AN ABSTRACT OF THE THESIS OF

Waldemar Hermina for the degree of Master of Science in Human Performance. Presented on June 8, 1999. Title: The Effects of Different Resistances on Peak Power during the Wingate Anaerobic Test.

Redacted for Privacy

Abstract approved: ______________________

Anthony Wilcox

This study evaluated the effects of four resistances on power output during a 15-s WAnT to determine which resistance was the most appropriate to elicit true peak power output. The resistances used were 7.5%, 10.5%, 12.5% and 14.5% of the subject's body weight.

Fifteen (N =15) elite male road cyclists were tested at each of the four resistances. Following ANOVA, a post hoc Scheffé revealed statistically significant (P = 0.0001) increases in peak power output (PPO) with increasing resistance for absolute power (W), power relative to body weight (Watts · kg $^{-1}$), and relative to lean body mass (Watts · LBM $^{-1}$). Mean values for absolute power were as follows: 951 W, 1244 W, 1354 W and 1450 W for 7.5%, 10.5%, 12.5% and 14.5% respectively. Mean values for power relative to body weight (Watts · kg $^{-1}$) were as follows: 12.5, 16.4, 17. 9 and 19.2 for 7.5%, 10.5%, 12.5% and 14.5% respectively. Mean values for power relative to lean body mass (Watts · LBM $^{-1}$) were as follows: 13.9, 18.2, 19.9, and 21.3 for 7.5%, 10.5%, 12.5% and 14.5% respectively. Results showed statistically significant increases in peak power output (PPO) with increasing resistance.

The findings of this study revealed that for peak power output, each resistance tested was significantly different from the other resistances. Our findings support using a resistance of 10.5% of body weight when the intent is to elicit PPO in the WAnT.

At this point it is difficult to determine at which resistance peak power will decline since the combination of high spinning (RPM) during the 5-s countdown and the application of high resistance results in greater peak power output. We understand that this issue should be investigated in greater detail since it reveals a possible limitation of the WAnT. In addition, the role of the flywheel kinetic energy, and how to address it, represents one of the major issues concerning the WAnT.

The Effects of Different Resistances on Peak Power during the Wingate Anaerobic Test.

By

Waldemar Hermina

A Thesis

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 8, 1999
Commencement: June 2000

Master of Science thesis of Waldemar Hermina presented on June 8, 1999.

APPROVED:

Redacted for Privacy

Major Professor, representing Human Performance

Redacted for Privacy

Chair of Department of Exercise and Sport Science

Redacted for Privacy

Dean of Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes the release of my thesis to any reader upon request.

Redacted for Privacy

Waldemar Hermina, Author

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF TABLES

LIST OF APPENDIX FIGURES

LIST OF APPENDIX TABLES

Tables Page

The Effects of Different Resistances on Peak Power during the Wingate Anaerobic Test.

INTRODUCTION

The development of the Wingate anaerobic test (WAnT) in 1974 at the Department of Research and Sport Medicine of the Wingate Institute for Physical Education and Sport in Israel (Inbar, Bar-Or, & Skinner, 1996) stimulated great interest in studying anaerobic capacity and power output. According to Bar-Or (1983), prior to 1974, most of the power tests available were focused on maximal aerobic power, not addressing fitness-related components, such as anaerobic muscle power and local muscle endurance, which are important for different populations and activities.

Anaerobic capacity tests involve very high-intensity exercise lasting between a fraction of a second to one minute (Skinner and Morgan, 1985). The 30-second WAnT has been one of the most accepted and extensively used protocols to assess anaerobic power output (Inbar, Bar-Or, & Skinner, 1996). In the standardized WAnT protocol, the subjects pedal as fast as they can for 30-seconds against a resistance equal to 7.5% of their body weight. The WAnT is a safe, noninvasive procedure that can be performed by individuals regardless of gender, fitness level and age (Bouchard, Taylor, Simoneau and Dulac, 1991).

The protocol of the WAnT has undergone modifications and refinements since its development in 1974 (Inbar, Bar-Or, & Skinner, 1996). The use of a higher force to maximize power output has represented a major change in the WAnT protocol and is highly recommended (Inbar, Bar-Or, & Skinner, 1996).

Evans and Quinney (1981) investigated the resistance setting for 30-second tests of maximal anaerobic power output on a modified bicycle ergometer. They used a test-retest design in which they tested twelve highly trained individuals at various resistances ranging from 4 to 10 kiloponds (Kp) to determine which resistance was the most appropriate to elicit maximal power output in a 30-second ergometer test. They recommended that an optimal combination of resistance and pedaling speed was necessary to elicit true peak power output in trained individuals. They also reported that the power output obtained with their modified bicycle ergometer protocol exceeded those values obtained with the weight-relative Wingate protocol. Similarly, Murphy and Frederick (1985) used the WAnT to determine which resistance loads would elicit maximal values of peak power output in nineteen male subjects. They conducted multiple Wingate tests in a random order at resistances ranging from 3.23 to 6.76 joules/rpm/kg of body weight, which are equal to 0.055 $Kp \cdot kg^{-1}$ or 5.5% of the subject's body weight and 0.11 $Kp \cdot kg^{-1}$ or 11% of the subject's body weight, respectively. In contrast to Evans and Quinney, their modification to the bicycle ergometer was similar to the actual self-calibrating Monark 824-weight cycle ergometer, which makes possible the instantaneous application of a resistance. Resistances higher than the standardized 4.41 joules/pedalrev/kg of body weight, which is equivalent to 0.075 $Kp \cdot kg^{-1}$ or 7.5% of the subject's body weight, resulted in greater peak and mean power. They concluded that resistances should be used according to the subject's body weight but that consideration should be given to higher resistances when determining peak power output in male subjects.

Recently, Sidner (1998) evaluated peak power output and mechanical work with different resistances during a 20-second power test in trained female power athletes. The resistances tested were 7.5%, 8.5%, 10.5%, 12.5% of the subjects' body weight. The mean peak power value with the 7.5% resistance was 752.2 W, with the resistance of 8.5%, 809.9 W, with 10.5%, 917.6 W and with 12.5%, it was 971.5 W. The peak power output at the 10.5% and 12.5% resistances were significantly greater than peak power at the at 7.5% resistance but not statistically different from each other. He concluded that at least 10.5% of the subject's body weight should be used, instead of 7.5%, in order to elicit true peak power output in trained female power athletes.

Study Rationale

Most of the power studies conducted with cyclists have used the 7.5% loading factor. Resistances greater than 7.5% of body weight with test durations of less than 30 seconds have not been widely tested. Inbar, Bar-Or, & Skinner, (1996) have shown that peak power is achieved during the first 5 to 10 seconds in a standard WAnT. Therefore, it seems that when the main interest of a study is to determine peak power, the duration of the test can be much shorter than 30 seconds. However, when doing so, one loses the ability to assess mean power, which is calculated over the standard 30-second protocol of the WAnT.

It has been shown that higher resistances can elicit greater peak power output in female power athletes when the time of the protocol is reduced (Sidner, 1998). Also, Patton, Murphy and Frederick (1985) concluded that resistances should be used according to the subject's body weight, but that consideration should be given to higher resistances when determining peak power output in male subjects.

This study evaluated the effects of four resistances on peak power output in elite male road cyclists during a 15-s WAnT to determine which resistance is the most appropriate to elicit true peak power output in elite male road cyclists during a 15-second WAnT. Since the focus of this study was on peak power, which occurs during the first 5 to 10-seconds of a WAnT, the test duration was reduced to 15 seconds, and mean power and the fatigue index were not assessed.

Research Hypotheses

A review of the literature lead to the following hypotheses:

1. A resistance of 10.5% of the subjects' body weight will be the most appropriate to elicit true peak power output in elite male road cyclists.

2. Resistances greater than 12.5% of the subjects' body weight will compromise the subjects' ability to turn the chainring, which will negatively affect peak power output.

Statistical Hypotheses

The following statistical hypothesis was designed to determine if significant differences exist among the peak power output values exerted with the four different resistances. One index of performance was evaluated during the WAnT.

1. A) Ho: $\mu_1 - \mu_2 - \mu_3 - \mu_4 - \mu_5 = 0$ B) Ho: $\mu_1 - \mu_2 - \mu_3 - \mu_4 - \mu_5 \neq 0$
Where μ_1, μ_2, μ_3, and μ_4 are means for peak power output.

Study Limitation and Delimitations

This study was delimited to volunteer elite male cyclists aged 20 to 35 years with no documented disease or illness. The small number of subjects, fifteen subjects in total, limits generalizability of the results to a wider population. The subjects of the study were not randomly selected, which may limit the generalizability of the results to other populations. Also, female cyclists were not included in the study, which also limits the generalizability of the results. In addition, the following was assumed:

1. Participants provided a maximal effort during each of the tests.
2. Participants understood the instructions provided.
3. Participants refrained from strenuous exercise or strenuous physical activity during the 24 hours prior to the test.
4. A 10-minute warm-up was sufficient time for an elite cyclist to prepare for the physical stress imposed during each peak power test.

5. A 15-second WAnT was sufficient time to elicit peak power output.

Definition of Terms

The following terminology was used throughout the study:

1. Repeated Measures ANOVA

A statistical technique used to compare the means of different treatments when the same individuals have been tested on successive occasions, such as a series of test trials.

2. Standard Wingate Anaerobic Test (WAnT)

A 30-s test protocol used widely to evaluate anaerobic performance. It is usually conducted on a Monark cycle ergometer. During the test, subjects are instructed to pedal for five seconds against a very low resistance to overcome the inertia of the flywheel. The subject then pedals at maximal velocity, at which time a load is applied to start the 30-s test. The load applied is a resistance of 7.5% of the subject's body weight. The subject maintains as high a pedaling velocity as possible for the duration of the 30-s test.

3. Power

Power is the term used to define the intensity of exercise performed on a bicycle ergometer. Watts are the accepted unit of measurement for power. Power = Work $\cdot$ Time $^{-1}$.

4. Peak Power Output

Peak power output is the highest mechanical work per unit of time achieved during the power test. It is calculated by averaging the power achieved during the first 5-seconds of the test. Power can be expressed in absolute values (Watts), and relative values ($W \cdot kg^{-1}$).

5. Mean Power Output

Mean power output is the average power sustained throughout the 30-s power test.

6. Fatigue Index

Fatigue index is the degree of power drop-off during the power test. It can be calculated as the slope of the straight line connecting the peak power and the lowest power and divided by the time the peak power of the test is achieved until the lowest power is achieved.

7. Elite Road Cyclists

For the purposes of the study, trained cyclists are those individuals that train at least 5 days a week and that have been active in the sport for at least 2 years, and race at a regional or national level.

LITERATURE REVIEW

The following section is an in depth review of the literature. The aim of this section is to review relevant literature regarding the history of anaerobic power tests, development of the Wingate Anaerobic Test (WAnT), contemporary power research, power research conducted with cyclists, and finally a summary.

History of Anaerobic Power Tests

Many anaerobic power tests have been developed in the last 30 years. Some of these tests have brief 1 to 20-second protocols, such as the Margaria step test, and the vertical jump, whereas others can be as long as a minute, such as the cycle ergometer protocols for arms and legs, and the treadmill run to exhaustion.

