

Relationships Between Sprint Performance,
Power Output and Fatigue

by

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Thesis Submitted To The Faculty Of
Virginia Polytechnic Institute And State University
In Partial Fulfillment Of The Requirements For The Degree Of
Masters Of Science In Education
In
Exercise Physiology

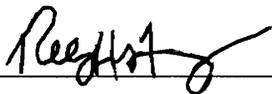
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July 1991

Blacksburg, Virginia

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(ABSTRACT)

This investigation used a constant-load cycle ergometer as a way of examining relationships between the cycle ergometer and sprint performance. Twenty-five college-aged males were used for this investigation. Following a three minute warm-up, each subject performed a 15 sec. maximal bout on the cycle ergometer. The resistance load on the ergometer was set at 0.12kg/kg of bodyweight. Peak power (PP), average power (AP), time to peak power (TTPP), power fatigue rate (PFR), and power fatigue index (PFI) were computed using a microcomputer system. In addition, PP, AP, and PFR were adjusted for total bodyweight (PP/kg, AP/kg, PFR/kg). On a separate day each subject performed six sprints two each at 50m, 100m, and 200m. Each sprint was electronically timed using an infra-red motion detector and starting blocks were used. Initially low correlations were found between the ergometer parameters and the sprint times ($r=.07-.55$). However upon closer evaluation stronger relationships appeared to exist for the faster subjects. Therefore, subject subgroups of faster subjects were formed. Subject subgroups

for the 50m (T<7.5sec.), 100m (T<14sec.), and 200m (T<26.6sec.) showed higher correlations (r=.06-.70). Further analysis revealed that high inter-variable correlations existed between many of the ergometer variables. Based on these correlations the parameters were separated into four groups. Group I contained variables of absolute power (PP,AP), group II were variables of relative power (PP/kg, AP/kg), group III contained variables of fatigue (PFR, PFI, PFR/kg), and group IV consisted of the acceleration variable (TTPP). Equations for predicting sprint performance were developed using one to four variables with only one variable from each group being used. The best equation was considered to be the one that yielded the highest r^2 value while also yielding the lowest Akakai Information Criteria value and MSE. Variables from the relative power group (PP/kg, AP/kg) and fatigue group (PFR, PFI, PFR/kg) were the best indicators of performance. These results suggest that the cycle ergometer used in this investigation can be used for evaluating the components of sprint performance in untrained males, and that this test is best when compared to the 200 m dash.

Acknowledgements

I would like to thank the following individuals for their contributions toward helping complete this research project.

Dr. Jay H. Williams, chairman of my committee, for his guidance and encouragement throughout this research project. Dr. Don R. Sebolt and Dr. Reed H. Humphrey, for serving on my committee.

I would also like to thank Chris Ward and Kim Lukin for their valued assistance with my data collection. Coach Russ Whiteneck for his cooperation and loaning of equipment.

Finally I would like to thank my girlfriend Suzanne Kobernick whose neverending support helped me make it through graduate school, and my family especially my parents Marcia and Jim Shorten whose guidance and support throughout my life made all of this possible.

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Chapter I

Introduction

Many daily activities as well as many athletic events involve short intense or sprint-type activities (Williams, Barnes, and Signorile, 1988). Such activities typically involve dynamic muscular contractions in which the muscle contracts with some velocity and with some force. Producing muscular power is the product of the force and velocity that is produced by the contracting muscles. The relationship between force and velocity is hyperbolic for human muscle. Therefore as muscle velocity increases, muscle force decreases (Harrison, 1970; Sargeant, Hoinville, and Young, 1981). There have been many methods developed to measure anaerobic power output. Some of these methods are; the verticle jump used by Sargeant (1921), stair-climbing used in the Margaria power test, sprints of varying distances, high speed treadmill running, and cycle ergometry tests (Bar-Or, Dotan, and Inbar, 1977; Cheetham, Boobis, Brooks, and Williams, 1986; Margaria, Aghemo, and Rovelli, 1966; Tharp, Newhouse, Uffelman, Thorland, and Johnson, 1985; Vandewalle, Peres, and Monod, 1987).

Possibly the most commonly used laboratory method of determining anaerobic power output is the cycle ergometer. This is probably due to the high reliability and the relative

ease of which force and velocity measurements can be taken (Bar-Or, 1987; Williams et al., 1988). A test for anaerobic power output using a stationary cycle ergometer was developed by Bar-Or et al. in 1977. This test is known as the Wingate Anaerobic Test (WAnT). This test measures power during an all out cycling bout that lasts for thirty seconds. This test was also shown to have high reliability coefficients of $r=0.95-0.97$ (Bar-Or et al., 1977). Since that time many researchers have shown high reliability values with different test protocols and with different populations (Bar-Or, 1987; Reilly, and Bayley, 1988). Cycle ergometer tests have also been compared to other methods of evaluating anaerobic power. The cycle ergometer compares favorably with the Margaria stair climbing test and with the verticle jump test. Cycle ergometry has also been compared with sprints of various distances with mixed results (Henrich, and Riley, 1988; Patton, and Duggan, 1987; Tharp et al., 1985).

Statement Of The Problem

The rate of oxygen consumption, ventilatory threshold, and running economy are thought to be important factors that affect performance in prolonged low-to-moderate intensity activities. It has been shown that these laboratory parameters are related to performance in endurance events (Conley, and Krahenbuhl, 1980; LaFontaine, Londeree, and Spath, 1981; Powers, Dodd, Deason, Byrd, and McKnight, 1983).

Since these occurrences may be important indications of an athlete's training and performance, it is obvious why so much time and effort has been spent studying this area.

Conversely, little work has been done studying the factors which might affect short, intense or sprint-type activities. This is unfortunate because sprinting or short explosive bouts of activity occur more commonly in the daily world than do endurance activities. More study in this area might take place if there were better laboratory measures of physiologic variables that relate to sprinting such as maximal power and fatigue. Recently a constant load cycle ergometer system for determining power output during short term high intensity exercise was described (Williams et al., 1988). With this system the researcher can closely examine the rapid changes in power output during a 15 second power output test. Early results indicate that during a 15 second test power output reaches a peak in the first 3-5 seconds. Following this, a slow decline in power output takes place until the end of the test (Williams et al., 1988; Williams, Signorile, Barnes, and Henrich, 1988). Thus, this system can determine the peak power output achieved (PP), the time to peak power (TTPP), the rate and magnitude of short-term fatigue (power fatigue rate, PFR, and power fatigue index, PFI), and finally the total work accomplished (TW). Low correlation coefficients between each parameter indicate that these

variables act independently of each other (Williams et al., 1988). This indicates that each of these parameters describes a different aspect of short term exercise performance.

Ikai showed a relationship between speed and time for the 100m dash that is qualitatively similar to the power curves obtained by Williams et al., (1988). He also showed that there is an inter-individual variation dependent upon training histories (Ikai, 1967). Undoubtedly there are many factors that contribute to sprint performance and measurements of PP and TW alone may not explain all of these factors. For this reason this cycle ergometer test can be useful in evaluating and predicting sprint performance.

Significance Of The Study

Anaerobic power is a primary factor in athletic performance, most commonly displayed as short explosive sprints. Despite this, little research has been directed at identifying the physiological variables that are associated with sprint performance. This investigation evaluated and modeled sprint performance using selected physiological variables. There are numerous factors involved in sprinting. Because of this, subjects with similar sprint times may exhibit very different power curves. For example, subject A may have a relatively slow acceleration phase, but exhibit a small amount of fatigue. Conversely, subject B may show a rapid acceleration phase, but also show a greater amount of

fatigue. Even though these subjects show obvious differences in their respective power curves, there might be only a small difference in their 100m times. The information collected by the ergometer test identified variables that could contribute to sprint performance (PP, TTPP, PFR, PFI, AP). This information could help pin-point an individuals performance weaknesses. For example, if subject A had a slow TTPP and PFR then he might want to change his training program to work on his acceleration. On the other hand, if subject B showed a high PFR then he might want to work on his short term endurance. This provides the athlete, coach, or trainer with a quantitative analysis of performance which could then be used to develop training programs to correct these weaknesses.

This system is superior to field observations, because not only is it highly reliable, but it also provides an objective basis for adjusting an athletes training program (Williams et al.,1988). This removes the subjective bias that may be included in subjective observations. The inexpensiveness of this system and the ease with which it can be operated may persuade many training facilities to incorporate it into their programs.

Research Hypothesis

The following null hypotheses were developed to define the objectives of the present study.

H_{01} : There were no individual relationships between the

parameters taken from the power curve (PP, TTPP, PFR, PFI, TW), and the sprint times (50m, 100m, 200m).

Ho₂: There were no relationships between the sub-groups of power variables [(PP, AP), (PP/kg, AP/kg), (PFR, PFI, PFR/kg), (TTPP)] and the sprint times.

Delimitations

The following delimitations were incorporated into the study by the investigator;

1. The investigation was delimited to 23 untrained male subjects and 2 sprinters from the Virginia Tech track team.
2. Sprint distances were set at 50m, 100m, and 200m.
3. Resistance of the ergometer was set at 0.12 kg/kg of body weight.
4. PP, TTPP, PFR, PFI, and TW were the indices measured from the cycling test.

Limitations

The investigator recognized the following limitations;

1. There may be some variation in the magnitude and direction of force application in the muscle groups used between the sprint test and the cycle test.

Basic Assumptions

The following assumptions were made prior to the start of the investigation;

1. The subjects complied with pretest instructions not to engage in strenuous physical activity for 12 hours prior to each test.
2. The subjects gave a maximal effort during the cycle test and during all of the sprint tests.

Definitions and Symbols

Anaerobic power - a term referring to the ability of an individual to produce force and velocity during short-term, high-intensity exercise.

Average power (AP) - an average of the total power attained every half pedal revolution during each bout, measured in watts.

Peak power (PP) - the highest power output achieved during a one-half pedal revolution within each bout, measured in watts.

Power fatigue index (PFI) - the percent decline in power from peak power to the end of the exercise bout.

Power fatigue rate (PFR) - the rate of power decline from peak power to the end of a bout, measured in watts/second.

Time to peak power (TTPP) - the time from the onset of the exercise bout until peak power is attained.

Summary

The information taken from the ergometer power test may contribute to the evaluation and modelling of sprint performance. Due to the many and varied physiological and mechanical factors contributing to both of these events, a

single measure of PP or TW may not be an adequate indicator of performance. Therefore, there is a need to determine what physiological factors and to what degree these parameters are associated with the performance in each sprint event. The natural assumption is that individuals who produce high levels of PP and TW on the ergometer test will also perform well in the sprints. However, other factors such as acceleration and fatigue can also influence performance. The extent to which each of these factors affect performance is not yet completely understood.

Chapter II

Review Of Literature

Introduction

This review focuses on power tests used to measure anaerobic power, the reliability and validity of these tests, and finally laboratory measures for predicting athletic performance. The section on anaerobic power includes power tests that were not used for this investigation. The section on performance prediction also reviews methods that were not used for this investigation. However, the information provided in these sections may help explain the rationale behind using a cycle ergometer power test as a method of predicting sprint performance.

Anaerobic Power

Intense, anaerobic, sprint-type activity usually lasts for less than 40 seconds (Evans, and Quinney, 1981). Developing muscular power in such a short period of time depends on the force and velocity that is produced by the contracting muscle(s). As the velocity of concentric contracting muscles increases the amount of force they are able to produce decreases (Harrison, 1970; Sargeant et al., 1981).

There have been many methods developed to measure anaerobic power output. Some of these methods are; the

verticle jump used by Sargeant (1921), Stair-climbing used in the Margaria power test, sprints of varying distances, high speed treadmill running, and cycle ergometry tests (Bar-Or et al., 1977; Cheetham et al., 1986; Margaria et al., 1966; Tharp et al., 1985; Vandewalle et al., 1987).

The verticle jump test was introduced as a measurement of muscular power in 1921 by L.W. Sargeant. In order to estimate power from the height of a jump you must calculate work and estimate the time required to do this work. This is typically based on the acceleration due to gravity (9.8 m/sec). Verticle jump tests can easily be administered as a field test (jump and reach) or a lab test. In the lab, a force platform can be used. This enables the researcher to measure instantaneous power by first calculating the acceleration of the centre of mass, subtracting bodyweight from the force exerted on the force platform and then dividing the result by body mass. The instantaneous velocity of the center of mass is calculated using the acceleration-time equation. Instantaneous power is then equal to the product of the force exerted on the force platform and the velocity of the subjects centre of mass (Vanderwalle et al., 1987). This test is relatively simple to administer and height is easily measured. Also a high correlation ($r=0.92$) has been found between the height of a jump and the power output calculated by the force platform. This test has also been

shown to have a test-retest reliability of greater than 0.92 (Vandewalle et al.,1987). This test however is not without fault. The height of a verticle jump has the dimension of work not power. The height of a jump also depends on the test protocol. For example is the subject allowed to swing his arms or bend his knees past 90 degrees? A counter movement such as squatting down right before jumping will usually improve a subjects performance (Enoka, 1988). However some power equations do not take into account the work that is performed by lifting the body from a squatted position. Other equations assume that the acceleration of the legs from the squatted position is constant, even though data from force platform experiments show that acceleration is not constant (Vanderwalle et al., 1987).

In 1966 Margaria, Aghemo and Rovelli proposed a method of measuring maximal power by calculating power output during stairclimbing at maximal speed. Originally the subjects were given a short run (2m) on a flat surface up to the stairs. Stair height was standardized at 17.5 cm. The subject would then bound up the stairs two at a time. Speed from the fourth to the sixth step was calculated using photocells attached to an electronic clock. This test assumes that the external work is provided by actual lifting of the body. This test also assumes that factors such as speed changes with each step are inconsequential. The reason the test keeps an even number of

steps between photocells is to insure that the subject will be in the same body position at each photocell. This test is also highly reliable with test-retest correlation coefficients between 0.85 and 0.90 (Margaria et al., 1966; Vandewalle et al., 1987). A drawback of the stair-climbing test is that bodyweight is not the optimal load to produce the best power output results. Adding an additional 40% of the subjects bodyweight results in 16% power output increase (Caiozzo, and Kyle, 1980).

