Fainting
______Obesity

______Arthritis/Orthopedic Problems

______Musculo-Skeletal Problems

COMMENTS/EXPLANATIONS ____

____

SURGERY
(Description/Dates) ____

OTHER MEDICAL PROBLEMS, RECENT ILLNESS, HOSPITALIZATION OR INJURY ____

List any medications or drugs (INCLUDING Birth Control Pills) you are currently using:

____

____

Date of your last complete medical exam ____________________

Do you know of any medical problems that might make it dangerous or unwise for you to participate in vigorous exercise?

_______ Yes _______ No

If yes, please explain

____

FAMILY HISTORY

Indicate the number of blood relatives who:

have had a heart attack prior to age 65 ____________
have had a stroke ____________
have had high blood pressure ____________
have had diabetes ____________
have been substantially overweight ____________

****
HEALTH INVENTORY

Height:____________ inches
Are your menstrual cycles normal? _____Yes _____No

If not, please
explain____

____

Have you had significant weight gains or losses (> 15 lbs.) in the last year?

_____Yes _____No

Do you follow a specific diet presently? If Yes, please explain:

____

____

Is the diet you are currently on your normal diet or is it different? Please explain. (Ex. current diet has a reduced amount of sodium compared to your regular diet.)

____

____

____

Do you add protein supplements to your diet? If yes, please explain.

____

____

Approximate your daily intake of the following:

Coffee (cups) __________ Tea ___________ Cola ___________

Approximate your weekly alcohol intake: _______ drinks/week

Do you smoke cigarettes? _______ Yes _______ No

If yes, how much? _______________ How long?______________

****
EXERCISE HISTORY

Please be VERY SPECIFIC IN ANSWERING THESE QUESTIONS, THE INFORMATION IS IMPORTANT TO THE SUCCESS OF THE STUDY !!!

Do you currently exercise on a regular basis ?
_____Yes _____No

Do you participate in AEROBIC EXERCISE ?
_____Yes _____No

If YES, how many days per week? ________

for how long? ________min.

Doing what activity (s) ? Please be SPECIFIC.

____

____

Do you exercise within your training heart rate zone ?

(200-age=____; ____x .70 & ____x .85)
_____Yes _____No
(The above defines THRZ; leave blank.)

Do you participate in ANAEROBIC EXERCISE ?
_____Yes _____No

If YES, how many days per week? _______

for how long? _______

Doing what activity(s)? ____________________________________

____

If you participate in weight training activities, do you follow a body building workout or other types of workouts , for example general muscular fitness and endurance, circuit training, power lifting or other

____
____
____

If you participate in weight training activities, are you training for any particular event/show?

______Yes_____No,

If yes when is the event/show(s)?____________________________

Have you ever had any **PROBLEMS** while exercising (either aerobically or anaerobically) ?

______ Yes ______No

If yes, explain.____

____

Have you ever been advised NOT to exercise on the advice of a medical professional?

______ Yes ______No

If yes, please explain____

____

If you do not exercise regularly, when was the last time you exercised and what type of exercise ?

____

____

Please list any specific questions you have below:

____

____

PLEASE STATE BELOW THE TIMES YOU ARE AVAILABLE (TO THE BEST OF YOUR KNOWLEDGE) FOR TESTING; (REMEMBER, EACH TESTING SESSION WILL TAKE APPROXIMATELY 1 HR.)

Sunday______________________________

Monday______________________________

Tuesday_____________________________

Wednesday___________________________

Thursday____________________________

Friday______________________________

Saturday____________________________

Sources:

American College of Sports Medicine Guidelines for Exercise Testing and Prescription, 1991.
Health Horizons Risk Appraisal Information Forms, 1987.

Appendix H

INFORMED CONSENT

HUMAN PERFORMANCE LABORATORY

Division of Health and Physical Education
Virginia Polytechnic Institute and State University
INFORMED CONSENT

I,________________________________, do hereby voluntarily agree and consent to participate in a research project conducted by the personnel of the Human Performance Laboratory of the Division of Health and Physical Education of Virginia Polytechnic Institute and State University.

Title of the Study:

Determining optimal load for a constant-load cycle ergometer test relative to isotonic leg strength.

Purposes of the experiment include:

The main objective of this proposed research is the determination of an optimal load for a constant-load cycle ergometer test derived from a percentage of isotonic leg strength for females. Peak power output, power fatigue rate and index, average power and time to peak power are the parameters to be measured during the power output ergometer test. (Peak power-highest power attained; power fatigue rate-how fast one fatigues; power fatigue index- total amount of fatigue as measured by decrease in power; time to peak power-time needed to attain peak power output.) College age women will be the group assessed to examine the differences training may have on the ability to determine an optimal load relative to isotonic leg strength. An independent t-test, descriptive statistics and correlation procedures will be used.

I voluntarily agree to participate in this research study. It is my understanding that my participation will include:

1. Attendance at an orientation and instruction meeting prior to testing to inform participants about the research study.
2. Performance of six power output ergometer tests involving a 15 second bout of maximal intensity cycle ergometry exercise. The test measures the maximal power of the subject while cycling; 3, tests per day for 2 days; participant will have 15 -20 minutes rest between tests.)

3. Performance of one isotonic maximum voluntary contraction test of the leg extensors using a Nautilus leg extensor machine.*
4. Abstinence from exercise 12 hours prior to each scheduled test trial.

* An isotonic measurement involves a muscle contraction where the length of the muscle does not change. A maximum voluntary contraction test involves an all out exertion lift performed by the participant. The participant is instructed on how to do the lift and to lift as much as possible without injuring herself. The participant is instructed to provide feedback concerning the feeling of the muscles during the lift, and to proceed on a volunteer basis.