According to Bar-Or (1983), prior to 1974, most of the power tests available were focused on maximal aerobic power. Before 1970 few laboratories were available to conduct anaerobic power tests (Inbar, Bar-Or, and Skinner, 1996). However, there is evidence to support that anaerobic power or capacity has been a matter of interest to professionals in different fields since the early 1900s. For example, the oldest anaerobic power test published in the scientific literature is the vertical jump test developed by Sargent (1921). This test was developed to measure the vertical height attained in a jump, as well as mechanical power. During the vertical jump test, a subject's height and arm length is measured and subtracted from the height jumped. The vertical jump test is an inexpensive test and can be conducted in a laboratory and in real-world settings. It is often used for power athletes who incorporate jumping in their sport, such as basketball players, volleyball players, etc.

Through the years, newer techniques and devices to measure the power attained in a jump or in sequence jumping have been developed and improved. Devices such as platforms, helmets, moving rulers, sonar system, video cameras, ultra sensitive stopwatches, and techniques such as jumping continuously for 15 s to 60 s have been used during the Vertical Jump Test (Vandewalle, Peres and Monod, 1987).

Following the vertical jump test, the development of laboratory measurements of oxygen consumption, blood lactate, and measurements of oxygen deficit during intense exercise (Hill, Long and Lupton 1924; Margaria, Edwards and Dill 1933) contributed to the development of the Margaria Step-Running Test in 1966 (Margaria, Anghemo, and Rovelli, 1966). The Margaria test is one of the best-known tests of peak muscle power, which allows for the calculation of maximal power at any time between the 2^{nd} and the 4^{th} second of the run, when a constant speed is reached (Margaria, Aghemo, and Rovelli, 1966). The Margaria test made possible the calculation of anaerobic power over less than 1 s by taking the time from the fourth to the sixth step, usually 70-cm height in 0.40 to 0.50 seconds.

The reason for the development of the Margaria Step-Running Test was that measurements of blood lactate, oxygen consumption and oxygen deficit, among others, were not specific enough to reflect performance during a short-term, high-intensity exercise (Inbar, Bar-Or, and Skinner, 1996). This test involves running upstairs while contracting large muscle groups at maximal velocities. It is a very brief anaerobic test, taking approximately 2 to 4 seconds, and was used extensively to study muscle power energetics during supramaximal, short-term exercise (Inbar, Bar-Or, & Skinner, 1996).

The Margaria stair running test was modified in 1968 (Kalamen, 1968). In Kalamen's version, vertical velocity is calculated while jumping over three stairs at a time instead of the original two stairs that Margaria recommended. Since then, the Margaria-Kalamen has been widely used to measure anaerobic power (Fox, Bowers and Foss, 1988).

Cycling protocols are among the most popular protocols to measure anaerobic capacity. Most of these cycling protocols last 30 to 60 seconds, and in these, different modifications were made to aerobic power test protocols for cycle ergometry. For example, Borg, Edstrom, and Marklund, (1971) developed a protocol of a repeated 45-second task in which resistance was constantly increased at a pre-established rate. Borg's protocol was developed in an attempt to evaluate perceptual and motivational aspects of high-intensity exercise. In Borg's protocol, the resistance was increased throughout the 45-second test in order to elicit peak power. Similarly, Chaloupecky (1972) developed a cycling test were the subjects pedaled at 85 RPM and with a constant (4Kp) resistance for a period of 30 to 60 seconds. Subsequently, and just before the WAnT test was developed in Israel, Katch (1973) used a 1-minute supramaximal cycling task to analyze the kinetics of maximal oxygen consumption during high intensity exercise. Eventually Katch (1973) suggested that a 40-s cycling test should be used to analyze anaerobic power and anaerobic work instead of the 1-minute protocol test.

It is important to note that in Borg's, Chaloupecky's, and Katch's studies, 30 to 60-second protocols were used to analyze maximal anaerobic power. If the high phospate energy pathway, which is activated for less than 30 seconds, facilitates the energy for an all-out effort in which maximal anaerobic power is accomplished, then a shorter 10 to 20-second protocol will be more appropriate to elicit and evaluate maximal anaerobic power. Also, as suggested by Inbar, Bar-Or, and Skinner (1996), subjects reach their highest power output (maximal anaerobic power) during the first seconds of the test, which makes a test protocol shorter than 30-seconds more reliable to determine maximal anaerobic power.

Treadmill tests to determine anaerobic power have also been used (Numela, Alberts, Rijntjes, Luhtanen, and Rusko, 1996). Among them, the Maximal Anaerobic Running Test (MART) has been one of the most used protocols to determine mechanical power during running since its development in 1993 (Nummela, Alberts, Rijntjes, Luhtanen, and Rusko, 1996). Rusko and colleagues developed the MART, originally MARP or maximal anaerobic running power, to provide a new laboratory test to determine metabolic and neuromuscular components of maximal anaerobic running performance. In the MART the high-velocity treadmill run to exhaustion is used as an index of anaerobic performance (Cunningham and Faulker, 1969). Rusko's MARP protocol consisted of various 20 s runs on a treadmill starting at a speed of 3.97

$m \cdot s^{-1}$ ($14.3\ km \cdot h^{-1}$) with a 5° gradient. Consequently, the speed was increased by $1.26\ km \cdot h^{-1}$ while the gradient remained constant. In conclusion, Rusko and colleagues provided a new laboratory test that correlated well with the speed of a 400-m run and provided information regarding the force-velocity characteristics of the leg muscles associated with a 20-m sprinting speed.

In the scientific literature available, it is hard to find evidence regarding which test prior to the development of the WAnT was the most successful in measuring muscle power. However, an important fact that these anaerobic power tests share in common is that they all served the same purpose, which is to evaluate muscle power, and even more, they together contributed to the development of the most accepted and widely used anaerobic test, known as the WAnT.

Development of the Wingate Anaerobic Test (WAnT)

Anaerobic capacity tests involve very high-intensity exercise lasting between a fraction of a second to one minute (Skinner and Morgan, 1985). The development of different very high-intensity exercise tests, laboratory measurements of oxygen consumption, blood lactate and muscle biopsies, and finally the contribution of classic studies regarding muscle energy metabolism contributed to the development of the Wingate Anaerobic Test (WAnT). The Wingate anaerobic test (WAnT) was developed in 1974 at the Department of Research and Sport Medicine of the Wingate Institute for Physical Education and

Sport in Israel (Inbar, Bar-Or, & Skinner, 1996). WAnT has been one of the most accepted and extensively used protocols to assess anaerobic power output.

The aim of this test is to provide information on peak power output, muscle endurance, and muscle fatigability. The WAnT is a safe, noninvasive procedure that can be performed by individuals regardless of gender, fitness level, age (Bouchard, Taylor, Simoneau and Dulac, 1991). The WAnT has also been tested for reliability and validity. Correlation coefficients for tests performed under standardized environmental conditions have ranged between 0.89 and 0.99 (Inbar, Bar-Or, & Skinner, 1996). Studies that have evaluated test-retest reliability during the WAnT have been conducted with various age, ethnic, and fitness level groups. Bar-Or, Dotan, and Inbar (1977) conducted a test-retest reliability study with children and young adults. They reported a test-retest reliability coefficient of 0.95 and 0.97 for children and young adults, respectively. Similarly, Hebestreit, Mimura, and Bar-Or (1993) studied boys between the ages of 8 to 12 years old, and men between the ages of 18 to 23 years old. Test-retest reliability coefficients in their study ranged between 0.93 and 0.99. They also suggested that at least 20 minutes of rest should be used to obtain reliable results between multiple tests. Modified protocols have also been tested for reliability with individuals with chronic obstructive disease, neuromuscular disease, cerebral palsy and spastic cerebral palsy. Test-retest reliability coefficients in these studies have ranged from 0.89 and 0.96 (Tirosh, Rosenbaum, and Bar-Or, 1990).

When planning studies to validate the WAnT, researchers confronted the problem that none of the anaerobic tests available could be considered a gold standard (Inbar, Bar-Or, & Skinner, 1996). Therefore, validation studies for the WAnT have been conducted with several indices of anaerobic performance, such as the 40 meter run, 500 meter speed skate, 50 meter run, 50 yard run time, 25 meter swim time, and vertical jump, among others (Inbar, Bar-Or, & Skinner, 1996). For example, Thompson, Foster, Rogowski, and Kaplan (1986) conducted a study with 87-male skaters from the US national team. They correlated a standardized leg WAnT with a 500-meter speed skate. Their findings showed a moderate correlation of 0.66.

One argument against the WAnT is regarding the power output that can be associated to the contribution of the flywheel. Bassett (1989) corrected the WAnT for changes in kinetic energy of the ergometer flywheel. The rotating flywheel of a cycle ergometer possesses kinetic energy because of its rotation about the center of mass. This energy, according to Bassett, decreases during the course of a WAnT. The kinetic energy of the flywheel was calculated by loading the ergometer with 1 Kp (9.8 Newtons) and calculating the pedaling rate at the beginning and end of every 5-s interval throughout the test. The flywheel power (W) = 0.00185 ($FVstart^2$ - $FVend^2$)/5s, where FV is expressed in RPM.

Bassett concluded that the subject should not be credited with all the peak power output since it was proven that there is a contribution from the flywheel. Thus, subject power output = (total power – flywheel power), which overall reduces peak power by 6.2%, mean power by 3% and fatigue index by 6.6%.

Kinetic energy is positively affected by the subjects' spinning ability. Basset (1989) corrected the WAnT for the flywheel kinetic energy, but the formula he developed is sensitive to subject variation and makes difficult the quantification of peak power.

Coleman and Hale (1998) studied different methods of calculating kinetic parameters of friction-braked cycle ergometers, and the subsequent effects on calculating power outputs in the Wingate Anaerobic Test. They conducted a standardized WAnT in 10-male subjects and compared the uncorrected results to the corrected values. They used also several methods to correct the WAnT results. Their findings showed significant differences between correction methods and between uncorrected and corrected power outputs. They suggested that WAnT results must be corrected to obtain true peak power outputs.

Kinetic energy is positively affected by the subjects' spinning ability. Thus, it seems that this formula is sensitive to subject variation because the higher the subject's spinning ability the greater the flywheel kinetic energy that is developed before the beginning of the test. Therefore, the percentages provided to correct that will differ from subject to subject, and would have to be calculated in each test, which will make the quantification of peak power difficult.

The standard protocol of the WAnT consists of a 10-minute warm-up followed by a 5-s countdown during which the subjects pedal against zero resistance to reach the highest RPM possible. By the end of the 5-s countdown, a resistance of 7.5% of the subject's body weight is applied to the ergometer. The subjects attempt to maintain the highest RPM they are able to generate against the resistance for a period of 30-s. When the 30-s power test is finished, the subjects cool down for period of 2 to 3 minutes, or for as long as they feel necessary.

Many indices of performance can be analyzed during the WAnT. Among them, Peak Power Output, Mean Power, and Fatigue Index (power drop off) are three indices of performance that relate to the subject's ability to produce muscle power. Peak power output is the highest mechanical work per unit of time achieved during the power test. It is usually achieved at the beginning of the test. Power can be expressed in absolute values (Watts), and relative values ($W \cdot kg^{-1}$). Mean power output is the average power sustained throughout the 30-s power test. Mean power is expressed in Watts. Fatigue index is the degree of power drop-off during the power test. It can be calculated as the slope of the straight line connecting the peak power and the lowest power and divided by the time the peak power of the test is achieved until the lowest power is achieved. It is usually expressed as a percentage.