Power tests using cycle ergometers have recently become very common in most laboratories. Originally these tests looked at not only peak power output but also anaerobic power capacity (Katch, and Weltman, 1979). Over time, different protocols as well as different cycling apparatuses have been developed. Some of these cycles used standard braking forces while others used braking forces related to body weight (Dotan, and Bar-Or, 1983; Katch et al., 1979). Given the fact that maximal power output is a function of optimal force and velocity, tests were done assessing only maximal power output. These tests only lasted 5-7 seconds and were performed against many different braking forces. The best value for peak power was used (Crielaard, and Pirnay, 1981).

Much interest has been directed toward studying the force-velocity relationship on a cycle ergometer. These studies produced linear force-velocity relationships and

parabolic power-velocity relationships. Most of these studies used either friction loaded ergometers or isokinetic cycle ergometers (Dotan, and Sargeant, 1984; McCartney, Heigenhauser, and Jones, 1983; Nadeau, Brassard, and Cuerrier, 1983; Sargeant et al., 1981; and Too, 1990). The classical hyperbolic force-velocity relationship is not as evident in cycle ergometer tests. This is possibly due to the fact that cycle ergometer protocols are very different from individual muscle studies. Therefore the results of a cycle ergometers force-velocity test are dependent on the protocol used. For example; maximal power output was found to be 15% higher when a subject is allowed to use a standing protocol as compared to a sitting protocol (Vanderwalle et al., 1987).

Of all the cycle ergometer tests for anaerobic power perhaps the best known is the Wingate anaerobic power test (WAnT). The WAnT was first introduced in 1974, and consisted of a 30 second all out cycle test. This simple test was designed as a non-invasive method of measuring muscle performance. Furthermore this test works on the assumption that anaerobic power production is a local rather than a systemic process. Therefore this test can be performed on both the legs and the arms. The WAnT was developed to measure three variables. Peak power which is the highest average power during any 3-5 second period, mean power is the average power sustained throughout the test and the rate of fatigue,

the degree to which power dropped during the test (Bar-Or, 1987). So far most research has focused on the indices of peak power, and mean power while the fatigue rate has received relatively little attention (Bar-Or, 1987).

Another type of ergometer test involves an isokinetic dynamometer. This type of ergometer has an electronic motor attached to it. This motor drives the cranks through a variable speed gearbox. This allows the investigator to control the pedaling frequency. The subject is instructed to exert a maximal effort in an attempt to increase the pedaling speed. While strain gauges that are attached to the cranks monitor force production (Sargeant et al., 1981). Power values for this type of test tend to show a parabolic relationship with velocity. Peak power values are usually found at approximately 110 rev/min with power output decreasing at higher and lower velocities (Sargeant et al., 1981).

The cycle ergometer system used in this investigation was developed by Williams et al., (1988). This system has been validated using a 40 yard dash. The study used a 15 second cycling protocol and concluded that the 40 yard dash was a valid estimate of anaerobic power production ability as predicted by the cycle ergometer test (Henrich et al., 1988). This cycle ergometer test measures six power indices, PP, TTPP, PFI, PFR, AP, and TW. Unlike the WAnT this test

measured PP as the highest power output value for one-half pedal stroke (Williams et al., 1988). It has been suggested that this system may provide insight into physiological and mechanical factors which contribute to performance (Williams et al., 1988; Williams, Barnes, and Signoile, 1990). The more precise measure of PP that this system provides makes this system preferable to other cycle ergometer systems that have previously been used.

Anaerobic power tests are a valuable tool for assessing human performance. All of the tests discussed have proven to be very valuable to researchers. However, these tests are not completely flawless. Many times the peak power measured in these tests may not equal true maximal anaerobic power. Power output can be influenced by a number of factors. One such factor is motivation. If the subject is not motivated then he will not exert a maximal effort and true PP will not be achieved. Optimal loading is another factor that can affect power output. For example, bodyweight is not the optimal load for the Margaria stair climbing test. Increasing bodyweight can improve power output by up to 16% (Caiozzo et al., 1980). Another problem is that some tests determine a peak power value by averaging power over a short period of time, usually 3-5 seconds (Vanderwalle et al., 1987). The cycle ergometer system used in this investigation alleviates many of these problems. Verbal encouragement was given to the subjects in

an effort to help motivate them. The optimal loading study that was used for this investigation, Davy, Williams, Ward, Smith, and Franke, (1990), was performed on the same ergometer that was used for this investigation. This system also does not determine peak power by averaging power values over a 3-5 second period.

Reliability

The reliability of high-intensity short-term cycle ergometry was investigated by Bar-Or et al. in 1977 while developing the WAnT. They reported test-retest correlations between 0.95 and 0.97. Other investigators have also shown high reliability correlations using different protocols and subject populations.

The WAnT has been shown to have a high day to day correlations for PP ($r= 0.93$), AP ($r= 0.93$), and the PFR ($r= 0.74$) (Patton, Murphy, and Frederick, 1985). This test used a resistance of 4.41 joules/rev/kgBW (Patton et al., 1985). Another investigation used a five second all out cycling protocol at a resistance from 9.8 to 63.6 N and showed significant test-retest reliability. This study went on to show that it is possible to take reliable measurements of power for both men and women while varying the resistance settings (Nadeau et al., 1983). Isokinetic cycle ergometers have also shown high test-retest reliability for a range of

resistance settings. These correlation coefficients have been as high as 0.99 (McCartney, Heigenhauser, and Jones, 1983).

It is important to establish reliability at different resistance settings, but an important factor that must not be overlooked is optimal loading. Properly loading a cycle ergometer allows investigators to changes in performance and increases reliability. Many different loads have been suggested over the years. Initially for the WAnT a load of 0.075kg/kgBW was considered optimal. These tests however used manly adolescent males as subjects (Vandewalle et al., 1987).

Later studies demonstrated that peak power was achieved when the cycle ergometer was loaded at higher levels ranging from 0.09 to 0.15 kg/kg of bodyweight. When assigning an optimal load a researcher should take gender, age, and anaerobic fitness level into account (Bar-Or, 1987; Davy et al., 1990; Dotan et al., 1983; Patton et al., 1985). Recently a study was performed on the constant load cycle ergometer used in this study (Davy et al., 1990). This study concluded that the optimal load for this ergometer was not the same as the optimal load for the WAnT. This study concluded that significantly higher values for PP were achieved when loads between 0.12 and 0.15 kg/kg of bodyweight were used (Davy et al., 1990).

An investigation using a constant load cycle ergometer, and an all out cycling protocol with varying durations was

done by Burke, Wojcieszak, Puchow, and Michael (1985). The protocol consisted of four cycling trials (15, 30, 60, and 120 seconds). Each trial used a load of 5 kp. The investigation showed intra-class correlations for AP (watts), TW (kj), and TTPP (sec) of 0.86, 0.79, and 0.97. These correlations indicate that these parameters are stable across the different time durations. However, as test duration increased, peak power decreased from 710 W for a 15 second test to 620 W for a 120 second test (Burke et al., 1985). This phenomena is believed to be related to subject motivation. It is believed that when facing a longer power test the subjects were less inclined to give a maximal effort at the onset of the test in an effort to conserve energy for the longer test duration (Burke et al., 1985). A more recent study found high intraclass correlations ranging from 0.91 to 0.97 for different power indices during a 15 second maximal cycling bout on a constant load cycle ergometer (Williams et al., 1988). A third study used a five second protocol and again found high reliability (Nadeau et al., 1983). These studies suggest that reliable power data can be obtained using protocols of various duration.

A major factor in increasing the reliability of power measurements has been the introduction of microcomputer data collection systems (Harman, Knuttgen, and Frykman, 1987; Williams et al., 1988). The cycle ergometer design, the

microcomputer system, and the data collection programs used for these investigation were based on the equipment used by Williams et al. (1988).

Validity

A major concern in any investigation is whether or not the study is actually measuring the variables it claims to be measuring. The presence of blood lactic acid, a byproduct of glycolysis, is an indirect indicator that anaerobic metabolism is taking place in the skeletal muscle. This method of validating anaerobic power tests has been successfully used in other investigations (Jacobs, Bar-Or, Dotan, Karlsson, and Tesch, 1983; Margaria, Cerretelli, and Mangili, 1964; McCartney et al., 1983; McCartney, Spriet, Heigenhauser, Kowalchuk, Sutton, and Jones, 1986). Normally resting blood lactic acid values range from 1.0 to 2.5 mmol/l (McArdle, Katch, and Katch, 1986). However after a 30 second all out cycle ergometer trial, blood lactic acid values increase significantly to 61 mm/kg of body weight (Jacobs et al., 1983). Other investigations have reported similar changes in blood lactic acid level after all-out cycle ergometer tests of varying durations and using a variety of populations (Bar-Or, 1987; Vanderwalle et al., 1987). Significant increases in blood lactic acid were also found for cycling tests of varying duration (Burke et al., 1985).

Blood lactic acid is not the only direct measurement of anaerobic metabolism. Intramuscular lactic acid levels can also be measured using muscle biopsy techniques. Research has shown that muscle lactic acid levels can significantly increase after only 10 seconds of maximal exercise (Hiroven, Rehunen, Rusko, and Harkonen, 1987; Jacobs et al., 1983). Blood and muscle lactic acid levels during intermittent maximal treadmill or cycling were compared. These tests showed that blood lactic acid increased continuously while muscle lactic acid increased during exercise and recovered slightly during the rest intervals but eventually plateaued (Hermansen, and Osnes, 1972). These results suggest that blood lactic acid may not directly indicate changes in intramuscular pH (Roberts, and Smith, 1989). These studies show that there has been a lot of research validating different anaerobic power test protocols using blood and muscle lactic acid tests. These results show that high intensity exercise lasting at least 10 seconds in duration definitely uses anaerobic metabolic pathways.

Predicting Performance

Researchers have been using laboratory measures as a means of predicting athletic performance for many years. Throughout this time the most widely used physiological variable for predicting running performance has been maximum

oxygen uptake (VO_2 max). In fact many athletes believe that this one variable alone can accurately predict their athletic performance (Noakes, 1988). More recent research however has shown that VO_2 max may not be the best predictor of running performance (Noakes, Myburgh, and Schall, 1990). This investigation found that peak treadmill running velocity was the best predictor of running performance. This investigation went on to show that when peak treadmill running velocity was combined with other laboratory measures such as VO_2 max and lactate turnpoint that their combined ability to predict performance was greater than any one single measure. Multiple linear regression techniques were used to show this relationship.

VO_2 max measurements have also been used in testing sprint athletes. The VO_2 max values were lower for elite sprinters than is normally found for elite endurance athletes. This is expected and reflects the fact that endurance events are largely aerobic while sprinting is mainly anaerobic. The different results may be attributed to the different training regimens that these athletes use or simply natural selection. While athletes with a higher aerobic capacity, and VO_2 max compete in distance events, those with a lower VO_2 max may be more apt to compete in sprinting events (Barnes, 1981).

Whether or not cycle ergometer tests are valid predictors of performance outside of the lab is a question that has not

been sufficiently answered. There are conflicting opinions in the literature as to whether or not cycle ergometer performance is related to sprint performance. Some research has shown that the WAnT can be used to predict sprinting ability (Bar-Or, and Inbar, 1978). This investigation showed significant correlations between the WAnT and times for the 40m, 300m, and 600m runs. Another study compared not only the WAnT and sprint times (50yd, and 600yd) but also the verticle jump and the long jump (Tharp et al., 1985). This study found that the WAnT was only a moderate predictor of sprint performance. However, the values did increase when power output was expressed relative to body weight. Another question that needs to be answered is whether or not cycle ergometer tests are specific to sprint performance. Tharp, Johnson, and Thorland (1984) confirmed this question when he found that the WAnT was able to differentiate between sprint and endurance runners. Sprinters developed a greater amount of anaerobic power and had a larger anaerobic capacity than the distance runners (Tharp et al., 1984). It is interesting to note that in each of the previously mentioned studies the correlations between cycle ergometry and sprint performance increased when power values were expressed relative to body weight.

Muscular power is another important factor in human performance. The relationship between muscular power and

swimming performance has been looked at by a number of investigators (Reilly et al., 1988; Sharp, Troup, and Costill, 1982). These investigations showed a high correlation between power output and swimming velocities. Although these correlations fell as swim distance increased. Both of these investigations used a swimbench to measure muscular power values. One of the investigations also used arm and leg cycle ergometers (Reilly et al., 1988). This study showed strong relationships between the ergometer values and the swim speeds at shorter distances. This study went on to show that PP values were a better indicator of performance than AP values. The results from these studies clearly show that training programs designed to improve arm and leg power can improve short distance swimming performance.

Like swimming, power tests have also been used as performance indicators for sprinters. Investigations using cycle ergometer tests as predictors of sprint performance have yielded conflicting results. Studies have concluded that the WAnT is not a strong predictor of sprint performance, another study has shown that the WAnT is a fair predictor of sprint performance while a third study has shown that a 15 second cycle ergometer test is significantly related to sprint performance (Henrich et al., 1988; Tharp et al., 1984; Tharp et al., 1985). However two of these investigations used adolescent males and females as subjects. Therefore, the

results may be different for an adult population. Obviously running speed varies as a function of time and the speed-distance relationship is dependent on the age and gender of the subject. Another factor that must be considered is the training level of the subject. Ikai (1967) found that the propelling force, calculated from the speed curve, was greater in trained sprinters than in untrained sprinters of equal muscle strength. This suggests that the isometric muscle strength that is used at the start of a sprint can be more efficiently transformed into dynamic propelling force by trained sprinters than by untrained sprinters. Another study went on to show that even though sprint times were shown to be highly reproducible, there are significant differences between experienced and beginning sprinters, with respect to maximal attained speed, the time needed to reach this speed, and reaction time to the start of the sprint (Volkov, and Lapin, 1979). The same study by Volkov, and Lapin (1979), went on to conclude that the energy supply to muscles during sprinting comes from the cleaving of intramuscular reserves of ATP and creatine Phosphate. Therefore, maximal speed in sprint running may be considered the equivalent of the maximal rate of energy liberation in the lactic anaerobic process.

Conclusions

As this review shows, anaerobic power tests have proven to be highly reliable and valid. The previous research done in this area is encouraging but many of the tests use modes of action that are not commonly found in sport, such as stair-climbing and broad jumping. Cycle ergometer tests use most of the same muscle groups as sprinting. However a more precise measure of power output is needed to predict performance outside the lab. This investigation used a computer integrated cycle ergometer system to measure power output. The results of these power output tests were then correlated to sprint times of varying distances, in an effort to develop a method of using a laboratory measure to predict performance.