I understand that participation in this experiment may produce certain discomforts and risks. These discomforts and risks include:

1. Muscle soreness and fatigue due to poor testing using a cycle ergometer.

2. Risk of injury including, but not limited to tendinitis, bursitis, strains, sprains, fractures and even the possibility of death. Attending staff is trained in CPR techniques.

I understand that certain personal benefits may also be expected from participation in this experiment. These include:

1. Knowledge of one's ability to generate power and to resist short term fatigue.

2. Knowledge of one's ability to generate isotonic strength.

I understand that there may be one or more appropriate alternative procedures that might be advantageous to me. These include:

1. Physical examination by a physician prior to exercise participation.

I understand that any data of a personal nature will be held confidential and will be used for RESEARCH PURPOSES ONLY. I also understand that these data may only be used when not identifiable with me.

I understand that I may abstain from participation in any part of the experiment or with draw from the experiment should I feel the activities might be injurious to my health. The experimenter may also terminate my participation should she feel that the activities might be injurious to my health.

I understand that it is my personal responsibility to advise the researchers of any PREEXISTING MEDICAL PROBLEMS that may affect my participation or ANY medical problems that might arise in the course of this experiment and that no medical treatment or compensation is available if the injury is suffered as a result of this research. A telephone is available which would be used to call the local hospital for emergency service.

I have read the above statements and have had the opportunity to ask questions. I understand that the researchers will, at any time, answer my inquiries concerning the procedures used in this experiment.

Date________________________________
Time____________a.m./p.m.

Participant signature_______________________________________

Witness____

Project Director__________________________
Telephone____________

HPE Human Sbjcts. Chairman: Dr. Elyzabeth Holford, Tele.: 231-7543

Dr. Ernie Stout, 301 Burruss Hall, 231-5281

To receive the results of this investigation, please indicate this choice by marking in the appropriate space provided below. A copy will then be distributed to you as soon as the results are made available by the investigator. Thank you for making this important contribution.

_________ I request a copy of the results of this study.

Appendix I

DATA RECORD SHEET

DETERMINATION OF OPTIMAL LOAD FOR A CONSTANT-LOAD CYCLE ERGOMETER TEST RELATIVE TO ISOTONIC STRENGTH

DATA SHEET

ID #______________________

COMPUTER CODE LETTERS _______________

NAME____
DATE______________

Age___________________ Ht.___________________inches

Wt.___________________kg

One Repetition Maximum of isotonic leg strength:

______________________ lbs

______________________ kg

Cycle test:

Warm - Up ___________

Seat height:______________ holes

Percent of 1 RM Actual Wt. Day 1 (kg)	Resistance Wt. (lbs.)	Resistance Wt. (kg)
____________	____________	____________
____________	____________	____________
____________	____________	____________
Day 2		
____________	____________	____________

Data Record Sheet Cont'd.

Other information:

VITA

Holly Ann Wagner was born on February 1, 1968 in Ames, Iowa to Richard and Charanne Wagner. She was accompanied into this world by her twin sister, Jill Michelle. Holly resided in Ames until her father's completion of graduate school. Afterwards the family moved to Pittsburgh, Pennsylvania, where she would reside until she was thirteen years old. At the beginning of high school, the family moved once more to Lynchburg, Virginia. She graduated from Brookville High School in 1986 with honors and then attended James Madison University, Harrisonburg, Virginia in the Fall of 1986. At James Madison University, she was a Health Science-Fitness and Health Promotion major and was involved with many extracurricular activities. In the May of 1990, Holly graduated from James Madison University with a Bachelor of Science degree. Her next goal was to attend graduate school in exercise physiology. She chose Virginia Tech and majored in Adult Fitness-Cardiac Rehabilitation. In addition, she was a graduate research assistant and teaching assistant for the two years of graduate school. Her long term career goal is to work as a corporate fitness director and work in fitness/health promotion.

DETERMININATION OF OPTIMAL LOAD FOR A CONSTANT-LOAD ERGOMETER RELATIVE TO ISOTONIC LEG STRENGTH

(ABSTRACT)

Holly A. Wagner

This study investigated the determination of an optimal resistive force for use during a short-term, high-intensity cycling power test. Twenty-four college females [age (yrs) $\bar{x}$=22.0 ±0.50; weight (kg) $\bar{x}$=60.3 ± 1.46] gave consent and participated in a 1 repetition maximum (RM) test of the leg extensors and 5 maximal 15 s cycling tests using a modified Monark cycle ergometer. The 1 RM test was performed using a Nautilus leg extensor machine. Even increments between six to ten % 1RM test were utilized to determine the resistive force applied to the flywheel. The 5 tests were divided into a 2 testing sessions occurring at least 48 h apart. Each subject warmed-up at 50 - 60 rpms for 2 - 5 minutes without resistance prior to testing. Each test consisted of a maximal cycling bout of 15 s with 20 minutes rest between tests. The variables measured included peak power (PP), time to peak power (TTPP), power fatigue rate (PFR), power fatigue index (PFI), and average power (AP). These values were collected by a microcomputer interfaced with the cycle ergometer. In general, PP decreased at a resistance greater than 9 % 1RM. The average reported PP values were 363±15, 413±19, 465±19, 520±21, and 460±41 for loads 6 to 10 % 1RM

respectively. Similar results were reported for AP. The differences in PP for loads between 8 and 10 % 1RM were statistically different. Results show that PP varies based on loads of % 1RM and the optimal range is between 8 and 10% 1RM.