The WAnT is a reliable test to evaluate the power capabilities of the primary muscle groups involved in cycling. It is easy to perform, and although it measures performance of several muscle groups combined, it is one of the most accepted tests to determine peak power, mean power and power drop off over a period of 30-seconds.

Contemporary Power Research

The protocol of the WAnT has undergone modifications and refinements since its development in 1974 (Inbar, Bar-Or, & Skinner, 1996). The use of a higher force to maximize power output has represented a major change in the WAnT protocol and is highly recommended (Inbar, Bar-Or, & Skinner, 1996). Evans and Quinney (1981) investigated the resistance setting for 30-second tests of maximal anaerobic power output on a modified weight bicycle ergometer. The modifications consisted of a racing handlebar, a reinforced and lengthened seat stem, and toe clips. The reason for the modifications was to provide a more comfortable ergometer and to simulate the position of a normal racing bicycle. They used a test-retest design in which they tested twelve highly trained individuals with resistances ranging from 4 to 10 kiloponds (Kp) to determine which resistance was the most appropriate to elicit maximal power output in a 30-second ergometer test. They recommended that an optimal combination of resistance and pedaling speed was necessary to elicit true peak power output in trained individuals. They also reported that the peak power output values (661.6 W) obtained with their modified bicycle ergometer exceeded those values obtained with the weight-relative resistance used in the standard 30-second WAnT protocol.

Dotan and Bar Or. (1983) conducted a study to determine the optimal loads for eliciting maximal power during a 30-second leg and arm WAnT. Seventeen male and eighteen females were administered two WAnT in five different testing sessions, with resistances ranging from 2.43 to 5.39

joules/rpm/kg of body weight, which are equivalent to 0.04 $Kp \cdot kg^{-1}$ or 4% of the subject's body weight and 0.09 $Kp \cdot kg^{-1}$ or 9% of the subject's body weight, respectively. They concluded that the optimal load resistance when conducting the WAnT in healthy male and female subjects was between 5.04 and 5.13 joules/rpm/kg of body weight, which are equal to 0.085 and 0.087 $Kp \cdot kg^{-1}$, or 8.5% and 8.7% of the subject's body weight. They concluded that even though the WAnT is sensitive to load variation, the optimal load provided by the guidelines should be used to obtain improved results. He also suggested that modified loads may be used according to the individual body build, composition, and especially anaerobic fitness level.

Similarly, two years later Patton, Murphy and Frederick (1985) used the Wingate test to determine which resistance loads would elicit maximal values of peak power output in nineteen male subjects. They conducted multiple Wingate tests in random order at resistances ranging from 3.23 to 6.76 joules/pedalrev/kg of body weight, which are equal to 0.055 $Kp \cdot kg^{-1}$ or 5.5% of the subject's body weight and 0.11 $Kp \cdot kg^{-1}$ or 11% of the subject's body weight, respectively. In contrast to Evans and Quinney, their modification to the bicycle ergometer was similar to the actual self-calibrating Monark 824-weight cycle ergometer, which makes possible the instantaneous application of a resistance. Resistances higher than the standardized 4.41 joules/pedalrev/kg of body weight, which is equivalent to 0.075 $Kp \cdot kg^{-1}$ or 7.5% of the subject's body weight, resulted in greater peak and mean power. A resistance of 5.59 joules/pedalrev/kg of body weight (0.095 Kp · kg $^{-1}$ or 9.5% of the subject's body weight) was suggested to be the most appropriate resistance to elicit peak power output. They concluded that resistances should be used according to the subject's body weight but that consideration should be given to higher resistances when determining peak power output in trained male subjects.

It seems that in both Dotan and Bar Or (1983) and Patton and colleagues (1985) studies, peak power output could have been maximized with the use of greater resistances than the ones they tested. However, their studies were among the first studies devoted to getting a better understanding of how higher resistances affected power output.

Vandewalle and colleagues (1987) tested 152 power-trained male and female athletes using an optimized force-velocity resistance in a Monark 864-cycle ergometer with weights. After a warm-up, the subjects performed a series of 7 to 8 6-second sprints on the Monark cycle ergometer. The resistances used were 2 Kp and 1 Kp for men and women, respectively. The resistance was increased by 2 and 1 Kp for men and women respectively, in each additional test until the subjects were unable to reach a peak velocity higher than 100 rev · min. The resistances were set before beginning the test. They reported peak power values to be as high as 1226 W (17 W/kg). They concluded that resistances as high as 13% of body weight should be given consideration when evaluating maximal power output in men power athletes. A resistance of 12% of body weight should be considered when evaluating maximal power output in women power athletes, and a resistance as high as 10.5% for men and female endurance athletes. They also concluded that if one wants to measure maximal power with a simplified WAnT or 2 to 3 braking forces, peak velocity must be about 125 rev · min for sprinters and 105 for endurance athletes. It is apparent that they are the only researchers that have suggested the use of 13% of body weight as an optimal resistance when evaluating maximal power output in men power athletes.

Recently, Sidner (1998) evaluated peak power output and mechanical work with different resistances during a 20-second power test in 17-female power athletes. The resistances tested were 7.5%, 8.5%, 10.5%, 12.5% of the subjects' body weight. The mean peak power value with the 7.5% resistance was 752.2 W, with the resistance of 8.5%, it was 809.9 W, with 10.5%, 917.6 W and with 12.5%, it was 971.5 W. He concluded that at least 10.5% of the subject's body weight should be used instead of 7.5% in order to elicit true peak power output in trained female power athletes. The differences in peak power output obtained from the 10.5% and 12.5% resistances were not statistically significant. One of the weaknesses of Sidner study is that men were not included in the test, which limited the generalizability of the results. Also, the four resistances were tested on the same day, thus subject fatigue may have affected the test results.

Few studies have focused on establishing the appropriate resistance values to develop maximal peak power output. To restate the above mentioned studies, it seems that the resistances that were thought to be optimal are, for the most part, insufficient to elicit true peak power output in elite athletes.

Power Research Conducted with Cyclists

The sport of cycling has remarkably improved in the last decades, especially in the United States. Tanaka, Bassett, Swensen, and Sampedro, (1993) studied the aerobic and anaerobic capabilities of 38-competitive road cyclists from the U.S. Cycling Federation. VO_2 max and WAnT results showed higher VO_2 max, higher peak and mean power for male cyclists than for female cyclists. They also demonstrated that category II cyclists, or the most experienced cyclists among the groups, were characterized by higher aerobic and anaerobic power outputs than the category III and IV cyclists.

Hawley and Noakes (1992) also used trained cyclists to determine the relationship between peak power output and maximal oxygen uptake, and to assess the relationship between peak power output and the time in which a 20-km cycling trial is completed. They conducted a standardized WAnT to evaluate peak power output in 100-trained cyclists. A VO_2 max test was also performed to established a correlation between peak power output and 20-km cycling time. Highly significant relationships were obtained between peak power output and the VO_2 max ($r = 0.97$, $P < 0.001$) and between peak power output and the 20-km cycling time ($r = -0.91$, $P < 0.001$). They concluded that peak power output was a valid predictor of a 20-km time and that VO_2 max can be accurately predicted from peak power output.

Modified power protocols to elicit peak power output in cyclists have been used in few studies. For example, Craig and colleagues (1989) conducted a study to analyze the specificity of test duration when assessing the anaerobic lactacid capacity of track cyclists. They conducted 10-, 30-, 40- and 60-second power tests on a modified Repco wind-braked cycle ergometer. The resistances used on each power test were not specified. The cyclists also performed a 1000-m time trial and a power test with each of the specified test duration. Peak power output, blood lactate and percent power loss were determined for each test. Results showed non-significant differences in peak power between the four tests. Peak power during the 10-s test was 988 W, during the 30-s test was 989 W, and during the 40 and 60 s tests 992 W. Also, the longer the duration of the test the greater the power loss or fatigue index. Results showed that during the 30-s test fatigue index was 0.25, and during the 40 and 60 s tests 0.46 and 0.54 respectively. Peak power and total work achieved during the 60-second test correlated significantly ($r = 0.88 - 0.99$, $P<0.05$) with the 1000-m time trial. After comparing the correlation results, they suggested that when assessing anaerobic power and capacity of elite 1000-m time trial cyclists, a cycle ergometer of at least 60-s should be used. It seems that the reason for their suggestion is that a 1000-m cycling time trial usually lasts from 1 minute to 1:10 minutes. Therefore, the 60-second power test should be representative of the power outputs exerted during the 1000-m time trial.

It is interesting to note that peak power output was higher during the longer tests but not significantly different than the peak power output obtained in the shorter tests. In addition, as stated by Craig and colleagues in the experimental procedure, the subjects were instructed to reach their peak power at the beginning of the test and maintain it for the remaining time to evaluate their anaerobic lactacid capacity. Therefore, it seems that in all the tests, peak power was achieved during the beginning of the test and a training effect may have been the reason why higher values were achieved during the 40 and 60 s tests.

In conclusion, very little research has focused on the optimal duration of the WAnT when assessing peak power output in trained or elite cyclists. On the occasions in which the duration of the test has been modified, short duration, 10 to 20-second tests have not been widely reported. In addition, very little research has investigated the effects of high resistances during the WAnT in trained cyclists, which raises the question of which is the most appropriate resistance to elicit true peak power output in trained cyclists. It has been shown that higher resistances can elicit greater peak power output when the time of the protocol is reduced. However, it seems that more research is needed to systematically evaluate the effects of resistances higher than the established 7.5% of body weight, on power output among athletes of different disciplines and levels.

Summary

Anaerobic capacity tests involve very high-intensity exercise lasting between a fraction of a second to one minute, and they can vary from a simple vertical jump or a step test to a more elaborated WAnT or MART (Skinner and Morgan, 1985). The WAnT, created in 1974, has proven to be the most often used test to measure muscle power, mechanical work, muscle endurance, and muscle fatigability (Bouchard, Taylor, Simoneau and Dulac, 1991). According to Skinner and Morgan (1985), there is insufficient information to tell whether any given test is superior to others. However, it is accepted that the WAnT is the most used and tested.

One disadvantage of the WAnT, as well as a disadvantage of many other anaerobic power test instruments, is that it measures performance of several muscle groups combined and therefore cannot yield information about any specific muscle or muscle group (Inbar, Bar-Or, & Skinner, 1996). It seems that newer techniques and protocols are needed to evaluate the anaerobic power exerted by specific muscle groups during different athletic activities. In addition, it seems that more research is needed to evaluate how higher resistances and modified protocols affect peak power output among athletes of different disciplines and levels. Lastly, more research is needed to determine which resistance should be used as a standard optimal resistance, and to determine at which resistance peak power starts to drop off.

METHODS

The purpose of this study was to determine which resistance is the most appropriate to elicit true peak power output in elite male road cyclists during the Wingate Anaerobic Test (WAnT). The following section includes a description of the subjects, the study procedures and apparatus, a description of the test protocols, the experimental design, and the statistical analysis.