Chapter III

Journal Manuscript

Relationships Between Sprint Performance, Power Output, and Fatigue

Abstract

James Shorten

This investigation used a constant-load cycle ergometer as a way of examining relationships between the cycle ergometer and sprint performance. Twenty-five college-aged males were used for this investigation. Following a three minute warm-up, each subject performed a 15 sec. maximal bout on the cycle ergometer. The resistance load on the ergometer was set at 0.12kg/kg of bodyweight. Peak power (PP), average power (AP), time to peak power (TTPP), power fatigue rate (PFR), and power fatigue index (PFI) were computed using a microcomputer system. In addition, PP, AP, and PFR were adjusted for total bodyweight (PP/kg, AP/kg, PFR/kg). On a separate day each subject performed six sprints two each at 50m, 100m, and 200m. Each sprint was electronically timed and starting blocks were used. Initially low correlations were found between the ergometer parameters and the sprint times ($r=.07-.55$). However upon closer evaluation stronger relationships appeared to exist for the faster subjects. Subject subgroups for the 50m ($T < 7.5\text{sec.}$), 100m ($T < 14\text{sec.}$),

and 200m ($T < 26.6$ sec.) showed higher correlations ($r = .06 - .70$). Further analysis revealed that high inter-variable correlations existed between many of the ergometer variables. Based on these observations the parameters were separated into four groups. Group I contained variables of absolute power (PP, AP), group II were variables of relative power (PP/kg, AP/kg), group III contained variables of fatigue (PFR, PFI, PFR/kg), and group IV consisted of (TTPP), the only variable of acceleration. Equations for predicting sprint performance were developed using one to four variables with only one variable from each group being used. The best equation was considered to be the one that yielded the highest r^2 value while also yielding the lowest Akakai Information Criteria value and MSE. Variables from the relative power group and fatigue group were the best predictors of performance. These results suggest that the cycle ergometer used in this investigation can be used for evaluating the components of sprint performance in untrained males, and that this test is best when compared to the 200 m dash.

Introduction

Many daily activities as well as numerous athletic events involve short-term intense or sprint-type efforts. Compared to prolonged aerobic activities, little effort has been directed towards the study of short, intense, anaerobic activities. Such activities typically involve dynamic muscular contractions in which the muscle contracts with some velocity and with some force. As muscular contraction velocity increases, force decreases. The product of these parameters is power which reaches a peak at moderate force and velocity (Harrison, 1970; Sargeant et al., 1981).

A number of methods have been developed to measure anaerobic power output. Some of these methods are; the verticle jump, stair-climbing, sprints of varying distances, high speed treadmill running, and cycle ergometry tests (Bar-Or et al., 1977; Cheetham et al., 1986; Margaria et al., 1966; Tharp et al., 1985; and Vanderwalle et al., 1987). Possibly the most commonly used laboratory method for assessing anaerobic power output is the cycle ergometer. This may be due to the high reliability and the relative ease of which force and velocity measurements can be taken (Bar-Or, 1987; Williams et al., 1988). A test for anaerobic power output using a stationary constant load cycle ergometer which allows for the close examination of the rapid changes in power was recently developed by Williams et al., 1988. Early results

indicate that during a 15 second effort, power output reaches peak power in 3-5 seconds. Following this, a slow decline in power output takes place until the end of the test (Williams et al., 1988; Williams et al., 1988). Thus, this system can determine the peak power output achieved, the acceleration to peak power, the rate and magnitude of short term fatigue. Low correlation coefficients between each parameter indicates that these variables are independent of each other (Williams et al., 1988). Indicating that each describes a different aspect of short term exercise performance.

A relationship between speed and time for the 100m dash that is qualitatively similar to the power curves obtained by Williams et al. (1988) was shown by Ikai in 1967. Undoubtedly there are many factors that contribute to sprint performance such as acceleration and resistance to short term fatigue. Thus, a single measurement of PP alone may not fully account for sprint performance (Williams et al., 1990). For example, one sprinter may have a slow TTPP but a low PFR while another sprinter may have a fast TTPP but a high PFR. Even though the sprint styles of these two sprinters are very different they may still have similar sprint times. For this reason this constant-load cycle ergometer test may be useful in evaluating and predicting sprint performance. The purpose of this study was to determine the individual relationships between sprint performance and each of the power test parameters, and to

determine the best subset of parameters to predict performance in each of the sprint events.

Methods

Subjects

Subjects were 25 college-aged males. All subjects were physically active but were not engaged in an organized training program. Each subject was required to read and sign an informed consent form that explained participation procedures, risks, and benefits before the onset of the study.

Each subject completed one anaerobic power test on the cycle ergometer and 6 sprints, 2 each of 50m, 100m, and 200m. The power test and the sprints were administered on separate days. In addition, the subjects were instructed to abstain from exercise for at least twelve hours prior to any of the tests.

Power Tests

A modified 818 front loading Monark cycle ergometer was used in conjunction with a microcomputer to collect and record the power output data from each subject. The ergometer design, computer software, data collection procedures, and cycling protocol were modeled after those used by Williams et al., (1988). This system determines power output for each one-half peddle revolution and also calculates from the temporal changes in power peak power (PP), time to peak power

(TTPP), power fatigue rate (PFR), power fatigue index (PFI), and average power (AP). Values of PP, AP, and PFR were also adjusted for total bodyweight (PP/kg, AP/kg, and PFR/kg).

The cycle ergometer protocol consisted of a 3 minute warm-up at 50 rpm. This was followed by a 15 second maximal cycling effort. The resistance load was set at 0.12 kg/kg of bodyweight (Davy et al., 1990). The test began with the pedals in a static horizontal position with the subjects preferred foot forward. Toe clips were also worn. Previous work using this ergometer system has shown very high test-retest correlation coefficients ($r = 0.90-0.95$). Thus, only one cycle ergometer bout was required for each subject (Williams et al., 1988).

Sprint Testing

Sprint performance was based on the finish time for each sprint. Each sprint was timed electronically and was performed individually. All sprints took place on an outdoor track using starting blocks and an auditory starting signal. Since the sprints took place on a outdoor track care was given to avoid adverse conditions such as high winds or a wet track.

The subjects were allowed to stretch, jog, practice accelerating out of the blocks, familiarize themselves with starting positions and otherwise warm up for the sprints. When the subject was ready, the starter depressed a switch. This simultaneously started an electronic timer and sounded

an auditory tone. At the sound of the tone the subject began sprinting. At the finish line was placed a infra-red motion detector. The beam, emitted by the infra-red unit, bounced off of a reflector placed on the opposite side of the running lane and was detected by the unit that emitted it. The infra-red unit was also connected to the electronic timer. Once the timer was started it ran freely as long as the infra-red beam was intact. Once the beam was broken by the subject the timer stopped. The time was then noted by the investigator.

Statistics

Multiple linear regression was used to determine which individual variables and which combination of variables had the highest correlations with the sprint times. The Akaike Information Criteria (AIC) was also used to determine the best combination of variables for predicting performance. The group of variables with the lowest AIC value and mean squared error (MSE) was considered to be the best. Significance was established at $p < .05$.

Results

The subjects displayed a wide range of sprinting ability. Ranging from 6.55-8.27 sec. in the 50m, 12.16-15.92 sec. in the 100m, and 22.7-30.75 sec. in the 200m. However, these times were highly reproducible. Correlations between the first and second sprints were $r=0.98$ for the 50m, $r=0.86$ for the 100m, and $r=0.88$ for the 200m. When each subjects best

time for each sprint was compared to the parameters taken from the ergometer test (PP, TTPP, PFR, PFI, AP) and the relative parameters (PP/kg, AP/kg, and PFR/kg) low correlations were found ($r = 0.07-0.55$) (table 1). After plotting the ergometer and relative parameters versus the sprint times, stronger relationships appeared to exist for the faster subjects. In fact for subjects whose 50m sprint times were below 7.5 sec. ($n=16$), 100m times below 14 sec. ($n=15$), and 200m times below 26.7 sec. ($n=15$) somewhat higher correlations were found ($r = 0.06-0.70$) (table 1).

Further analysis of the data revealed that high inter-variable correlations ($r \geq .88$) existed between several of the ergometer variables (table 2). Based on these correlations, the variables were separated into four groups. Group I contained variables of absolute power (PP, AP), group II were variables of relative power (PP/kg, AP/kg), group III consisted of variables of fatigue (PFR, PFI, PFR/kg), and finally group IV contained the only variable of acceleration (TTPP).

When the best variable from each of the four groups was compared to the sprint times, as expected negative correlations were found with the variable from the absolute power, relative power and fatigue groups, while a positive correlation was found with the acceleration variable (figures 1, 2, and 3). Although the magnitude of these correlations were

low the directions were as expected. For example, as PP/kg increased sprint time decreased.

Equations for predicting sprint performance were developed using a combination of one to four variables with only one variable from each group being used. Multiple regression was performed on all possible variable combinations and the best equation was considered to be the one that yielded the highest r^2 value while also yielding the lowest AIC value and MSE. These procedures were performed on the entire subject group and on the subgroups of more accomplished subjects (Tables 3 and 4). In the more accomplished group the best model for each distance contained two variables, one from the relative power group and one from the fatigue group (Table 4). This was somewhat surprising because acceleration was initially thought to be a large factor in the 50m sprint. As expected fatigue was a major factor in the 200m sprint.

The data obtained from these correlations was then used to develop equations for predicting sprint performance. These equations are presented in table 5. When the predicted sprint times were compared with the actual sprint times, it was noticed that these equations tended to predict even faster times for the faster subjects and slower times for the slower subjects (figures 4, 5, and 6). The subjects were then divided into subgroups, as described earlier. A separate set of prediction equations were derived from these data subsets.

These equations are presented in table 6. For most of the subjects in these subgroups the equations predicted slower sprint times than were actually the case. However, the faster subjects still had faster predicted times and the slower subjects had slower predicted times (figures 7, 8, and 9).

Discussion

These results show that performance on this cycle ergometer test can account for a significant amount of the variability in performance for the 50m, 100m, and 200m dashes of untrained male subjects. This investigation also demonstrated that the cycle ergometer test used in this investigation is a better predictor of performance for a group of faster subjects than for a large heterogeneous group. Furthermore, this cycle ergometer showed a better ability to predict performance for the 200m sprint than for the 50m sprint.

The most indicative parameters of performance were the relative power and fatigue variables. Surprisingly, especially for the 50m sprint, of the four parameter groups that were used, acceleration, namely TTPP, was the poorest indicator of performance. Initially TTPP was thought to play a large part in short sprint performance. However, these results suggest that either TTPP, as determined by cycle ergometry, is not a sensitive measure of acceleration during a sprint, and/or acceleration contributes little to

performance in this subject group.

As established earlier, the cycle ergometer can account for a significant portion of the variability associated with sprint performance. However it cannot account for all of the variability. There are a number of factors which might account for this unexplained variance. First is the extent to which upper body arm movement contributes to sprint performance. The arms and shoulders contribute to sprint performance mainly as compensatory movements. For example, if you viewed a sprinter from above you would notice that as the lower body (hips and legs) rotates clockwise the upper body (arms and shoulders) rotates counter-clockwise. Also as the left leg comes forward the right arm goes back and vice versa (Tricker, and Tricker, 1967). Another factor may be that these were untrained subjects. This conclusion is supported by the fact that there was a stronger correlation between the power output values and sprint performance of the group of faster subjects. Also these subjects were untrained in using starting blocks. It has been suggested that trained sprinters are better able to convert the isometric forces exerted on the starting blocks into propelling force for sprinting (Ikai, 1967). This may also explain why TTPP was a poor indicator of performance. Another possibility is the difference in exercise duration between the cycle ergometer and sprint efforts. It took longer to run the 200m than it

did to complete the power test. However longer cycle ergometer tests have been associated with a decrease in peak power output. This has been attributed mostly to motivational factors (Burke et al., 1985). Finally there are differences between cycling and running. As discussed earlier cycling does not utilize the upper body. When the subject is cycling his feet travel in a circular path. Although the path of a sprinters feet does not move in a perfectly circular path, it does follow the motion of a point on the circumference of a wheel surprisingly closely (Tricker et al., 1967). For the most part the same major muscle groups are used for both actions, but the application of forces from these muscles differs somewhat.

These data suggest that the cycle ergometer test used in this investigation can be used for evaluating the components of sprint performance in untrained males. They also suggest that this test is best when it is compared to the 200m dash. It remains to be seen if this test is applicable to trained or elite calibre athletes and females, and if specific training programs improve specific aspects of sprint performance. The results from this study suggest that the ergometer test may yield better results with trained sprinters. This raises the possibility that this test could be used to design training program targeted at specific sprinting deficiencies, and then used to evaluate these

programs. For example, a sprinter who displays high PP/kg but a lower PP compared to other sprinters may want to work on other aspects of his performance instead of trying to generate a higher PP. Also a sprinter with a high PFR/kg may want to work on his short term endurance in order to improve his performance. A coach, trainer, or athlete could then use this information to construct a specific training program. The ergometer test could then be used to gauge progress and quantify resulting changes in performance. Further study in this area is needed to confirm these speculations.