Subjects

The participants in the study were 15 elite, male road cyclists aged 20 to 35 years. Elite road cyclists are those individuals who train at least 5 days a week, have been active in the sport for at least 2 years, and race at a regional or national level. Cyclists from the Corvallis community and surrounding area were contacted and invited to participate. The purpose of the study and the experimental protocol and procedures were explained to the participants before testing. Each subject read and signed the informed consent form before participation in the study (See Appendix B). A copy of the WAnT instructions was provided prior to the test (See Appendix C). The study was approved by the Oregon State University Institutional Review Board (IRB) for the Protection of Human Subjects.

Procedures and Apparatus

The cycling peak power tests were conducted on a self calibrating Monark 824e weight ergometer, which feeds velocity data into an on-line Dell 325SX computer that uses POWER 3.02 Software from Sports Medicine Industries, Inc. (1995). Peak power output was evaluated using four different resistances during a 15-s WAnT. A calibrated Toledo Scale was used to measure body weight, which was be the basis for determining the appropriate resistance that was applied during the test. Height was measured with a calibrated height measurement scale. Body fat assessment was achieved using a skinfold caliper. The sum of three sites (chest, abdomen, and thigh) were used to determine body density with the Pollock and Jackson Formula (Pollock and Jackson, 1984). The Siri formula was used to predict body fat from body density (Siri, 1961).

This study consisted of two testing sessions over the course of one week. The subjects reported to the OSU Human Performance Laboratory for height and weight measurements and for two cycling power tests on the first testing session. On the next testing session, each subject performed two additional power tests. The tests were randomized in a counter-balance order. Each power test was separated by a 20-minute recovery interval. The length of each testing session was from 40 to 45 minutes, and the testing sessions were separated by at least 48 hours. The subjects were given a 10-minute warm-up before each power test. Subjects were asked to avoid strenuous physical activity 24 hrs prior to any testing session.

Power Test Protocol

This study used a 15-s WAnT protocol and four different resistance factors (7.5%, 10.5%, 12.5%, and 14.5% of the subjects' body weight). During the test, subjects were instructed to pedal for five seconds against a very low resistance to overcome the inertia of the flywheel. By the end of the 5-s countdown when maximum pedaling velocity is reached, one of the resistance factors was applied to the cycle ergometer to start the 15-s test. The subjects maintained as high a pedaling velocity as possible for the duration of the 15-s test. A minimum 10-minute warm-up was provided before each power test. The test began whenever the subjects felt ready to perform the trial. The subject received verbal encouragement throughout the duration of the test. After each test was completed, the subject was able to cool down for as long as necessary.

Experimental Design and Data Analysis

The study consisted of a single blind design, in which the subjects were not told of the resistance used on each power test. The experimental design of the study was a 4 x 1 design (4 treatments x 1 trial).

The statistical analysis included means, standard deviations, and analysis of variance (ANOVA) for repeated measures. Post hoc Scheffé analysis was used to determine where specific mean differences were found. This study determined if significant differences exist between the peak power output achieved with each of the four resistances during the WAnT.

The Power software used provided peak power results at the end of testing. (POWER 3.02 Software from Sports Medicine Industries, Inc. (1995).) Peak power output was calculated by averaging the power achieved during the first 5-seconds of the test. Power was expressed in absolute values (Watts), relative values (Watts · kg $^{-1}$) and relative to lean body mass (Watts · LBM $^{-1}$). The statistical comparison among the four different resistances was made using ANOVA for repeated measures. An alpha level of 0.05 was selected to determine statistical significance. In order to obtain a power of 0.80, this study looked for an effect size of 0.6 and included 15-subjects in total. The distribution of the data was inspected for outliers and normality. The data was analyzed with Statistics with Finesse (Bolding, 1989) and JMP Start Statistics 3.2.1 Software packages (Sall and Lehman, 1996).

RESULTS

The purpose of this study was to determine which resistance is the most appropriate to elicit true peak power output in elite male road cyclists during the Wingate Anaerobic Test (WAnT). This section includes a description of the subjects' characteristics and peak power output results.

Subjects

Fifteen elite male road cyclists (N = 15) from the Corvallis Community participated in the study. The overall group data were (Mean ± Standard Deviation): weight = 75.8 ± 6.8 kg, height = 180 ± 4.5 cm, age = 25 ± 4.8 yr., per cent body fat = 10.4 ± 3.1, and lean mass = 67.8 ± 5.6 kg.

Peak Power Results

The results for peak power output are expressed in absolute watts (W), watts per kilogram of body weight (Watts · kg^{-1}), and watts relative to lean body mass (Watts · LBM^{-1}) and are presented in Table 1 below. Resistances equivalent to 7.5%, 10.5%, 12.5% or 14.5% of the subjects' body weight were tested during a 15 second WAnT. Results showed statistically significant increases in peak power output (PPO) with increasing resistance.

Peak Power Outputs

Resistance	Watts	Watts·kg $^{-1}$	Watts·lbm $^{-1}$
7.5% BW			
Mean	951.73	12.5	14.0
Highest	1120.0	14.0	15.4
Lowest	746.0	10.2	11.0
St. Dev.	115.19	0.96	1.23
10.5% BW			
Mean	1244.0	16.4	18.3
Highest	1453.0	19.2	20.6
Lowest	1085.0	14.4	16.2
St. Dev.	118.15	1.23	1.19
12.5% BW			
Mean	1354.0	17.9	20.0
Highest	1543.0	20.6	23.5
Lowest	1146.0	14.8	15.5
St. Dev.	130.47	1.94	2.08
14.5% BW			
Mean	1450.73	19.2	21.3
Highest	1665.0	22.3	23.9
Lowest	1079.0	14.8	16.0
St. Dev.	167.14	1.85	1.93

Table1. Means, standard deviations, maximum and minimum values for Peak Power Output at resistances of 7.5%, 10.5%, 12.5% or 14.5% of the subjects' body weight.

The repeated measures ANOVA demonstrated significant differences among the four resistances tested. The p values for absolute watts were [$F_{(3, 42)} = 125.87$ $p<0.0001$], watts relative to body weight [$F_{(3, 42)} = 118.90$ $p<0.0001$], $p<0.0001$ and watts relative to lean body mass [$F_{(3, 42)} = 125.77$ $p<0.0001$], $p<0.0001$. Complete ANOVA tables are shown in Table 2, 2a and 2b.

ANOVA Tables for Peak Power Output measures

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	776779. 44	14	55485. 67	1. 07	0. 4091
Within Subj.	2335619. 50	45	51902. 66		
Treatments	2101840. 20	3	700613. 38	125. 87	0. 0001
Error	233779. 36	42	5566. 18		
Total	3112419. 00	59	52752. 86		

Table 2. ANOVA Table for absolute peak power outputs (watts).

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	90. 40	14	6. 46	0. 69	0. 7725
Within Subj.	421. 65	45	9. 37		
Treatments	377. 23	3	125. 74	118. 90	0. 0001
Error	44. 42	42	1. 06		
Total	512. 05	59	8. 68		

Table 2a. ANOVA Table for peak power outputs relative to body weight.

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	102. 84	14	7. 35	0. 64	0. 8167
Within Subj.	516. 19	45	11. 47		
Treatments	464. 49	3	154. 83	125. 77	0. 0001
Error	51. 70	42	1. 23		
Total	619. 04	59	10. 49		

Table 2b. ANOVA Table for peak power outputs relative to lean body mass.

The post hoc Scheffé analysis revealed that the peak power output for each resistance was significantly different from the other resistances. The pairwise comparisons showed statistically significant differences between 7.5% and 10.5% (p = 0.0001), 7.5% and 12.5% (p = 0.0001), and 7.5% and 14.5% (p = 0.0001) for absolute watts, watts relative to body weight, and watts relative to lean body mass. The pairwise comparisons showed statistically significant differences between 10.5% and 12.5% (p = 0.0001), and 10.5% and 14.5% (p = 0.0001) for absolute power, power relative to body weight, and power relative to body fat. Lastly, the pairwise comparison showed statistically significant differences between 12.5% and 14.5% (p = 0.0001) for absolute power, power relative to body weight, and power relative to body fat. Complete post hoc Scheffé analyses are shown in Table 3, 3a and 3b.

Post Hoc Scheffé Analysis for Peak Power Output Measures

Resistances	F ratio	P values
7.5% with 10.5%	115.1	0.0001
7.5% with 12.5%	218.11	0.0001
7.5% with 14.5%	335.51	0.0001
10.5% with 12.5%	16.32	0.0001
10.5% with 14.5%	57.59	0.0001
12.5% with 14.5%	12.59	0.0001

Table 3. Scheffé pairwise comparisons for absolute peak power.

Resistances	F ratio	P values
7.5% with 10.5%	109.71	0.0001
7.5% with 12.5%	207.81	0.0001
7.5% with 14.5%	315.81	0.0001
10.5% with 12.5%	15.53	0.0001
10.5% with 14.5%	53.24	0.0001
12.5% with 14.5%	11.26	0.0001

Table 3a. Scheffé pairwise comparisons for peak power relative to body weight.

Resistances	F ratio	P values
7.5% with 10.5%	114.05	0.0001
7.5% with 12.5%	221.28	0.0001
7.5% with 14.5%	333.02	0.0001
10.5% with 12.5%	17.61	0.0001
10.5% with 14.5%	57.3	0.0001
12.5% with 14.5%	11.38	0.0001

Table 3b. Scheffé pairwise comparisons for peak power relative to lean body mass.

Peak power output (PPO) is calculated as the mean of the first 5 seconds of the WAnT. Each test begins with the application of the resistance (7.5, 10.5, 12.5 or 14.5% BW) against a flywheel that is rapidly spinning. To investigate the effect of flywheel inertia on PPO, the PPO was determined for 5-second intervals that began with the 2nd, 3rd, 4th, and 5th seconds of the trial. The PPO from these incremented 5-second intervals is presented in Table 4.

<u>Absolute Peak Power Outputs</u>

Resistance	1st to 5th	2nd to 6th	3rd to 7th	4th to 8th	5th to 9th
7.5% of BW	951	935.3	912.4	890.6	868.0
10.5% of BW	1244 [1]	1190.4 [1]	1127.2 [1]	1074.9 [1]	1029.9 [1]
12.5% of BW	1354 [1,2]	1246.02 [1]	1149.3 [1]	1078.3 [1]	1026 [1]
14.5% of BW	1450 [1,2,3]	1280.6 [1,2]	1153.3 [1]	1064 [1]	999.02 [1]

Table 4. Peak Power Outputs in Watts during the 1st to 5th Second, the 2nd to 6th Second, the 3rd to 7th Second, the 4th to 8th Second and the 5th to 9th Second, where:

[1] statistically significantly different from 7.5%.
[2] statistically significantly different from 10.5%.
[3] statistically significantly different from 12.5%.

In each of these 5-second intervals, the PPO at 10.5%, 12.5% and 14.5% BW were significantly greater that the PPO at 7.5% BW. None of the other pairwise comparisons reached a level of statistically significant differences, with the exception that the PPO at 14.5% BW during seconds 2-6 was significantly greater than the PPO at 10.5% BW. The complete post hoc Scheffe analyses are presented in Tables 5, 5a, 5b and 5c.

Post Hoc Scheffé Analysis for Mean Absolute Peak Power Outputs in 4 Different Time Intervals

Resistances	F ratio	P values
7.5% with 10.5%	37.51	0.0001
7.5% with 12.5%	55.64	0.0001
7.5% with 14.5%	68.74	0.0001
10.5% with 12.5%	1.78	0.1867*
10.5% with 14.5%	4.69	0.0137
12.5% with 14.5%	0.69	0.5692*

Table 5. Scheffé pairwise comparisons for absolute peak power output during the 2^{nd} to 6^{th} Second of the Test.
* Non- Statistically Significantly Different

Resistances	F ratio	P values
7.5% with 10.5%	27.03	0.0001
7.5% with 12.5%	32.89	0.0001
7.5% with 14.5%	34.00	0.0001
10.5% with 12.5%	0.29	0.8340*
10.5% with 14.5%	0.40	0.7550*
12.5% with 14.5%	0.01	0.9987*

Table 5a. Scheffé pairwise comparisons for absolute peak power output during the 3^{rd} to 7^{th} Second of the Test.
* Non-Statistically Significantly Different

Resistances	F ratio	P values
7.5% with 10.5%	19.45	0.0001
7.5% with 12.5%	20.18	0.0001
7.5% with 14.5%	17.22	0.0001
10.5% with 12.5%	0.01	0.9992*
10.5% with 14.5%	0.07	0.9761*
12.5% with 14.5%	0.12	0.9487*

Table 5b. Scheffé pairwise comparisons for absolute peak power output during the 4th to 8th Second of the Test.
* Non-Statistically Significantly Different

Resistances	F ratio	P values
7.5% with 10.5%	14.92	0.0001
7.5% with 12.5%	14.20	0.0001
7.5% with 14.5%	9.77	0.0005
10.5% with 12.5%	0.01	0.9988*
10.5% with 14.5%	0.54	0.6588*
12.5% with 14.5%	0.41	0.7447*

Table 5c. Scheffé pairwise comparisons for absolute peak power output during the 5th to 9th Second of the Test.
* Non-Statistically Significantly Different

DISCUSSION

The purpose of this study was to determine which resistance is the most appropriate to elicit true peak power output in elite male road cyclists during an abbreviated Wingate Anaerobic Test (WAnT). Peak power output is calculated as the mean of the first 5 seconds of the WAnT and depends on the product of resistance and speed (force and velocity). As reported by Inbar, Bar-Or, & Skinner (1996) the use of a higher force to maximize power output represents a major change to the WAnT and is highly recommended. Also, Beld, Skinner and Tran (1989) have suggested that resistances higher than the standardized resistance can elicit greater peak power output.

It was hypothesized that 10.5% was the most appropriate resistance to elicit peak power and that resistances greater than 12.5% of body weight would negatively affect peak power. The findings of this study revealed that for peak power output, each resistance tested was significantly different from the other resistances during the first 5-seconds of the test. The results of this study demonstrated how peak power output increased with increasing resistances in elite trained road cyclists. These findings are consistent with the findings of Sidner (1998) and Dotan and Bar Or (1983), in that resistances greater than the standardized 7.5% of body weight resulted in greater peak power output.

Dotan and Bar Or (1983) concluded that the WAnT is sensitive to load variation, therefore modified loads may be used according to the individual body build, composition, and especially anaerobic fitness level. Our study showed that in elite trained road cyclists, resistances of at least 10.5% of body weight elicited significantly higher peak power outputs than the standardized 7.5% resistance. However, in contrast to the findings obtained by Sidner (1998), the results of this study revealed significant differences in the mean peak power output between resistances of 10.5% and 12.5% of body weight. This has been one of the only studies that has evaluated the effects of these resistances on peak power, and so far the only one that has found statistically significant differences among high resistances. In this study, a resistance of 14.5% of body weight was also tested since it was thought that resistances greater than 12.5% would be, for this subject population, the resistances at which a decrease in peak power output would be observed. However, mean peak power output results for the 14.5% resistance still demonstrated an upward trend and were proven to be statistically significantly higher when compared with the peak power outputs elicited with the 7.5%, 10.5% and 12.5% resistances.

The abbreviated 15-second WAnT was very well accepted by the subjects. According to Brooks, Fahey, and White (1996), the three components of the immediate energy system; ATP, creatine phosphate, and the degraded ATP (ADP), cannot sustain maximal muscle contraction for more than 5 to 15 seconds without requiring the assistance of other energy sources. Therefore, the 15-second power test may better demonstrate the substrate patterns and energy pathway utilized during a short all-out effort. Also, cycling and running sprint events last ten to twelve seconds, thus the 15-second test is a good representation of the power needed to successfully perform a cycling or a running sprint. For these reasons, we suggest the use of an abbreviated 15 or even 10-second test in combination with a resistance of at least 10.5% of body weight when the main interest is to evaluate the maximal power capacity of elite road cyclists and other power or endurance athletes.

Our study showed that when the main interest of a study is to determine peak power, the duration of the WAnT can be much shorter than the standard 30-seconds. However, when doing so, one loses the ability to compare mean power with other studies, since mean power is calculated over the standard 30-second protocol of the WAnT. According to Inbar, Bar-Or, & Skinner (1996), peak power is achieved during the first 5 to 10 seconds in a standard WAnT. For that reason, it was proposed in our study to use an abbreviated 15-second power test. During a 30-second test, a subject may subconsciously reserve energy at the beginning of the test in order to complete the test, which limits his/her maximal power output. During a 15-second test the subject has less concern about the length of the test, thus is able to give an all out effort without reserving energy for the last part of the test. However, since this study did not compare performance in 15-second and 30-second protocols, the effect of test duration on peak power performance is a matter of speculation at this time.

The higher peak power produced with the higher resistances may be influenced by flywheel inertia. At the start of the test, the load is applied to the flywheel, which is spinning at a high RPM as the subjects prepare for the test by pedaling against no resistance. Basset (1989) provided a formula to correct the WAnT for the kinetic energy produced by the rotating flywheel. This formula seems to be sensitive to subject variation, thus, the greater the subjects' spinning ability, the greater the flywheel kinetic energy that will contribute towards peak power output. As suggested by Basset, the peak power values obtained in this study were corrected for the flywheel kinetic energy in Table 6, and were lower than the original values obtained during the test. The corrected values obtained for peak power showed statistically significant increases in peak power output (PPO) with increasing resistance.

Peak Power Outputs

Resistance	Watts	Watts·kg $^{-1}$	Watts·lbm $^{-1}$
7.5% of BW			
Mean PPO	951.73	12.5	14.0
Mean PPO Corrected	892.22	11.71	13.04
10.5% of BW			
Mean PPO	1244	16.4	18.3
Mean PPO Corrected	1166.33	15.38	17.16
12.5% of BW			
Mean PPO	1354	17.9	20.0
Mean PPO Corrected	1269.13	16.77	18.64
14.5% of BW			
Mean PPO	1450.73	19.2	21.3
Mean PPO Corrected	1360.26	17.96	19.98

Table 6. Mean peak power outputs and mean peak power outputs corrected for the flywheel kinetic energy with, at resistances of 7.5%, 10.5%, 12.5% and 14.5% of body weight (BW).

When reviewing the individual computer data reports, most of the subjects sustained about 190 RPM during the 1st second of the test, and in one case, 222 RPM. It seems that the combination of elevated pedaling RPM during the 5-s countdown and instant application of very high resistance, such as 12.5% and 14.5% of body weight, will produce high peak power output in the first second of the test. Therefore, it can be assumed that peak power output will tend to increase with increments in resistance during the 1^{st} second of the test because of the elevated subjects' RPM and the instant application of very high resistance. This will result in greater flywheel kinetic energy. Since peak power is calculated as the average of the first five seconds of the test, the power produced during the 1^{st} second of the test will have an impact on the overall result.

This denotes a bias in the WAnT itself, since the individual who possess the superior spinning ability will reach a very high RPM during the 5-second countdown, which will increase the flywheel RPM and kinetic energy. This will contribute to his/her overall peak power output. In addition, when looking at the individual data, one can notice how the peak power output during the 1^{st} second of the test increased with increments in resistance and then immediately dropped.

In another approach to investigate the effects of flywheel inertia on peak power output, peak power output was calculated for the five-second intervals between the 2^{nd} - 6^{th}, 3^{rd} - 7^{th}, 4^{th} - 8^{th} and 5^{th} - 9^{th} seconds of the test. The statistical analysis of these five-second intervals stands in contrast to the findings from the first 5 seconds of the WAnT. PPO was found to be greater at every resistance higher than the standard 7.5% body weight, but, except for one instance, there were no differences in PPO among the higher resistances (See Table 4). The one exception was during the second 5-second interval (seconds 2-6), where the PPO at 14.5% body weight was significantly greater than the PPO at 10.5% body weight. These findings indicate that there is a clear difference in PPO between the 7.5% BW and the 10.5% BW resistances, since PPO were consistently significantly greater across each of the 5-second intervals. However, flywheel inertia rather than increased capacity to produce anaerobic power is implicated in the differences in PPO noted among the higher resistances during the first and second 5-second intervals. These findings support the original hypothesis that 10.5% BW is the optimal resistance for the WAnT.

The analysis of the results of this study indicate that the peak power output results obtained during the first 5-seconds of the test with the greater resistances where positively influenced by the subjects' spinning during the 5-second countdown and the instant application of high resistance. In conclusion, our findings support using a resistance of 10.5% BW when the intent is to elicit PPO in the WAnT. In addition, it appears that the first second of the WAnT is influenced by flywheel inertia, so that using seconds 2-6 of the test may derive a truer representation of PPO.

CONCLUSIONS

The purpose of this study was to determine which resistance is the most appropriate to elicit true peak power output in elite male road cyclists during an abbreviated Wingate Anaerobic Test (WAnT). The results of this study demonstrated that peak power output increased with increasing resistances in elite trained road cyclists. However, it would be very difficult to determine what percentage of the subjects' peak power output could be accounted as the subjects' maximal effort and what percentage could be attributed to the contribution of the subjects' high RPM and the flywheel kinetic energy. It is also difficult to provide solid conclusions regarding which resistance is the most appropriate to elicit peak power since, in the literature available, there have not been many studies that have evaluated the same resistances we evaluated. Also, the results of the four 5-second time intervals analyzed did not show the same pattern that the peak power from the 1st to the 5th had demonstrated for each resistance.

In conclusion, we suggest the use of an abbreviated 15 or even 10-second test in combination with a resistance of at least 10.5% of body weight when the main interest is to evaluate the maximal power capacity of elite road cyclists. Special consideration should also be given to higher resistances when evaluating the maximal power capacity of athletes of different short-duration sports. In addition, the role of the flywheel kinetic energy, and how to address it, represents one of the major issues concerning the WAnT.

FUTURE DIRECTIONS

At this time it seems that more research is needed before concluding which resistance is the most appropriate to elicit peak power. Also, the issue of flywheel inertia on peak power output needs to be assessed. Studies should be conducted to determine how mean power is affected by the use of different resistances during a 30-second test.

The formula provided by Basset (1989) [1], in which he corrected the WAnT for the flywheel kinetic energy, should be considered when conducting WAnT to at least reduce the bias already inherent in the test.

However, since this will make peak power difficult to calculate, a new computer program should be developed that would make possible the calculation of the flywheel peak power contribution, in order to correct for the overall peak power output.