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Figure Captions

Figure

- 1 Individual Variable Plots For The 50m Sprint
- 2 Individual Variable Plots For The 100m Sprint
- 3 Individual Variable Plots For The 200m Sprint
- 4 Residuals For All Subjects In The 50m Sprint
- 5 Residuals For All Subjects In The 100m Sprint
- 6 Residuals For All Subjects In The 200m Sprint
- 7 Residuals For Subject Subgroup In The 50m Sprint
- 8 Residuals For Subject Subgroup In The 100m Sprint
- 9 Residuals For Subject Subgroup In The 200m Sprint

Table 1

Correlation Coefficients Between Each Power Parameter
and Sprint Times (All Subjects (n=25))

Ergometer

<u>Parameters</u>	<u>50m Time</u>	<u>100m Time</u>	<u>200m Time</u>
PP	-0.30	-0.43	-0.32
TTPP	0.14	0.19	0.14
PFR	-0.16	-0.18	-0.21
PFI	-0.11	-0.07	-0.16
AP	-0.30	-0.45	-0.32
PP/kg	-0.37	-0.50	-0.55
AP/kg	-0.37	-0.51	-0.54
PFR/kg	-0.17	-0.15	-0.28

Subject Subgroups

<u>Ergometer</u>	<u>50m Time</u>	<u>100m Time</u>	<u>200m Time</u>
<u>Parameters</u>	<u>(n=16)</u>	<u>(n=15)</u>	<u>(n=15)</u>
PP	-0.22	-0.24	-0.04
TTPP	0.06	0.04	0.21
PFR	-0.27	-0.22	-0.39
PFI	-0.34	-0.32	-0.47
AP	-0.33	-0.34	-0.16
PP/kg	-0.38	-0.59	-0.46
AP/kg	-0.54	-0.70	-0.62
PFR/kg	-0.27	-0.14	-0.29

Table 2

Correlation Matrix

Correlation Coefficients Between Each Power Parameter For All Subjects r values ≥ 0.38 are Significantly Different Than 0

($p < .05$, $n=25$)

	PP	TTPP	PFR	PFI	AP	PP/kg	PFR/kg	AP/kg
PP	1							
TTPP	-.39	1						
PFR	.71	-.22	1					
PFI	.43	-.41	.89	1				
AP	.98	-.34	.59	.28	1			
PP/kg	.66	-.23	.53	.38	.65	1		
PFR/kg	.49	-.12	.92	.88	.36	.63	1	
AP/kg	.59	-.14	.33	.14	.62	.97	.43	1

Table 3

Reduced 4 Variable Models

All Subjects (n=25)

Multiple Regression Results

Best Model Based on Highest r^2 , Lowest AIC, and MSE

* Designates the Best Model

 $r^2 \geq 0.145$ is significant

<u>Sprint Distance</u>	<u>Parameters Used</u>	<u>r^2</u>	<u>MSE</u>	<u>AIC</u>
50m	* PP/kg	0.14	0.15	-45.90
	PP/kg, PFR/kg	0.15	0.15	-44.11
	PP, PFR, PP/kg	0.15	0.16	-42.29
	TTPP, PFR, AP, PP/kg	0.15	0.17	-40.32
100m	* AP/kg	0.26	0.63	-9.48
	AP, AP/kg	0.29	0.64	-8.48
	PP, PP/kg, PFR/kg	0.31	0.64	-7.34
	PP, TTPP, PP/kg, PFR/kg	0.31	0.68	-5.35
200m	* PP/kg	0.30	3.80	35.30
	PFR, PP/kg	0.31	3.93	36.99
	TTPP, PFR, PP/kg	0.31	4.11	38.97
	PP, TTPP, PFR, PP/kg	0.31	4.31	40.96

Table 4

Reduced 4 Variable Models

Multiple Regression Results

Best Model Based on Highest r^2 , Lowest AIC, and MSE

Subject Subgroups

* Designates the Best Model

Sprint Distance	Parameters Used	r^2	MSE	AIC
50m (n=16)	AP/kg	0.29	0.05	-46.49
(T < 7.5sec) *	AP/kg, PFR/kg	0.44	0.04	-48.36
($r^2 \geq 0.232$	PP, PFR, AP/kg	0.45	0.04	-46.47
is significant)	TTPP, PFR, AP, PP/kg	0.45	0.05	-44.69
100m (n=15)	AP/kg	0.50	0.13	-28.71
(T < 14.0sec) *	PFR, AP/kg	0.53	0.13	-27.88
($r^2 \geq 0.247$	PFR, AP, AP/kg	0.54	0.14	-26.03
is significant)	TTPP, PFR, AP, AP/kg	0.54	0.15	-24.18
200m (n=15)	AP/kg	0.39	1.20	4.62
(T < 26.6sec) *	PFR, AP/kg	0.63	0.79	0.99
($r^2 \geq 0.247$	PP, PP/kg, pfr/kg	0.64	0.85	0.82
is significant)	TTPP, AP, PP/kg, PFR/kg	0.64	0.93	2.80

Table 5

Prediction Equations

Reduced 4 Variable Model

All Subjects

$$50\text{m time} = 8.87 - 0.110 (\text{PP/kg})$$

$$100\text{m time} = 18.58 - 0.405 (\text{AP/kg})$$

$$200\text{m time} = 38.49 - 0.906 (\text{PP/kg})$$

Subjects Subgroups

$$50\text{m time} = 8.69 - 0.168 (\text{AP/kg bod. wt.}) + 1.093 (\text{PFR/kg})$$