In addition, the results of this study provide the foundation for future studies interested in determining the resistance factor at which peak power output declines, since our findings showed that even at a resistance factor of 14.5% of body weight peak power output maintained an upward trend. Lastly, we suggest that further investigations should control for the subjects' RPM produced during the 5-s countdown to determine whether this has an impact on the peak power. For example, a new standard should be set to allow for a fixed number of subjects' RPM for all the subjects.

---

[1] See Bassett (1989) pp. 14

BIBLIOGRAPHY

Ayalon, A., Inbar O., and Bar-Or O. (1974) Relationship among measurements of explosive strength and anaerobic power. In International series on sport sciences. 1: Biomechanics IV, ed. R.C. Nelson and C.A. Morehouse, 527-32. Baltimore: University Press

Bar-Or, O. (1983). Pediatric sports medicine for the practitioner: From physiologic principles to clinical applications, 2-16. New York: Springer-Verlag.

Bar-Or, O., Dotan R., and Inbar O. (1977). A 30-second all-out ergometric test: Its reliability and validity for anaerobic capacity. Israel Journal of Sports Medicine, 1, 326.

Bassett, D. (1989). Correcting the Wingate test for changes in kinetic energy of the ergometer flywheel. International Journal of Sport Medicine, 10, 6, 446-449.

Beld, K., Skinner, J. and Vu Tran, Z. (1989). Load optimization for peak and mean power output on the Wingate anaerobic test. Medicine Science in Sports and Exercise, (Suppl): S28.

Bolding, J.T. (1989). Statistics with Finesse: User's manual. Fayetteville, AK: Statistics with Finesse.

Borg, G., Edstrom E.G, and Marklund G. (1971). A bicycle ergometer for physiological and psychological studies. Report no. 24, Institute for Applied Psychology, University of Stockholm.

Bouchard, C., Taylor A.W., Simoneau J-A. and Dulac S. (1991). Testing anaerobic power and capacity. In physiological testing of the high-performance athlete, ed. J.D. MacDougall, H.A. Wegner, and H.J. Green, 175-221. Champaign, IL: Human Kinetics.

Bressel, E. (1995). Anaerobic power, leg volume, and muscle composition as factors influencing efficiency of cycle ergometry (Master thesis California State University at Fresno). Dissertations Abstracts International, 36, 0029.

Brooks, G.A., Fahey, T.D. and White, T.P. (1996). Exercise Physiology: Human Bioenergetics and Its Applications, 28-29. Mountain View, CA: Mayfield Publishing Company

Chaloupecky, R. (1972). An evaluation of the validity of selected tests for predicting maximal oxygen uptake. Unpublished doctoral dissertation. Stillwater: Oklahoma State University.

Coleman, S.G. (1998). The effect of different calculation methods of flywheel parameters on the Wingate Anaerobic Test. Canadian Journal of Applied Physiology, 23, 4, 409-17.

Craig, N.P., Pyke F.S. and Norton K.I. (1989). Specificity of test duration when assessing the anaerobic lactacid capacity of high-performance track cyclists. International Journal of Sport Medicine, 10, 4, 237-242.

Cunningham, D., and Faulker J. (1969). The effect of training on aerobic and anaerobic metabolism during a short exhaustive run. Medicine Science in Sports and Exercise, 1: 65-69.

Dotan, R. and Bar. Or. (1983). Load optimization for the Wingate Anaerobic Test. European Journal of Applied Physiology, 51, 3, 409-417.

Fox, E.L., Bowers R.K. and Foss M.E. (1988). The Physiological Basis of Physical Education and Athletics. Philadelphia: Saunders, 674-676.

Ericson, M.O., Bratt A., Nisell R., Arborelius U.P., and Ekholm J. (1986). Power output and work in different muscle groups during ergometer cycling. European Journal of Applied Physiology, 55, 3, 229-235.

Ericson, M.O., Nisell R., Arborelius U.P., and Ekholm J. (1985). Muscular activity during ergometer cycling. Scandinavian Journal of Rehabilitation Medicine, 17, 2, 53-61.

Evans, J., and Quinney, H. (1981). Determination of resistance settings for anaerobic power testing. Canadian Journal of Applied Sport Science, 6, 2, 53-56.

Gastin, P.B. and Lawson D.L. (1994). Variable resistance all-out tests to generate accumulated oxygen deficit and predict anaerobic capacity. European Journal of Applied Physiology, 69, 4, 331-336.

Hawley, J.A. and Noakes, T.D. (1992). Peak power output predicts maximal oxygen uptake and performance time in trained cyclists. European Journal of Applied Physiology, 65, 1, 79-83.

Hebestreit, H., K. Mimura, and O. Bar-Or. (1993). Recovery of anaerobic muscle power following a 30-s supramaximal exercise: Comparing boys and men. Journal of Applied Physiology, 74: 2875-80

Inbar, O., Bar-Or, O., and Skinner, J.S. (1996). The Wingate Anaerobic Test. Illinois: Human Kinetics.

Kalamen, J.L. (1968). Measurement of muscular power in man. PhD dissertation, Ohio State University, Columbus, OH.

Katch, V. (1973). Kinetics of oxygen uptake and recovery for supramaximal work of short duration. Internationale Zeitschrift fuer Angewandte Physiologie Einschliesslich Arbeitsphysilogie, 31: 197-207.

Hill, A.V., C.N.H. Long, and H. Lupton (1924). Muscular exercise, lactic acid and the supply and utilization of oxygen. Part 7-8. Proceedings of the Royal. Society of London, 97: 155-76.

Margaria, R., P. Anghemo, and E. Rovelli. (1966). Measurement of muscular power (anaerobic) in man. Journal of Applied Physiology, 21: 1662-64.

Margaria, R., H.T. Edwards, and D.B. Dill (1933). The possible mechanism of contracting and paying the oxygen debt and the role of lactic acid in muscular contraction. American Journal of Physiology, 106:689-715.

Numela, A., Alberts, M., Rijntjes, R.P., Luhtanen, P., and Rusko, H. (1996). Reliability and validity of the maximal anaerobic running test. International Journal of Sport Medicine, S2, S97-S102.

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

Pollock, M.L., and Jackson,A.S. (1984). Research progress in validation of clinical methods of assessing body composition. Medicine Science in Sports and Exercise, 16, 603-616.

Rusko, H.K., A. Nummela, and A. Mero. (1993). A new method for the evaluation of anaerobic running power in athletes. European Journal of Applied Physiology, 66: 97-101.

Sall, J., and A, Lehman. (1996). A Guide to Statistics and Data Analysis Using JMP and JMP IN Software. California: Duxbury Press.

Sargent, D.A. (1921). The physical test of a man. American Physical Education Review, 26: 188-94.

Sidner, A. (1998) The Effects of High Resistances on Peak Power Output and Total Mechanical Work During Short-duration High Intensity Exercise in the Elite Female Athlete. (Unpublished Master thesis Oregon State University).

Siri, W.E. (1961). Body composition from fluid spaces and density: Analysis of methods. In J. Brozek & A. Henschel (Eds.), Techniques for measuring body composition (pp. 223-244). Washington, DC: National Academy of Sciences.

Skinner, J.S., and D. Morgan. (1985). Aspects of anaerobic performance. In limits of human performance, ed. D. Clarke and H. Eckert, 31-44. Champaign, IL: Human Kinetics.

Tanaka, H., J.R Bassett, T.C. Swensen, and R.M. Sampedro. (1993). Aerobic and anaerobic characteristics of competitive cyclists in the United States Cycling Federation. International Journal of Sports Medicine, 14, 6, 334-338.

Thompson, N.N., C. Foster, B. Rogowski, and K. Kaplan. (1986). Serial responses of anaerobic muscular performance in competitive athletes. Medicine Science in Sports and Exercise, 18: S1.

Tirosh, E., P. Rosenbaum, and O. Bar-Or. (1993). New muscle power in neuromuscular disease. Feasibility and Reliability. American Journal of Diseases of Children, 144:1083-87.

Too, D. (1990). Biomechanics of cycling and factors affecting performance. Sports Medicine, 10, 5, 286-302.

Vandewalle, H., Peres, G., and Monod, H. (1987). Standard anaerobic tests. Sports Medicine, 4, 4, 268-269.

Vandewalle, H., Peres, G., and Monod, H. (1987). Force-velocity relationships and maximal power on a cycle ergometer. Correlation with the height of a vertical jump. European Journal of Applied Physiology, 56: 650-656.

Vandewalle, H., Matson, B. Le Bozec, S., and Guerenbourg, G. (1991) An electromyographic study of an all-out exercise on a cycle ergometer. Archives International of Physiology, Biochemistry and Biophysics, 99,1, 89-93.

Winter, E.M., Brown, D., Roberts, N.K., Brookes, F.B., and Swaine, I.L. (1996). Optimized and corrected peak power output during friction-braked cycle ergometry. Journal of Sports Science, 14, 6, 513-521.

APPENDICES

APPENDIX A

APPLICATION FOR APPROVAL OF THE OSU INSTITUTIONAL REVIEW BOARD (IRB) FOR THE PROTECTION OF HUMAN SUBJECTS

Principal Investigator: Dr. Anthony Wilcox E-mail: anthony.wilcox@orst.edu

Department: Exercise and Sport Science Phone: 737-2643

Project Title: The effects of different resistances on peak power during the Wingate Anaerobic Test.

Type of Project: ____Faculty Research Project

X Student Project or Thesis

Student's name Waldemar Hermina Phone 737-6792
E-mail: herminaw@ucs.orst.edu
Student's mailing address: 1430 NW Division Apt. 5 Corvallis, OR 97330

Type of Review Requested: ____Exempt ____Expedited X Full Board

---

Signed______________________________Date____________________
Principal Investigator

1. Significance of the Study

Controversy has been reported when determining the resistance that is most appropriate to elicit true peak power output (Evans and Quinney, 1981; Patton, Murphy and Frederick, 1985). The standardized 30-second Wingate Anaerobic Test protocol has used 7.5% of the subject's body weight as the resistance. Sidner (1998) evaluated peak power output and mechanical work with different resistances during a 20-second power test. He concluded that at least 10.5% of the subject's body weight should be used instead of 7.5% in order to elicit true peak power output in trained female power athletes. Most of the power studies conducted with cyclists have used 7.5% of the subjects' body weight. In some of these studies the duration of the protocols have been modified from as short as 30-seconds to up to 1 minute. In the occasions in which the resistance has been slightly changed resistances greater than 7.5% of the subjects' body weight have not been widely tested.

The aim of this study is to determine which resistance is the most appropriate to elicit true peak power output in elite male road cyclists during the Wingate

Anaerobic Test (WAnT). The values in each test for peak power will be compared among one another. This study will provide valuable knowledge regarding the resistance that should be used when conducting investigations to determine peak power output in elite male road cyclists.

2. <u>Description of Methods and Procedures</u>

This study will consist of two testing sessions over the course of one week. The subjects will report to the OSU Human Performance Laboratory for height and weight measurements, body composition assessment and for two cycling power tests on the first testing session. Height and weight will be measured on a calibrated Toledo Scale. Body composition will be assessed at the chest, abdomen and thigh with a non-invasive skinfold caliper. On the next testing session, each subject will perform two additional power tests. Each power test will be separated by a 20-minute recovery interval. The length of each testing session will be from 40 to 45 minutes and the testing sessions will be separated by at least 48 hours. The power tests will be conducted on a self-calibrating Monark-824e weight cycle-ergometer. Peak power output will be evaluated using four different resistances. The resistances to be used will be counterbalanced among the subjects to reduce order effects.