$$100\text{m time} = 16.62 + 0.015 (\text{PFR}) - 0.314 (\text{AP/kg})$$

$$200\text{m time} = 34.96 + 0.124 (\text{PFR}) - 0.992 (\text{PP/kg})$$

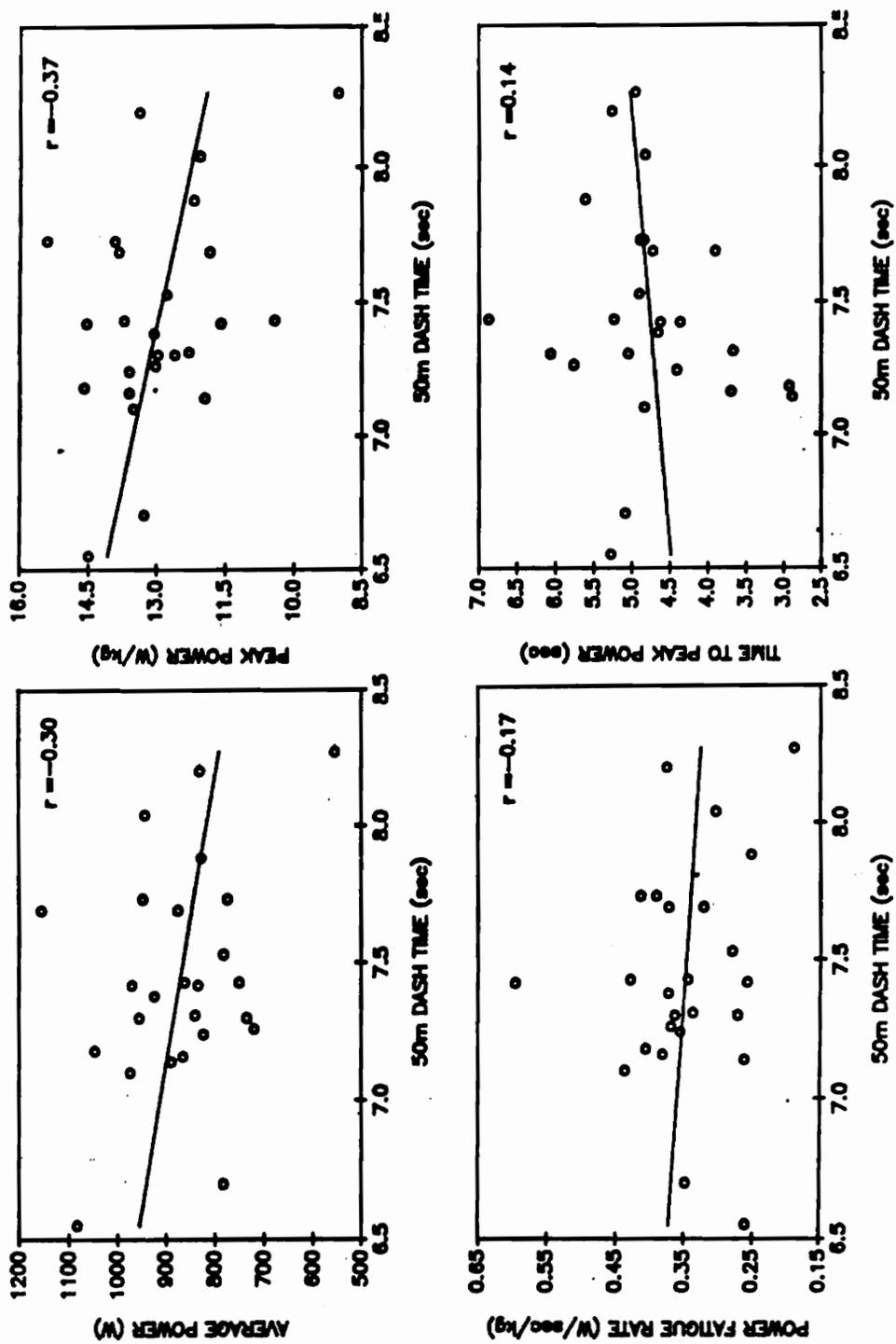


Figure 1

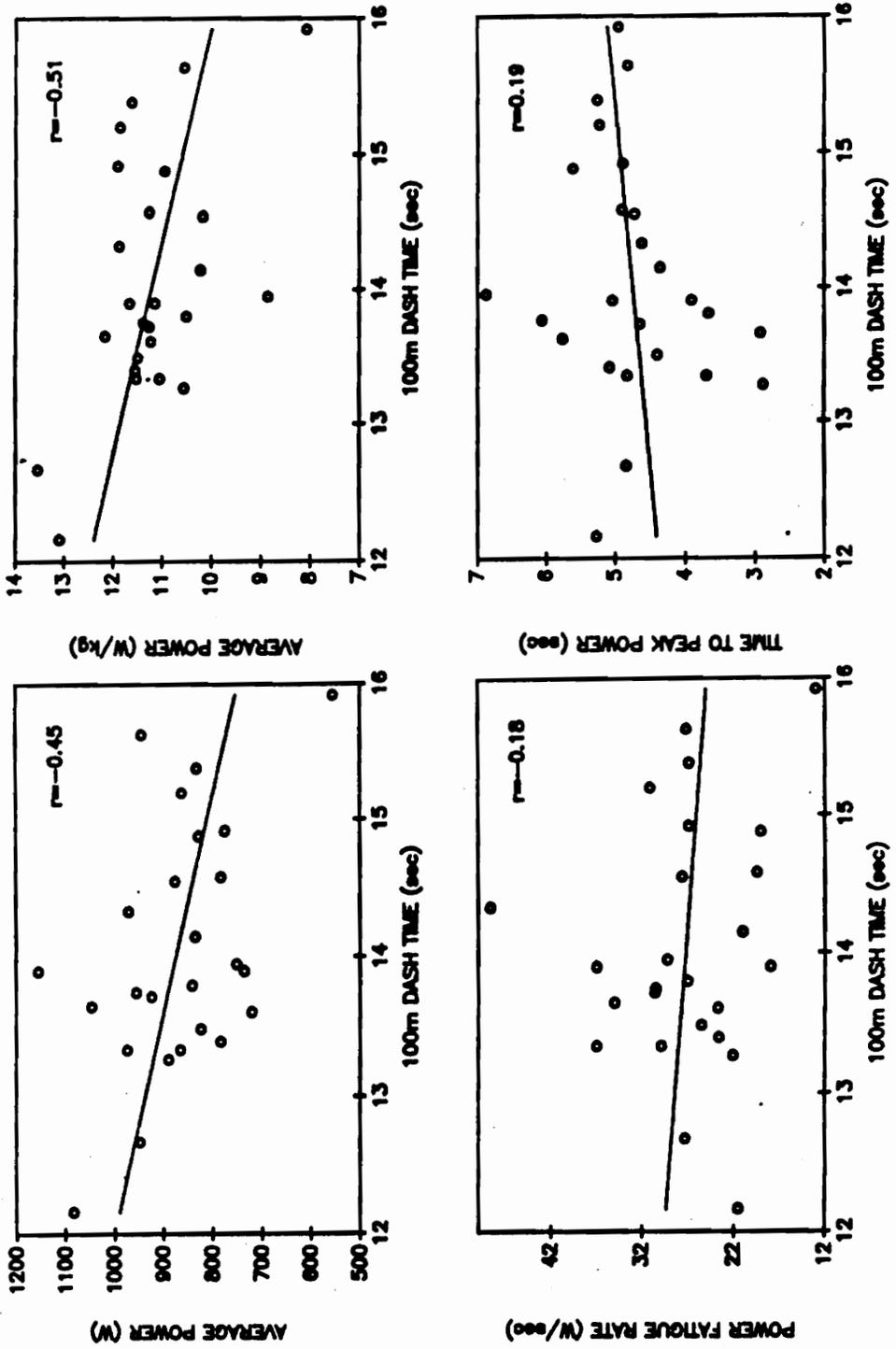


Figure 2

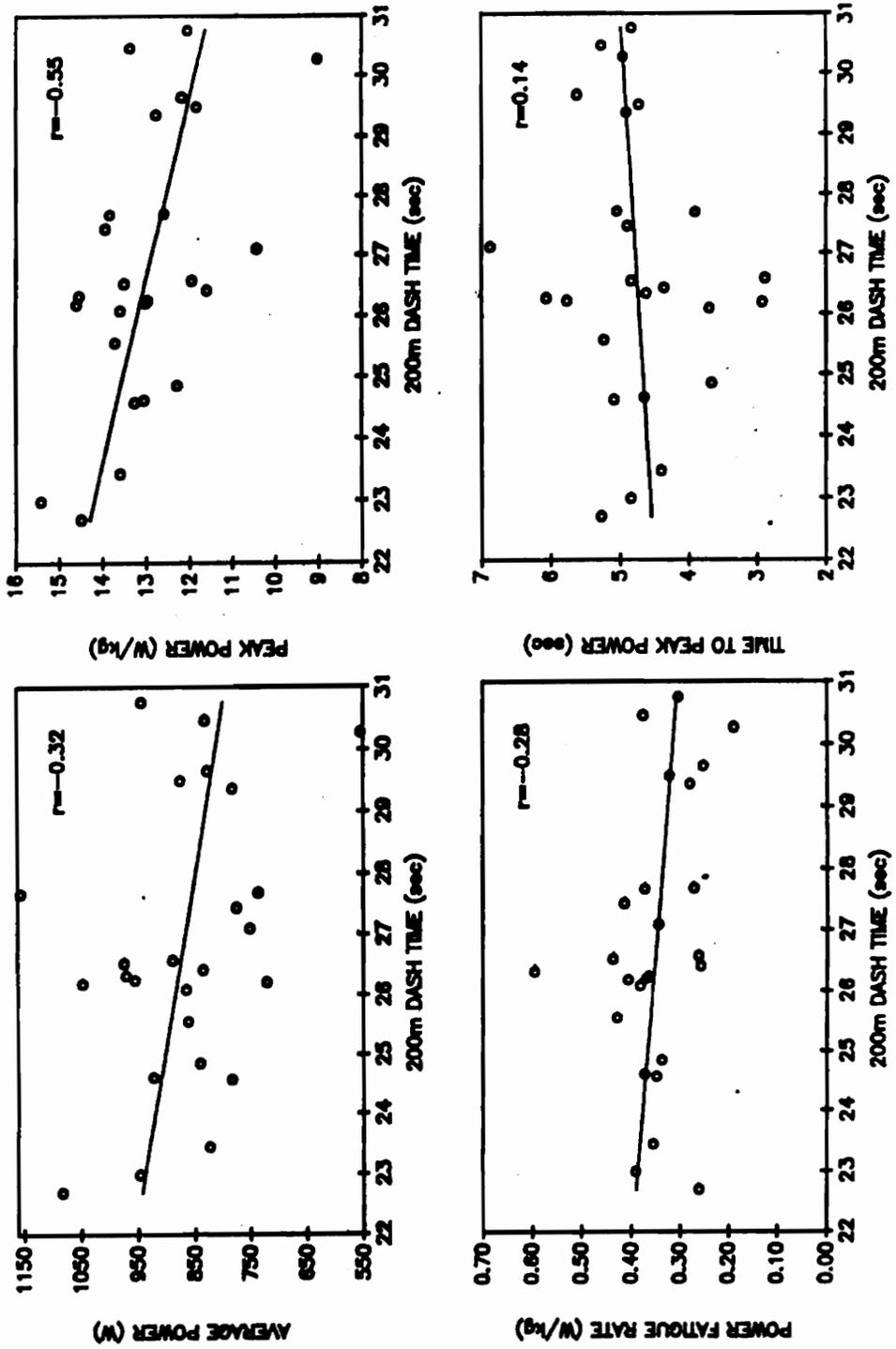
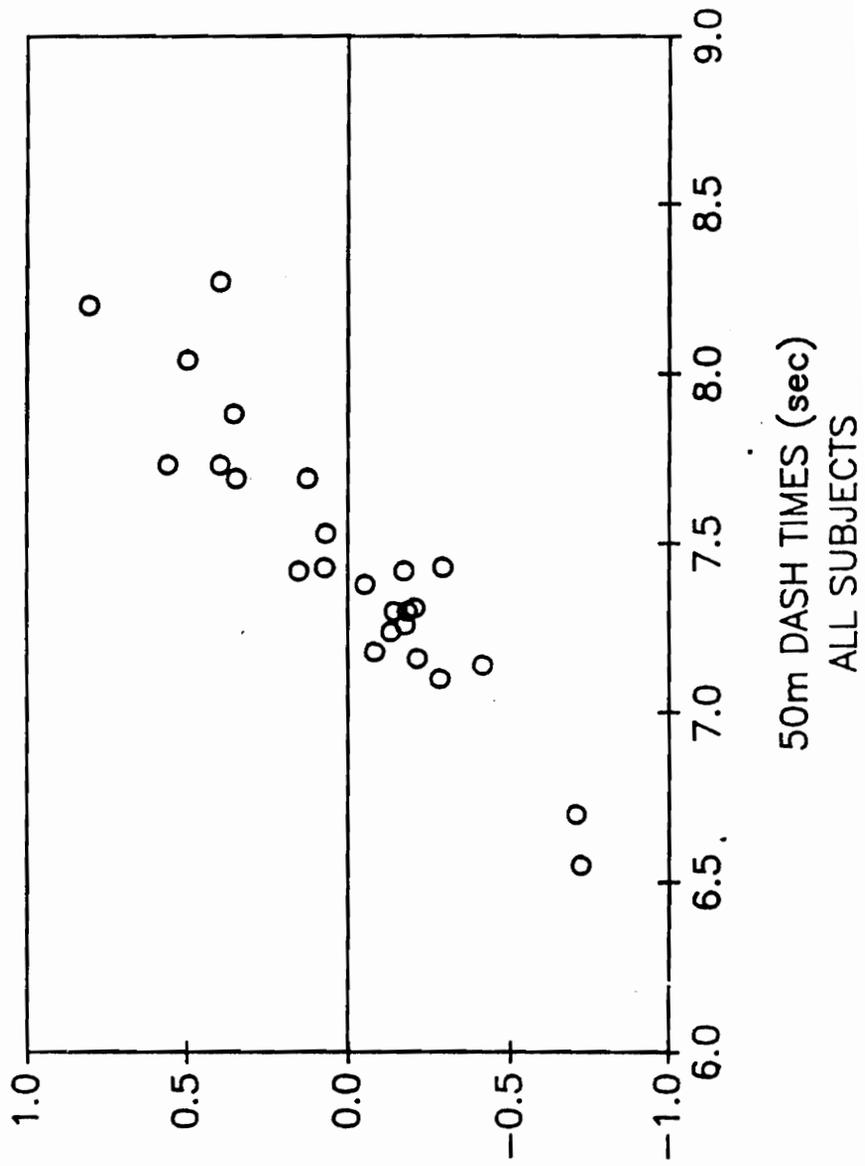