The resistances to be used are 7.5%, 10.5%, 12.5% and 14.5% of the subject's body weight. Each test will last 15-seconds. A minimum of a 10-minute warm-up will be provided before each test. The test will begin whenever the subjects feel ready to perform the test. A 5-second countdown will be provided during which the subjects will pedal against zero resistance. The subjects will be instructed to reach their maximum pedaling velocity (pedal revolutions per minute, RPM) by the time they reach zero on the 5-second countdown. At this time, the resistance will be applied to the ergometer. The subjects will maintain the highest RPM they are able to generate against the resistance for a period of 15-seconds. Upon completion of the test, the subjects will move to another ergometer where they will be able to cool down and recover for as long as they feel necessary.

3. <u>Risks and Benefits</u>

<u>Benefits</u>: As a benefit from participation in this study the subjects will receive information concerning their ability to generate muscular power and sustain high intensities during a short exercise bout.

<u>Risk Statement</u>: There are several risks or discomforts that the subjects can experience with their participation in the study. The test protocol may produce feelings of nausea, lightheadedness, or dizziness. In some cases, muscle soreness may occur after the test. The test will be stopped in the presence of any of the above feelings or discomforts, and the technician will provide physical assistance until the subject is recovered. However, these effects will not be

significantly different than what these trained cyclists experience during high-intensity training sessions or in competition.

4. Subject Characteristics.

The subjects volunteering in the study will be 15 elite male cyclists ages 20 to 35 years who have at least two years of competitive and rigorous training experience. Cyclists from the Corvallis community and surrounding area will be contacted and invited to participate either verbally or by e-mail. Subjects will receive a signed copy of the consent form.

5. Informed Consent

A written informed consent form will be provided to the subjects before their participation in the study. See attached copies.

6. Methods to Obtain Informed Consent

The subjects will receive a written copy of the informed consent document, and the procedures of the study will also be verbally explained to them. Subjects will read and understand the informed consent prior to signing.

7. Confidentiality Statement

All the information obtained from the subjects' participation in the study will be kept confidential. A code number will be used to identify any test results. Only the investigators will have access to the data, and no names will be used with the presentation or publication of the study results.

APPENDIX B

Informed Consent

A. Title of the research project. The effects of different resistances on peak power during the Wingate Anaerobic Test.

B. Investigators. Primary investigator: Anthony Wilcox, Ph.D., Department of Exercise and Sport Science, College of Health and Human Performance

Co-investigator: Waldemar Hermina, B.A.

C. Purpose of the research project. The aim of this study is to determine which resistance is the most appropriate to elicit true peak power output in elite male road cyclists during the Wingate Anaerobic Test (WAnT).

D. Procedures. I have received oral and written explanations of the study. My participation on this study will involve two testing sessions over the course of one week. Weight and height measurements, body fat assessment and two different cycling power tests will take place in the first testing session. Two different cycling power tests will be conducted in the second testing session. The length of each testing session will be from 40 to 45 minutes, and at least 48 hours will separate the two sessions. All testing will take place at the Human Performance Laboratory in the Women's Building. I understand that as a participant the following will take place:

1. **What I will do during the study.** As a participant in the study, my height, weight and body fat will be assessed using non-invasive methods. I will also perform four cycling power tests over the course of two test sessions. Each cycling power test will be 15-seconds in duration, and the resistance against I will be cycling will be either 7.5%, 10.5%, 12.5% and 14.5% of my body weight. I will perform two cycling power tests on the first session and two more cycling power tests on the second session, such that I will perform one cycling power test at each of the four resistances.

   Prior to each cycling power test, I will be given a 10-minute warm-up, and a 20-minute recovery will separate each power test. At the start of each cycling power test, I will pedal as fast as I can against no resistance during a 5-second countdown, and then the resistance will be applied and I will continue to pedal as fast as I can for 15-seconds. Upon completion of the test, I will move to another ergometer where they will be able to cool down and recover for as long as they feel necessary.

2. **Foreseeable risks or discomforts.** I understand there are several risks or discomforts that I can experience with my participation in the study. The high intensity of the cycling exercise might cause me to feel lightheaded or nauseous. In some cases, muscle soreness may occur after the test. If I experience either of these symptoms, I should immediately stop the test. However, the effort and effects of the cycling tests will not be significantly different than high intensity sessions in my personal training program.

3. **Benefits from the research.** I understand that as a benefit from my participation in the study I will receive information concerning my ability to generate muscular power and sustain high intensities during a short exercise bout.

E. **Confidentiality.** I understand that all the information obtained from my participation in the study will be kept confidential. A code number will be used to identify any test results or other information that I provide. Only the investigators will have access to the data, and no names will be used with the presentation or publication of the study results.

F. **Compensation for injury.** I understand that the University does not provide a research subject with compensation for medical treatment if an injury occurred.

G. **Voluntary participation.** I understand that my participation in this study is voluntary and that I may either refuse to participate or withdraw from the study at any time without penalty or loss of the benefits to which I am otherwise entitled.

H. **If I have questions.** I understand that any questions I may have about the research study and/or specific procedures should be directed to Waldemar Hermina, Langton Hall 121 B (737-6792) or Anthony Wilcox, Langton Hall 214 (737-2643). Any other questions that I have should be directed to Mary Nunn, Sponsored Programs Officer, OSU Research Office, 737-0670.

I. **Understanding and compliance**. My signature in the following page indicates that I have read and that I understand the conditions described above. I give my informed and voluntary consent to participate in the study and will receive a signed copy of this consent form.

Signature of the Subject Date Signed

Name of the Subject

Subject's Present Address Phone

Signature of the principal investigator Date Signed

APPENDIX C

Wingate Anaerobic Test Instructions

The following are the instructions for the Wingate anaerobic test protocol. A copy of the instructions will be provided to the subjects in addition to the verbal instructions before the test. Subjects will be asked to read the instructions and ask questions before the test.

- The warm-up will consist of at least 10 minutes of pedaling against a low resistance. The test will begin whenever you feel ready to perform the trial.

- A 5-s countdown will be provided during which you will pedal against zero resistance. You will be instructed to reach your maximum pedaling velocity or revolutions per minute RPM by the end of the 5-s countdown. At this time the full resistance, which have been determined according your body weight, will be applied to the ergometer.

- You will maintain the highest (RPM) you are able to generate against the resistance for a period of 15-s. You will receive verbal encouragement and will be kept informed of the elapsed time throughout the duration of the test. After the test is finished, you will move to a second ergometer where you will be able to cool down and recover for as long as you feel necessary.

APPENDIX D

Subject Individual Descriptive Data

Subjects	Height	Weight	Age	BF %	LBM	Peak Power Output 7.5% W	10.5% W	12.5% W
1	180.2	77.2	20	13.4	66.9	956	1196	1473
2	178.5	73	33	7.6	67.4	746	1096	1220
3	180.5	75	20	8.3	68.7	864	1243	1386
4	185.5	93	21	10.7	83.1	1120	1453	1291
5	178	83	35	12.9	72.3	1101	1382	1507
6	178.2	75	31	9.4	68	1051	1405	1543
7	175	64	23	8.3	58.7	758	1085	1223
8	185.5	73	20	12.5	63.8	961	1288	1500
9	177.8	69	23	6.3	64.7	845	1144	1299
10	179	76	21	10.7	67.9	1010	1365	1440
11	172	78	24	18.5	63.6	966	1122	1158
12	178.6	70.5	27	9	64.2	865	1159	1146
13	191	81	24	12.8	70.7	1033	1259	1318
14	181.5	80	28	7.8	73.8	1044	1295	1455
15	180	70.5	25	8.5	64.5	956	1168	1352

Height in cm: Weight in Kg: Lean Body Mass (LBM) in Kg: 7.5%, 10.5%, 12.5% and 14.5% W refers to peak power output values in absolute watts for each resistance respectively.

Subject Individual Descriptive Data (continued)

	Peak Power Output				Peak Power Output		
Subject	14.5% W	7.5% w (kg)	10.5 w (kg)	12.5 w (kg)	14.5% w (kg)	7.5% Lbm	10.5% Lbm
1	1556	12.4	15.5	19.1	19.9	14.2	17.8
2	1079	10.2	15	16.7	14.8	11	16.2
3	1534	11.5	16.6	18.5	21	12.5	18
4	1609	12	15.6	13.9	17.3	13.4	17.4
5	1665	13.3	16.7	18.2	20.1	15.2	19.1
6	1630	14	19.2	20.6	22.3	15.4	20.6
7	1241	11.8	17	19.1	19.4	12.9	18.4
8	1326	13.2	17.6	20.5	18.2	15	20.1
9	1321	12.2	16.6	18.8	19.1	13	17.6
10	1461	13.3	18	18.9	19.2	14.8	20.1
11	1364	12.4	14.4	14.8	17.5	15.1	17.6
12	1357	12.3	16.4	16.3	19.2	13.4	18
13	1478	12.8	15.5	16.3	18.2	14.6	17.8
14	1640	13.1	16.2	18.2	20.5	14.1	17.5
15	1500	13.6	16.6	19.2	21.3	14.8	18.1

Where 7.5%, 10.5%, 12.5% and 14.5% w (kg) refers to peak power output values relative to body weight in kilograms for each resistance respectively.

Subject Descriptive Data (continued)

	Peak Power Output	
Subject	12.5% Lbm	14.5% Lbm
1	22	23.2
2	18	16
3	20.1	22.3
4	15.5	19.3
5	20.8	23
6	22.6	23.9
7	20.8	21.1
8	23.5	20.7
9	20	20.4
10	21.2	21.5
11	18.2	21.4
12	17.8	21.1
13	18.6	20.9
14	19.7	22.2
15	20.9	23.2

Where 7.5%, 10.5%, 12.5% and 14.5% w (kg) refers to peak power output values relative to lean body mass for each resistance respectively.

APPENDIX E

Statistical Analysis Tables and Miscellaneous Tables

ANOVA Tables for Corrected Peak Power Output measures

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	683666. 75	14	48833. 34	1. 07	0. 4091
Within Subj.	2055536. 25	45	45678. 58		
Treatments	1847990. 62	3	615996. 88	124. 66	0. 0001
Error	207545. 67	42	4941. 56		
Total	2739203. 00	59	46427.17		

Table 7. ANOVA Table for corrected absolute peak power output (watts).

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	82. 79	14	5. 91	0. 72	0. 7405
Within Subj.	368. 14	45	8. 18		
Treatments	329. 49	3	109. 83	119. 34	0. 0001
Error	38. 65	42	0. 92		
Total	450. 93	59	7. 64		

Table 7a. ANOVA Table for corrected peak power output relative to body mass (Watts· kg $^{-1}$).

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	91. 19	14	6. 51	0. 65	0. 8088
Within Subj.	451. 42	45	10. 03		
Treatments	406. 76	3	135. 59	127. 50	0. 0001
Error	44. 66	42	1. 06		
Total	542. 61	59	9. 20		

Table7b. ANOVA Table for corrected peak power output relative to lean body mass (Watts· Lbm $^{-1}$).

Post Hoc Scheffé Analysis for Corrected Peak Power Output Measures

Resistances	F ratio	P values
7.5% with 10.5%	114.06	0.0001
7.5% with 12.5%	215.64	0.0001
7.5% with 14.5%	332.52	0.0001
10.5% with 12.5%	16.04	0.0001
10.5% with 14.5%	57.08	0.0001
12.5% with 14.5%	12.61	0.0001

Table 8. Scheffé pairwise comparisons for corrected absolute peak power.

Resistances	F ratio	P values
7.5% with 10.5%	110.25	0.0001
7.5% with 12.5%	206.30	0.0001
7.5% with 14.5%	318.48	0.0001
10.5% with 12.5%	14.93	0.0001
10.5% with 14.5%	53.97	0.0001
12.5% with 14.5%	12.13	0.0001

Table 8a. Scheffé pairwise comparisons for corrected peak power relative to body mass.

Resistances	F ratio	P values
7.5% with 10.5%	116.26	0.0001
7.5% with 12.5%	221.18	0.0001
7.5% with 14.5%	339.70	0.0001
10.5% with 12.5%	16.73	0.0001
10.5% with 14.5%	58.50	0.0001
12.5% with 14.5%	12.66	0.0001

Table 8b. Scheffé pairwise comparisons for corrected peak power relative to lean body mass.

Anova Tables for Mean Absolute Peak Power Outputs in 4 Different Time Intervals

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	366198. 44	6	61033. 07	2. 06	0. 1024
Within Subj.	622614. 50	21	29648. 31		
Treatments	513310. 03	3	171103. 34	28. 18	0. 0001
Error	109304. 47	18	6072. 47		
Total	988813. 00	27	36622. 70		

Table 9. ANOVA Table for Absolute Peak Power Output during the 2nd to 6th Second of the Test.

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	361270. 03	6	60211. 67	3. 24	0. 0205
Within Subj.	390183. 81	21	18580. 18		
Treatments	282640. 22	3	94213. 41	15. 77	0. 0001
Error	107543. 60	18	5974. 64		
Total	751453. 88	27	27831. 63		

Table 9a. ANOVA Table for Absolute Peak Power Output during the 3rd to 7th Second of the Test.

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	349351. 00	6	58225. 17	4. 30	0. 0055
Within Subj.	284078. 91	21	13527. 57		
Treatments	174156. 61	3	58052. 20	9. 51	0. 0006
Error	109922. 30	18	6106. 79		
Total	633429. 94	27	23460. 37		

Table 9b. ANOVA Table for Absolute Peak Power Output during the 4th to 8th Second of the Test.

Source	Sum of Sqr.	DF	Var. Est.	F-Ratio	Prob. F
Between Subj.	331799. 78	6	55299. 97	4. 98	0. 0026
Within Subj.	233049. 48	21	11097. 59		
Treatments	122444. 27	3	40814. 76	6. 64	0. 0033
Error	110605. 21	18	6144. 73		
Total	564849. 25	27	20920. 34		

Table 9c. ANOVA Table for Absolute Peak Power Output during the 5th to 9th Second of the Test.

APPENDIX F

Miscellaneous Figures

Comparison of the Subjects Individual Values for Peak Power

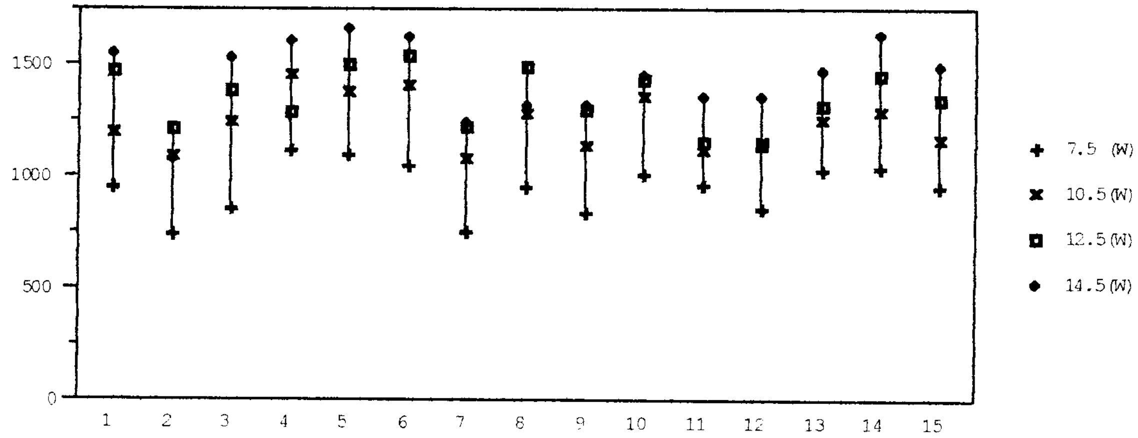

Figure 1. Subjects' individual values for absolute peak power. In the *X*-axis are the labels for the 15-subjects and in the *Y*-axis labels are peak power outputs in watts.

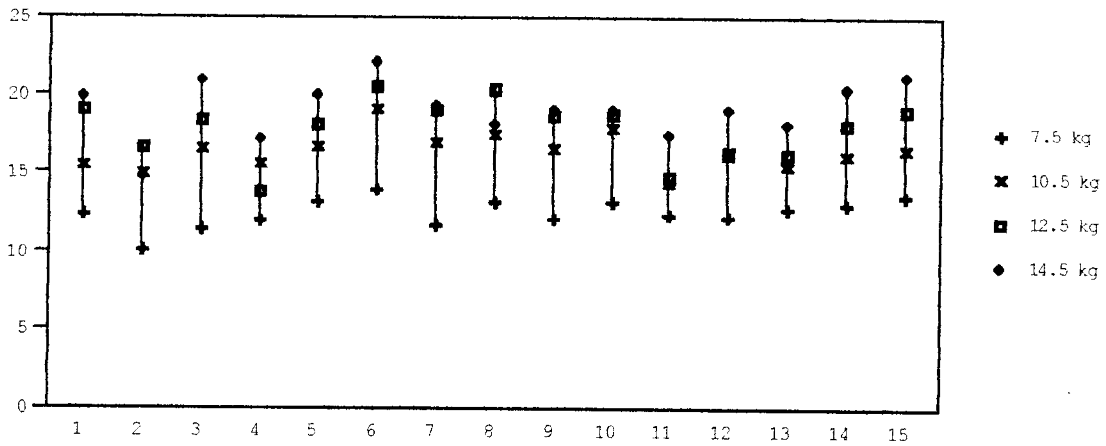

Figure 1a. Subjects' individual values for power relative to body weight. In the *X*-axis are the labels for the 15-subjects and in the *Y*-axis labels are peak power outputs in watts· kg.

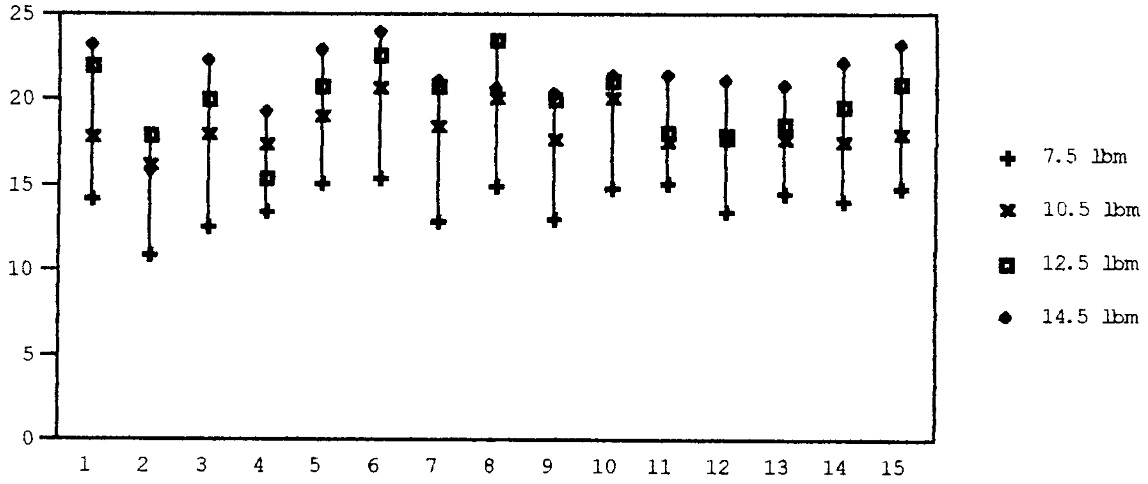

Figure 1b. Subjects' individual values for power relative to lean body mass. In the *X*-axis are the labels for the 15-subjects and in the *Y*-axis labels are peak power outputs in watts· lbm.

Printout from a WAnT: Power Data for one Subject at three Different Resistance Factors (12.5%, 14.5 and 10.5%)

Symbol	File name	Test date	Peak (W)	Peak (/kg)	Mean (W)	Mean (/kg)	Min (W)	Min (/kg)	Decrease (%)
•	12.5%	02-16-1999	1507	18.2	1114	13.4	879	10.6	42
◆	14.5%	02-16-1999	1665	20.1	1189	14.3	917	11.0	45
▪	10.5%	02-20-1999	1382	16.7	1049	12.6	822	9.9	41

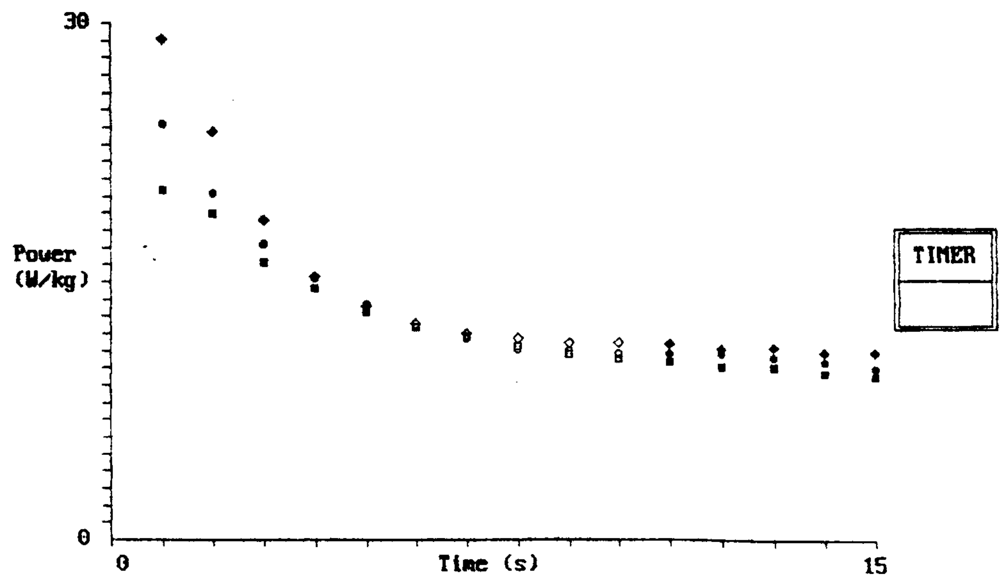

Figure 2. Comparison of three resistances for the same subject during the WAnT. In the *X*-axis is the label for the time and in the *Y*-axis labels are peak power outputs in watts· kg. Note that Mean, Minimum and Power Loss is also reported.