Figure 3



RESIDUALS

Figure 4

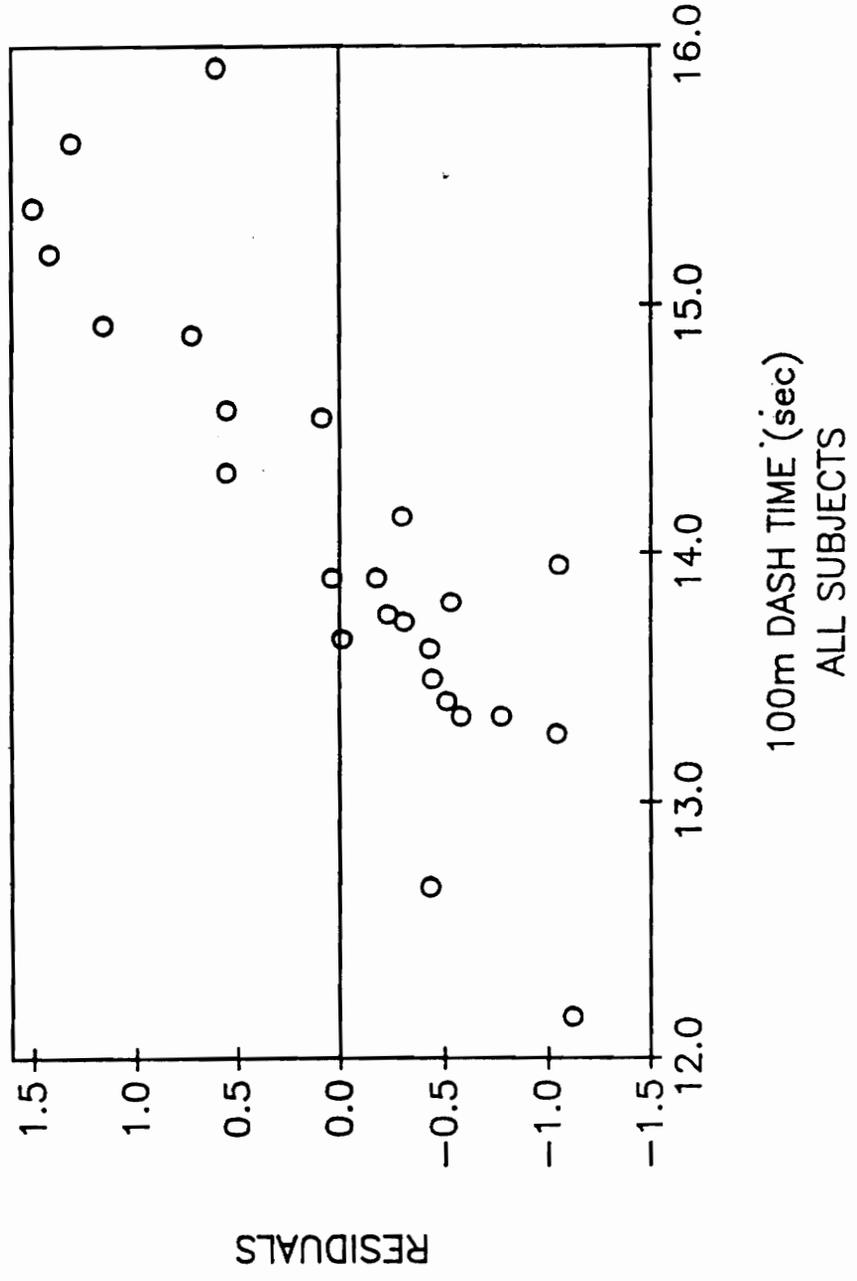


Figure 5

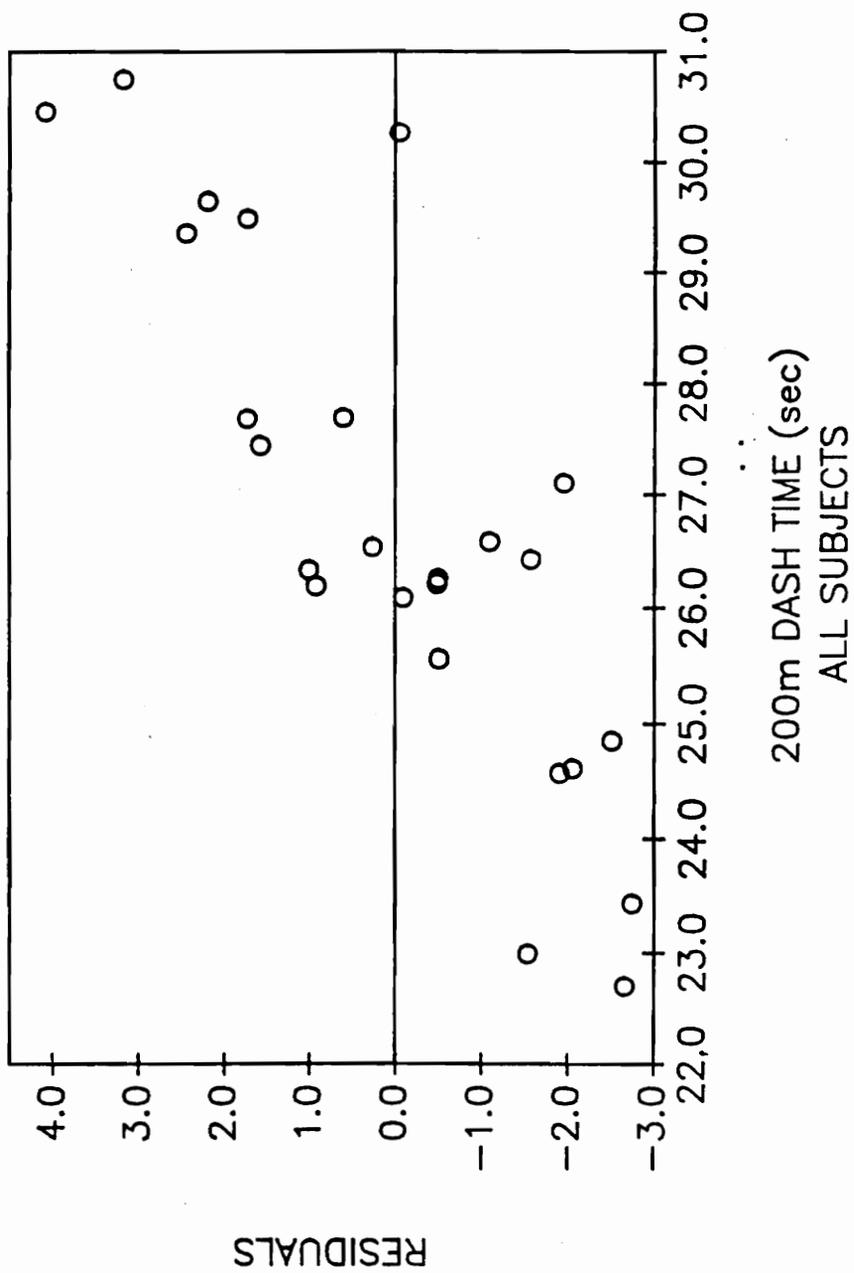


Figure 6

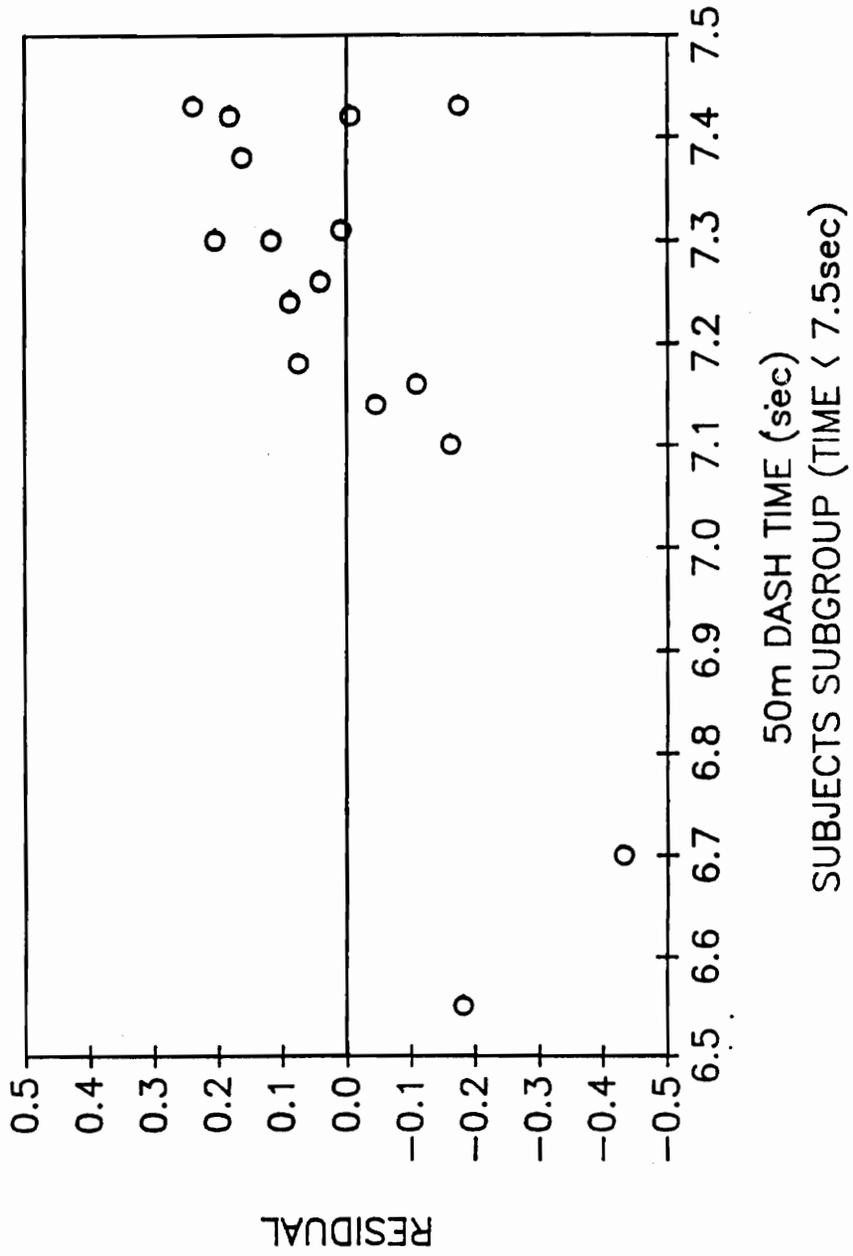


Figure 7

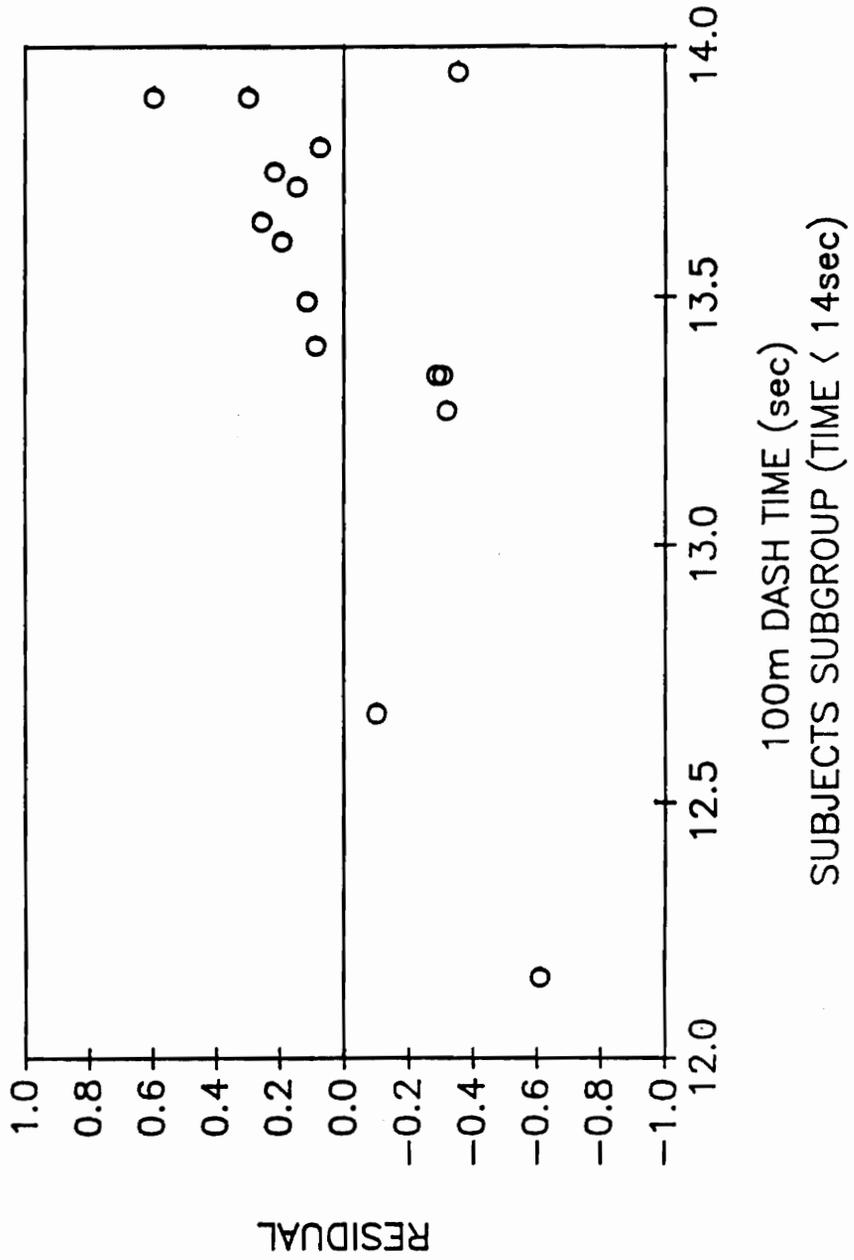


Figure 8

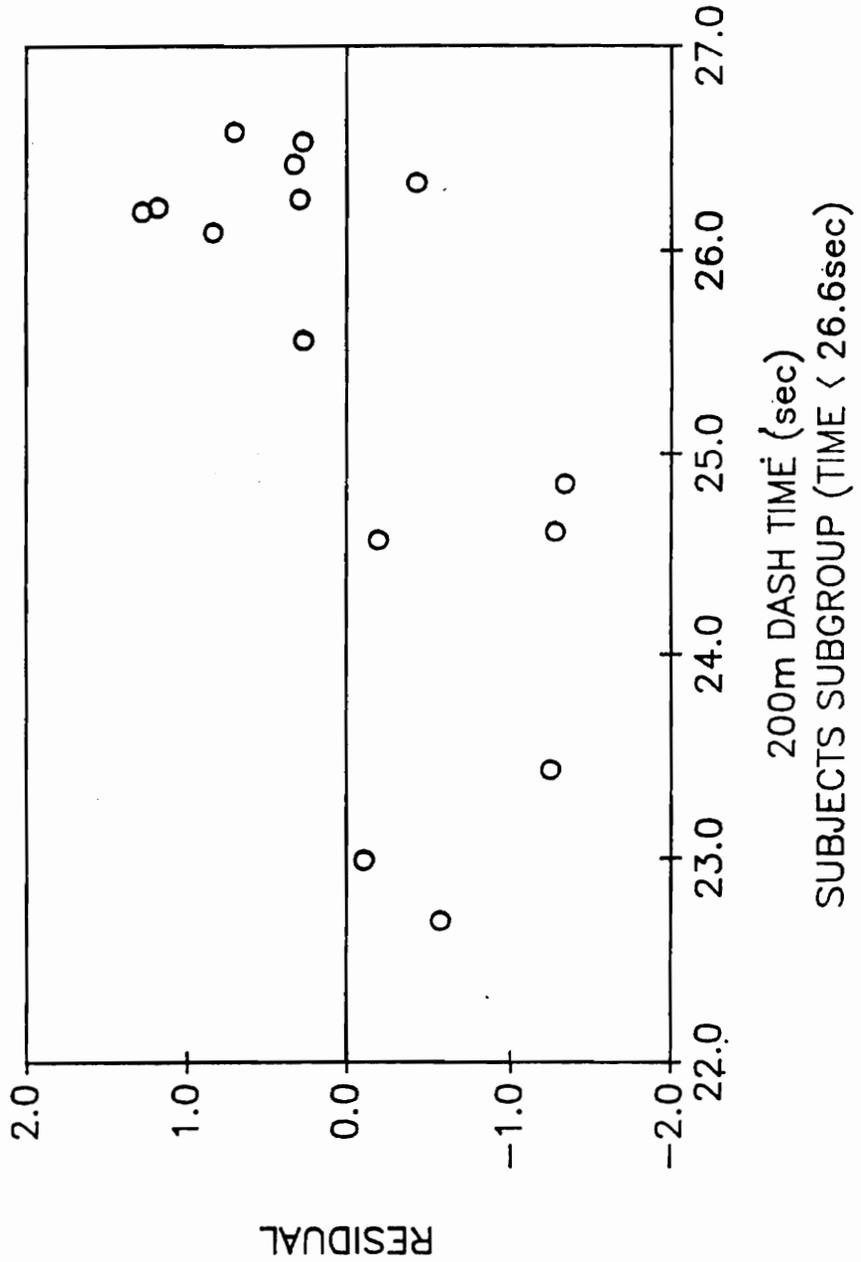


Figure 9

Chapter IV

Summary

Little work has been done studying the factors which might affect short-term, intense, sprint-type activities. This is unfortunate because short explosive bouts of activity are very common in our daily activities. More study in this area might take place if better laboratory measures of physiologic variables that relate to sprinting such as maximal power and fatigue were available. The present study compared sprint times in the 50m, 100m, and 200m with a high intensity cycle test. Twenty-five untrained college males performed a cycle ergometer test and performed the sprint tests. The cycling protocol consisted of a three minute warm-up followed by a 15 second maximal effort. The ergometer was preloaded with 0.12 kg/kg of hydrated bodyweight and was connected to a micro-computer for data collection. Peak power (PP), time to peak power (TTPP), average power (AP), power fatigue rate (PFR), and power fatigue index (PFI) were determined by the micro-computer. The sprint protocol consisted of at least a five minute warm-up of stretching jogging and very short sprints and sprint starts followed by 6 sprints, 2 at 50m, 2 at 100m, and 2 at 200m. A minimum of 15 minutes rest was given between each sprint. Further details on the methodology of the current study are presented in Appendix A.

Results

The subjects displayed a wide range of sprinting ability. Ranging from 6.55-8.27 seconds in the 50m, 12.16-15.92 seconds in the 100m and 22.7-30.75 seconds in the 200m. However, the sprint times were highly reproducible. Correlations between the first and second sprints were $r=0.98$ for the 50m, $r=0.86$ for the 100m, and $r=0.88$ for the 200m. When each subjects best time for each event was compared to the parameters taken from the ergometer test and relative parameters (PP/kg, PFR/kg, AP/kg) low correlations were found ($r= 0.07-0.55$). After plotting the relative parameters and those taken from the ergometer versus sprint times natural breaks in the data were observed. 50m sprint times below 7.5 seconds, 100m times below 14 seconds, and 200m times below 26.7 seconds showed higher correlations ($r= 0.04-0.70$).

Further analysis of the data revealed that high inter-variable correlations existed between many of the relative and ergometer variables. Judging from these correlations, the variables were separated into four groups. Group I contained variables of absolute power (AP, PP), group II were variables of relative power (PP/kg of bodyweight, AP/kg of bodyweight), group III were variables of fatigue (PFR, PFI, PFR/kg of bodyweight), finally group IV contained the only variable of acceleration (TTPP).

Equations for predicting sprint performance were

developed using a combination of 1 to 4 variables with one variable from each group used. The best equation was considered to be the one that yielded the highest r^2 value while also yielding the lowest Akaike Information Criteria (AIC) value and Mean Square Error (MSE). For each sprint distance the best model contained two variables, one from the relative power group and one from the fatigue group. This was somewhat surprising because acceleration was initially thought to be a large factor in the 50m sprint. As expected fatigue was a major factor in the 200m sprint.

Power Output

When the best variable from each of the 4 groups was compared to sprint times, as expected negative correlations were found with the variable from the absolute power, relative power, and fatigue groups, while a positive correlation was found with the acceleration variable. Although these correlations are quite low, the general trends of the data were as expected. At each distance the variable representing the relative power group had the highest correlation with sprint time.

The data obtained from these correlations was then used to develop equations for predicting sprint performance. These equations are presented in table 5. When predicted sprint times were compared with the actual sprint times, it was noticed that these equations tended to predict even faster

times for the faster subjects and slower times for the slower subjects. The subjects were then divided into subgroups, as described earlier. Different prediction equations were derived from these data subsets. These equations are presented in table 5. For most of the subjects in these subgroups the equations predicted slower sprint times than were actually the case. However, as with the full subject group, the faster subjects had faster predicted times and the slower subjects had slower predicted times.

Discussion

These results show that performance on this cycle ergometer test can account for a significant amount of the variability in performance for the 50m, 100m, and 200m dashes of untrained subjects. These results also show that this cycle ergometer is a better method of predicting performance for a group of faster subjects than for a large heterogeneous group. The cycle ergometer also showed a better ability to predict for the 200m sprint than for the 50m sprint. This is somewhat surprising because the cycle ergometer test did not last as long as the 200m sprint did.

Relative power and fatigue were the most indicative parameters of sprint performance. This was expected for a longer sprint such as the 200m, but was unexpected for a short sprint like the 50m. Surprisingly of the four parameter groups that were used acceleration, namely TTPP, was the poorest

indicator of performance. In the 50m sprint especially this parameter was thought to play a large role in performance. Initially TTPP was thought to play a large part in short sprint performance because initially little fatigue takes place in the first few seconds after a subject reaches PP. Therefore, the logical assumption is that the faster a sprinter reaches PP then he will run a greater portion of this short sprint at or near PP. This should result in a faster sprint performance. These results suggest that either TTPP as determined by cycle ergometry is not a sensitive measure of acceleration during a sprint and/or acceleration contributes little to performance in this group of subjects.

As stated earlier the cycle ergometer test can account for a significant portion of the variability associated with sprint performance. However it cannot account for all of the variability. One factor that contributes to this variability is to what extent upper body arm movement contributes to sprint performance. The upper body, namely the arms and shoulders, contribute to sprint performance mainly as compensatory movements. For example, if you viewed a sprinter from above you would notice that as his left leg comes forward, his right leg drops back. This results in a clockwise rotation of the lower body, namely the legs and hips. In order for this to happen, a clockwise angular momentum must be generated. This is done partially through

contact with the ground but mainly through the use of the abdominal muscles. Using the abdominal muscles to achieve this clockwise angular momentum also results in an equal counter-clockwise angular momentum in the upper body. Put simply, as the legs and hips rotate clockwise the arms and shoulders rotate counter-clockwise. As the left leg comes forward the left arm goes back and vice versa (Tricker et al., 1967). The question arises that if the legs are longer and have more mass than the arms then how can the arms possibly compensate for the angular momentum of the legs. Since the feet come in contact with the ground and the arms do not, complete compensation may not be necessary. However, the moment of inertia of the arms can be increased by holding them away from the body (Tricker et al., 1967).

Another factor may be that these were untrained subjects. This conclusion is supported by the fact that there was a stronger correlation between the power output values and the sprint performance of the group of faster subjects. Also these subjects were untrained in using starting blocks. It has been suggested that trained sprinters are better able to convert the isometric forces exerted on the starting blocks into propelling force for sprinting (Ikai, 1967). This could explain why TTPP was a poor indicator of performance. Another possibility is the difference in exercise duration between the cycle ergometer and sprint efforts. It took longer to run the

200m than it did to complete the power test. However, longer cycle ergometer tests have been associated with a decrease in peak power output. This has been attributed mostly to motivational factors (Burke et al., 1985). Finally there are differences between cycling and running. As discussed earlier cycling does not utilize the upper body. When the subject is cycling his feet travel in a circular path. Although the path of a sprinters feet does not move in a perfectly circular path, it does follow the motion of a point on the circumference of a wheel suprisingly closely (Tricker et al., 1967). For the most part the same major muscle groups are used for both actions, but the magnitude and direction of force application by these muscles may differ somewhat.

Applicability

These data suggest that the cycle ergometer test used in this investigation can be used for evaluating the components of sprint performance in untrained males. They suggest that this test is best when it is compared to the 200m sprint. It remains to be seen if this test is applicable to trained or elite calibre athletes and females.

Suggestions For Further Research

Further research with this ergometer test should focus on whether or not using trained sprinters yeilds different results. Also this test should be done with elite sprinters. The results of the present investigation suggest that if more

highly trained subjects are used then more sprinting variability can be accounted for. Females have not been studied using this power test this is another obvious avenue for further research. Future projects could use more motion detectors and timers perhaps placing one every ten meters. This would generate a speed curve similar to the one found by Akai (1967). Specific comparisons could then be made between the speed curve and the power curve. Another project could involve a sprint training program. Measurements could be taken before and after the training program. After completing the program, the subjects should have faster sprint times and this should be reflected by changes in the power values from the ergometer. Another investigation might compare the cycle ergometer test to sprint cycling.

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Appendix A
METHODOLOGY

Methodology

Subjects

25 college age males (mean \pm SE age 20.56 \pm 1.41 years, height 178.02 \pm 5.02 cm, and weight 77.8 \pm 8.85kg) were used for this investigation. All of the subjects were physically active but none were currently engaged in an organized training program.

Each subject was required to read and sign an informed consent form (appendix E). This form explained the risks and benefits involved with high intensity cycle ergometer tests and sprinting. The investigator then verbally reviewed the form with the subject and answered any question the subject had.

The subject was first oriented with the testing equipment and testing procedures. He was then allowed to ride the ergometer without a load on it. This allowed the subject to get a feel for the apparatus. Upon completion of the orientation, the subject scheduled his cycle test. Each subject was instructed to abstain from exercise for at least twelve hours prior to any of the tests. Finally the subjects were told that they were not allowed to perform both the cycle and the sprint tests on the same day.

Ergometer Testing

A modified 818 front loading Monark cycle ergometer was

used in conjunction with a microcomputer to collect and record the power output data from each subject. Power output was computed for each one-half pedal revolution. The ergometer's flywheel resistance strap was attached to an electronic load cell (Genesco AVW-250), wrapped around the flywheel and over a pulley so that calibrated weights could be attached. Two small magnets were mounted on the pedal sprocket at 0 and 180 degrees, and a magnetic reed switch was mounted on the ergometer frame near the top of the pedal sprocket. A 9-volt power supply was connected to the reed switch so that when a magnet passed over the switch a square wave pulse was generated. Thus two pulses were generated for each pedal revolution. Signals from both the load cell and the reed switch were amplified by an AMOD-x amplifier (3mv/3VDC), sampled at 500Hz and digitized by a Metra Byte, 16-bit analog-to-digital converter. These signals were then stored for later analysis. Flywheel velocity was calculated for each one-half revolution. This was done by dividing the distance travelled by the flywheel (3m) by the time interval between square wave pulses. The resistive load was calculated by taking the difference between the load attached to the resistance strap and the load registered by the load cell. Power output was then calculated as the product of force and velocity. Output from the computer consisted of a graph which plotted power vs. time. The computer also calculated the

following indices; peak power (PP), time to peak power (TTPP), average power (AP), power fatigue rate (PFR), and the power fatigue index (PFI). In addition to these parameters peak power, average power, and power fatigue rate were expressed by bodyweight; peak power per kg of bodyweight (PP/kg), average power per kg of bodyweight (AP/kg), and power fatigue rate per kg of bodyweight (PFR/kg).

The protocol for the cycle ergometer consisted of a three minute warm-up at 50 rpms . The resistance load for the ergometer was then set at 0.12kg/kg of bodyweight (Davy et al., 1990). The test began with the pedals in a static horizontal position with the subject's preferred foot forward. Toe clips were also worn. At the sound of the tone from the computer the subject began pedalling. The subject gave an all out maximal cycling effort for 15 seconds. The preceding cycle ergometer design, cycling protocol and data collection programs were modeled after those used by Williams et al., (1988). Previous work using this ergometer system has shown very high test-retest correlations coefficients ($r=0.90-0.95$). For this reason only one cycle ergometer bout was required for each subject (Williams et al., 1988).

Sprint Testing

Sprint performance was based on the finish time for each sprint. Each sprint was performed individually and took place

on an outdoor track using starting blocks and an auditory starting signal. Since the sprints took place on an outdoor track care was given to avoid adverse conditions. To this end no sprints were run on days when there was a lot of wind and all sprints were run on a dry track.

The subjects were allowed to warm up until they felt comfortable. This warm up consisted of light jogging, stretching, and practicing sprint starts. All of the sprint tests were done in the following order. Two trials at 50m followed by two trials at 100m and finally two trials at 200m. Each subject was given a minimum of 15 minutes of rest between each trial. This helped to ensure that a maximal effort was given on each trial. High test-retest correlations were found between sprint trials at each distance (50m $r=0.98$, 100m $r=0.86$, 200m $r=0.88$). Thus, although the subjects were not specifically sprint trained their sprint times were still highly reliable. The best time at each distance was used for comparison with the cycle ergometer data.

When the subject was ready the starter depressed a switch. This simultaneously started the electronic timer and sounded an auditory tone. At the sound of the tone the subject began sprinting. At the finish line was placed an infra-red motion detector. Directly opposite the infra-red unit on the other side of the sprinting lane was a reflector. The beam, emitted by the infra-red unit, bounced off of the

reflector and was picked up again by the same unit that emitted it. The infra-red unit was connected to the electronic timer. Once the timer was started it ran freely as long as the infra-red beam was intact. Once the beam was broken the timer stopped. The time was then recorded by the investigator.

Statistics

Multiple linear regression was used to determine which variables and which combination of variables had the highest correlations with the sprint times. The Akaike Information Criteria (AIC) was also used to determine the best combination of variables for predicting sprint performance. The group of variables with the highest r^2 value and the lowest AIC and MSE values was considered to be the best. All of the statistical procedures were performed by the Statistical Analysis System (SAS). Significance was established at $p < 0.05$ for the MAXR procedure that was used.

Appendix B
REGRESSION RESULTS
FOR ALL SUBJECTS
AND SUBJECT SUBGROUPS

Table 6

Regression Results of the Power Parameters and the 50m Dash

All Subjects ($r^2 \geq 0.145$ is significant) .

Parameters Used	r^2	MSE	SSE	AIC
PP/kg	.14	.15	3.40	-48.06
PP/kg, PFR/kg	.15	.15	3.32	-46.12
PFI, PP/kg, PFR/kg	.16	.16	3.32	-44.50
TTPP, PFI, PP/kg, PFR/kg	.22	.15	3.10	-44.43
TTPP, PFI, PP/kg, PFR/kg, AP/kg	.29	.16	2.79	-41.81
PP, PFR, AP, PP/kg, PFR/kg, AP/kg	.29	.16	2.79	-42.81
PP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.29	.16	2.79	-40.87
PP, TTPP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.32	.17	2.68	-39.87

Table 7

Regression Results of the Power Parameters and the 100m Dash
 All Subjects ($r^2 \geq 0.145$ is significant)

Parameters Used	r^2	MSE	SSE	AIC
AP/kg	.26	.63	14.58	-11.48
AP, AP/kg	.29	.64	14.01	-10.48
PFR, PP/kg, PFR/kg	.31	.64	13.49	-9.43
TTPP, PFI, PP/kg, PFR/kg	.38	.61	12.24	-9.85
TTPP, PFR, PFI, PP/kg, PFR/kg	.38	.64	12.08	-8.18
PP, TTPP, PFR, PFI, PP/kg, PFR/kg	.40	.66	11.81	-6.75
PP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.41	.68	11.58	-5.25
PP, TTPP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.46	.67	10.70	-5.22

Table 8

Regression Results of the Power Parameters and the 200m Dash

All Subjects ($r^2 \geq 0.145$ is significant)

Parameters Used	r^2	MSE	SSE	AIC
PP/kg	.30	3.80	87.45	33.30
PFR, PP/kg	.31	3.93	86.36	34.99
PFR, PFI, PP/kg	.31	4.09	85.90	36.86
PFR, PFI, AP, PFR/kg	.32	4.23	84.70	38.51
TTPP, PFR, PFI, AP, PP/kg	.34	4.36	82.77	39.93
PP, PFR, AP, PP/kg, PFR/kg, AP/kg	.39	4.22	75.89	39.76
PP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.39	4.46	75.84	41.74
PP, TTPP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.39	4.72	75.48	43.63

Table 9

Regression Results of the Power Parameters and the 50m Dash
 Subjects Subgroup (n=16) (Times < 7.5sec)
 ($r^2 \geq 0.232$ is significant)

Parameters Used	r^2	MSE	SSE	AIC
AP/kg	.29	.048	.68	-48.50
PFR/kg, APkg	.44	.041	.54	-50.37
PFI, PFR/kg, AP/kg	.56	.044	.42	-48.43
TTPP, PFI, PFR/kg, AP/kg	.56	.038	.42	-50.13
TTPP, PFI, PP/kg, PFR/kg, AP/kg	.56	.042	.42	-48.20
PP, TTPP, PFI, AP, PP/kg, PFR/kg	.56	.046	.42	-46.32
PP, TTPP, PFI, AP, PP/kg, PFR/kg, AP/kg	.56	.052	.42	-44.32
PP, TTPP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.57	.059	.41	-42.47

Table 10

Regression Results of the Power Parameters and the 100m Dash
 Subjects Subgroup (n=15) (Times < 14.0sec)
 ($r^2 \geq 0.247$ is significant)

<u>Parameters Used</u>	r^2	MSE	SSE	AIC
AP/kg	.49	.130	1.69	-30.71
PP/kg, AP/kg	.57	.119	1.43	-31.23
PFI, PP/kg, AP/kg	.62	.115	1.27	-31.02
TTPP, PFI, PFR/kg, AP/kg	.69	.103	1.03	-32.15
TTPP, PFI, PP/kg, PFR/kg, AP/kg	.71	.106	.95	-31.33
PP, TTPP, PFR, PFI, AP, PFR/kg	.80	.084	.68	-34.45
PP, TTPP, PFR, PFI, AP, PP/kg, AP/kg	.81	.091	.64	-33.39
PP, TTPP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.81	.106	.64	-31.39

Table 11

Regression Results of the Power Parameters and the 200m Dash
Subjects Subgroup (n=15) (Times < 26.6sec)

($r^2 \geq 0.247$ is significant)

<u>Parameters Used</u>	<u>r^2</u>	<u>MSE</u>	<u>SSE</u>	<u>AIC</u>
AP/kg	.39	1.20	15.63	2.62
PFR, PP/kg	.63	.78	9.41	-2.99
PFR, PFI, PP/kg	.63	.85	9.35	-1.09
PP, PFR, PP/kg, PFR/kg	.64	.91	9.06	.43
PP, TTPP, PFI, PP/kg, PFR/kg	.69	.87	7.83	.25
PP, TTPP, PFR, PFI, PP/kg, PFR/kg	.72	.88	7.02	.61
PP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.80	.71	4.98	-2.54
PP, TTPP, PFR, PFI, AP, PP/kg, PFR/kg, AP/kg	.84	.69	4.16	-3.24

Appendix C

RAW DATA

Raw Data

Sprint times

SUBJECT	50MT1	50MT2	100MT1	100MT2	200MT1	200MT2
1	8.04	8.17	15.63	15.96	30.75	30.83
2	7.24	7.32	13.49	15.05	23.43	27.10
3	7.42	7.64	14.33	14.44	26.33	27.22
4	8.27	8.46	15.92	16.32	30.27	32.26
5	7.26	7.44	13.61	13.61	26.21	26.66
6	7.14	7.19	13.27	13.34	26.58	27.03
7	7.42	7.45	14.15	14.17	26.42	26.66
8	7.38	7.41	13.72	14.24	24.61	25.10
9	7.88	7.90	14.88	15.23	29.65	32.41
10	7.31	7.43	13.80	13.89	24.85	25.08
11	6.55	6.76	12.16	12.26	22.70	26.15
12	7.73	7.81	12.67	12.67	22.99	-----
13	7.16	7.20	13.34	13.56	26.09	27.80
14	7.43	7.43	15.20	15.99	25.56	25.75
15	7.10	7.11	13.34	15.57	26.53	28.08
16	8.20	8.26	15.38	15.70	30.46	32.36
17	7.30	7.33	13.75	13.81	26.25	-----
18	6.70	6.89	13.40	13.51	24.57	25.11
19	7.69	7.84	14.55	14.88	29.49	32.24

20	7.73	7.9	14.92	15.02	27.44	27.78
21	7.30	7.38	13.90	14.72	27.69	28.87
22	7.53	7.56	14.58	14.84	29.36	29.92
23	7.43	7.47	13.95	14.07	27.10	27.15
24	7.69	7.87	13.90	14.20	27.68	27.84
25	7.18	7.29	13.65	13.73	26.19	26.32

Raw Data
Cycle Ergometer

SUBJECT	PP	TTPP	PFR	PFI	AP	PP/KG	PFR/KG	AP/KG
1	1076.41	4.82	27.12	25.66	941.84	12.04	.30	10.53
2	973.16	4.40	25.43	27.71	822.16	13.59	.36	11.48
3	1186.83	4.62	48.64	42.54	969.39	14.53	.60	11.87
4	620.25	4.95	12.97	21.02	554.40	9.02	.19	8.06
5	835.29	5.76	23.69	26.22	720.17	13.01	.37	11.22
6	1005.14	2.88	22.01	26.55	888.06	11.94	.26	10.55
7	945.65	4.36	20.98	23.60	833.54	11.59	.26	10.21
8	1069.94	4.65	30.55	29.54	922.49	13.05	.37	11.25
9	920.47	5.61	19.03	19.41	826.42	12.18	.25	10.93
10	982.63	3.66	26.97	31.12	839.67	12.28	.34	10.50
11	1198.00	5.27	21.51	17.48	1082.36	14.49	.26	13.09
12	1077.43	4.84	27.30	25.76	946.03	15.41	.39	13.53
13	1063.57	3.69	29.85	42.38	863.88	13.58	.38	11.03
14	994.98	5.23	31.10	30.54	860.44	13.70	.43	11.85
15	1140.21	4.83	36.89	32.91	972.82	13.49	.44	11.51
16	955.78	5.26	26.82	27.33	829.90	13.37	.38	11.61
17	1086.94	6.06	30.45	25.03	953.82	12.96	.36	11.37
18	898.93	5.08	23.55	25.99	781.99	13.26	.35	11.53
19	1017.53	4.72	27.63	27.91	874.45	11.83	.32	10.17
20	905.24	4.89	26.88	30.03	773.43	13.93	.41	11.90

21	830.74	5.04	17.91	21.46	734.67	12.59	.27	11.13
22	887.32	4.90	19.43	22.11	781.50	12.77	.28	11.24
23	883.20	6.87	29.19	26.87	749.92	10.42	.34	8.84
24	1370.96	3.90	36.91	29.87	1154.86	13.83	.37	11.65
25	1254.47	2.92	34.91	33.6	1045.08	14.59	.41	12.15

Appendix D
DATA COLLECTION
AND ANALYSIS
COMPUTER PROGRAMS

APPENDIX D

Source Listing for the Cycle Ergometer Data Collection Program

Written by: Jay H. Williams, Ph.D.

```

10 '
DIM DIO%(4), X%(20480) '@ 1024Hz - 1CH, 20sec or 4CH, 5sec
DIM F$(4)
COMMON SHARED DIO%(), X%()
DECLARE SUB DAS16 (MODE%, BYVAL dummy%, FLAG%)

'----- Initialize section -----
320 DIO%(0) = &H330           'set base address
330 DIO%(1) = 2             'interrupt level
340 DIO%(2) = 1             'D.M.A. level
360 FLAG% = 0               'error variable
370 MD% = 0                 'mode 0 - initialize
380 CALL DAS16(MD%, VARPTR(DIO%(0)), FLAG%)
390 IF FLAG% <> 0 THEN PRINT "INSTALLATION ERROR -"; FLAG%: STOP'Halt on
error
400 '
410 '----- STEP 2: Prompt for scan limits and set using mode 1
-----
420 SCREEN 9: CLS : COLOR 12, 0: BEEP
FOR I = 0 TO 36: LOCATE 1, 40 - I: PRINT CHR$(205): LOCATE 1, 40 + I:
PRINT
CHR$(205): NEXT I
LOCATE 1, 4: PRINT CHR$(201): LOCATE 1, 76: PRINT CHR$(187)
FOR I = 2 TO 22: LOCATE I, 4: PRINT CHR$(186): LOCATE I, 76: PRINT
CHR$(186):
NEXT I
FOR I = 36 TO 0 STEP -1: LOCATE 23, 40 - I: PRINT CHR$(205): LOCATE
23, 40
+ I: PRINT CHR$(205): NEXT I
LOCATE 23, 4: PRINT CHR$(200): LOCATE 23, 76: PRINT CHR$(188)
LOCATE 7, 4: PRINT CHR$(199): LOCATE 7, 76: PRINT CHR$(182)
FOR I = 5 TO 75: LOCATE 7, I: PRINT CHR$(196): NEXT I
COLOR 9, 0
LOCATE 3, 25: PRINT "ADLO - DATA COLLECTION PROGRAM"
LOCATE 5, 25: PRINT "Sampling frequencies < 3000 Hz"
440 LOCATE 9, 6: INPUT "NUMBER OF CHANNELS          ", NCHAN
450 LOCATE 10, 6: INPUT "STARTING CHANNEL          ", SCHAN
LOCATE 11, 6: INPUT "SAMPLING FREQUENCY (Hz)      ", FREQ
LOCATE 12, 6: INPUT "SAMPLING DURATION (sec)     ", DUR
L% = SCHAN: U% = SCHAN + NCHAN - 1
CPTS = FREQ * DUR
TPTS = FREQ * DUR * NCHAN
SFREQ = FREQ * NCHAN

```

```

460 '
470 DIO%(0) = LZ'set lower limit
480 DIO%(1) = UZ'set upper limit
490 MD% = 1 'mode 1 - set scan limits
500 CALL DAS16(MD%, VARPTR(DIO%(0)), FLAG%)
510 IF FLAG% <> 0 THEN PRINT "Error #"; FLAG%; " in setting scan limits":
STOP

'----- OPEN DATA FILES -----
FOR I = 1 TO NCHAN
  LOCATE I + 13, 8: PRINT "FILENAME FOR CHANNEL "; I; "(d.name.ext)";
: INPUT
  F$(I)
NEXT I
IF F$(1) <> "" THEN OPEN F$(1) FOR OUTPUT AS #1
IF F$(2) <> "" THEN OPEN F$(2) FOR OUTPUT AS #2
IF F$(3) <> "" THEN OPEN F$(3) FOR OUTPUT AS #3
IF F$(4) <> "" THEN OPEN F$(4) FOR OUTPUT AS #4

520 '
530 '----- STEP 3: Set timer rate to trigger A/D using mode 17
-----
560 '
  DD = 10000 / SFREQ
580 DIO%(0) = DD
590 DIO%(1) = 100
600 MD% = 17 'mode 17 - timer set
610 CALL DAS16(MD%, VARPTR(DIO%(0)), FLAG%)
620 IF FLAG% <> 0 THEN PRINT "Error #"; FLAG%; " in setting timer": STOP
630 '
640 '----- STEP 4: Do 500 conversions to array X%(*)
-----
650 N = TPTS 'number of conversions required
670 DIO%(0) = N 'number of conversions required
680 DIO%(1) = VARPTR(X%(0)) 'provide array location
690 DIO%(2) = 1 'trigger source, 1=timer, 0=external on IPO
FOR I = 8 TO 20: LOCATE I, 6: PRINT "
": NEXT I
COLOR 14, 0: LOCATE 10, 19: INPUT "PRESS RETURN TO BEGIN DATA
COLLECTION.....", ZZZ
BEEP: COLOR 9, 0
LOCATE 12, 19: PRINT "DATA COLLECTION IN PROGRESS, DON'T DISTURB"
700 MD% = 4 'mode 4 - A/D to array
740 CALL DAS16(MD%, VARPTR(DIO%(0)), FLAG%)
750 IF FLAG% <> 0 THEN PRINT "Error #"; FLAG%; " in mode 4": STOP
BEEP
LOCATE 16, 26: INPUT "SAVE THIS DATA (yes=1, no=2) "; SV
IF SV = 2 THEN 520
,
```

```
760 '----- STEP 5: STORE DATA TO DISK -----  
770 BEEP  
    LOCATE 18, 22: PRINT "STORING DATA TO DISK, DON'T DISTURB"  
    FOR I = 0 TO N - NCHAN STEP NCHAN  
        FOR J = 1 TO NCHAN  
            IF J = 1 THEN PRINT #1, X%(I + J - 1)  
            IF J = 2 THEN PRINT #2, X%(I + J - 1)  
            IF J = 3 THEN PRINT #3, X%(I + J - 1)  
            IF J = 4 THEN PRINT #4, X%(I + J - 1)  
        NEXT J  
    NEXT I  
    CLOSE : BEEP  
800 LOCATE 20, 22: INPUT "MORE DATA COLLECTION (yes=1, no=2) "; MR  
    CLEAR  
    IF MR = 1 THEN 10  
    IF MR = 2 THEN END  
820 PRINT : PRINT : END
```

APPENDIX D

Source Listing for the Cycle Ergometer Data Analysis Program

Written by: Jay H. Williams, Ph.D.

```

10 BEEP: CLS : COLOR 14, 0

FOR I = 0 TO 39: LOCATE 1, 40 - I: PRINT CHR$(205): LOCATE 1, 40 + I:
PRINT
  CHR$(205): NEXT I
LOCATE 1, 1: PRINT CHR$(201): LOCATE 1, 80: PRINT CHR$(187)
FOR I = 2 TO 21: LOCATE I, 1: PRINT CHR$(186): LOCATE I, 80: PRINT
CHR$(186):
  NEXT I
FOR I = 39 TO 0 STEP -1: LOCATE 22, 40 - I: PRINT CHR$(205): LOCATE 22,
40 + I:
  PRINT CHR$(205): NEXT I
LOCATE 22, 1: PRINT CHR$(200): LOCATE 22, 80: PRINT CHR$(188)
FOR I = 0 TO 39: LOCATE 4, 40 - I: PRINT CHR$(196): LOCATE 4, 40 + I:
PRINT
  CHR$(196): NEXT I
LOCATE 4, 1: PRINT CHR$(199): LOCATE 4, 80: PRINT CHR$(182)

LOCATE 1, 25
COLOR 12, 0
PRINT " CYCLE ERGOMETER POWER OUTPUT "
LOCATE 3, 20
PRINT "Power Output and Fatigue Analysis Program"
COLOR 11, 0
LOCATE 6, 5: INPUT "Subject Name           ", S$
LOCATE 7, 5: INPUT "Date of Testing           ", D$
LOCATE 8, 5: INPUT "Experimental Conditions ", C$
LOCATE 10, 5: INPUT "Total Data Collection Time (sec)      ", DURATION
LOCATE 11, 5: INPUT "Sampling frequency (Hz)              ", SFREQ
LOCATE 12, 5: INPUT "Number of Trials                      ", NTRIALS
LOCATE 13, 5: INPUT "Weight Applied to Flywheel (kg)      ", WEIGHT
LOCATE 14, 5: INPUT "Load Cell Calibration Slope (kg/v)    ", LCSLOPE
LOCATE 15, 5: INPUT "Load Cell Calibration Intercept (kg)  ", LCINT
LOCATE 17, 5: INPUT "Pulse DataFile Name (d:name.ext)     ", P$
LOCATE 18, 5: INPUT "Force DataFile Name (d:name.ext)     ", F$
FOR I = 6 TO 18: FOR J = 5 TO 70: LOCATE I,J: PRINT " ": NEXT J: NEXT I

DIM PP(NTRIALS), TTPP(NTRIALS), PFR(NTRIALS), PFI(NTRIALS), TW(NTRIALS),
  AP(NTRIALS)
PLSPT = 1: FRCPT = 1
TPS = DURATION * SFREQ
DIM PULSES(TPS), FORCES(TPS)
DIM PDUR(150), RPM(150), PNUM(150), AFRC(150), POWER(150), PTIME(150)

```

```
OPEN P$ FOR INPUT AS #1
OPEN F$ FOR INPUT AS #2
```

```
FOR TRL = 1 TO NTRIALS
```

```
  LOCATE 12, 25: PRINT "READING DATA FROM DISK....."
```

```
  SEEK #1, PLSPT
```

```
  FOR I = 1 TO TPS: INPUT #1, PULSES(I): NEXT I
```

```
  PLSPT = SEEK(1)
```

```
  SEEK #1, FRCPT
```

```
  FOR I = 1 TO TPS: INPUT #2, FORCES(I): NEXT I
```

```
  FRCPT = SEEK(2)
```

```
  LOCATE 12, 25: PRINT "COMPUTING POWER OUTPUT....."
```

```
  FOR I = 1 TO TPS
```

```
    PULSES(I) = PULSES(I) / 204.5
```

```
    FORCES(I) = (FORCES(I) / 204.5) * LCSLOPE + LCINT
```

```
  NEXT I
```

```
  TD = 0: T = 1
```

```
  FOR J = 1 TO TPS - 1
```

```
    IF PULSES(J + 1) - PULSES(J) > 2 THEN
```

```
      PTIME(T) = J
```

```
      T = T + 1
```

```
    END IF
```

```
  NEXT J
```

```
  FOR I = 1 TO T - 2
```

```
    TFORCE = 0
```

```
    PDUR(I) = PTIME(I + 1) - PTIME(I)
```

```
    RPM(I) = 1 / ((PDUR(I) / SFREQ) * 2) * 60
```

```
    FOR J = PTIME(I) TO PTIME(I + 1)
```

```
      TFORCE = TFORCE + FORCES(J)
```

```
    NEXT J
```

```
    AFRC(I) = (TFORCE / PDUR(I))
```

```
    AFRC(I) = WEIGHT - AFRC(I)
```

```
    POWER(I) = (AFRC(I) * 6 * RPM(I)) / 6.12
```

```
  NEXT I
```

```
  TP = 0
```

```
  FOR I = 1 TO T - 2
```

```
    PTIME(I) = PTIME(I) + ((PTIME(I + 1) - PTIME(I)) / 2)
```

```
    IF POWER(I) > PP(TRL) THEN
```

```
      PP(TRL) = POWER(I)
```

```
      TTPP(TRL) = PTIME(I) / SFREQ
```

```
    END IF
```

```
    TP = TP + POWER(I)
```

```
  NEXT I
```

```
  AP(TRL) = TP / (T - 2)
```

```
  TW(TRL) = AP(TRL) * DURATION / 1000
```

```
  PFI(TRL) = (1 - (POWER(T - 2) / PP(TRL))) * 100
```

```
' AP
```

```
' TW
```

```
' PFI
```

PFR(TRL) = (PP(TRL) - POWER(T - 2)) / (15 - TTPP(TRL)) ' PFR

SCREEN 9: CLS : BEEP

WINDOW (-.1 * DURATION, -100)-(1.1 * DURATION, 2500)

LINE (0, 0)-(DURATION, 1500), 12, B

FOR I = 0 TO DURATION

FOR J = 0 TO 1500 STEP 20

PSET (I, J), 12

NEXT J

NEXT I

FOR I = 0 TO 1500 STEP 100

FOR J = 0 TO DURATION STEP .1

PSET (J, I), 12

NEXT J

NEXT I

PSET (0, 0)

FOR I = 1 TO T - 2: LINE -(PTIME(I) / SFREQ, POWER(I)), 9: NEXT I

COLOR 14, 0

LOCATE 1, 25: PRINT "POWER OUTPUT ANALYSIS RESULTS"

LOCATE 3, 1: PRINT USING "PEAK POWER (W): #####.##"; PP(TRL)

LOCATE 4, 1: PRINT USING "TIME TO PEAK POWER (sec): #.##"; TTPP(TRL)

LOCATE 5, 1: PRINT USING "AVERAGE POWER (W): #####.##"; AP(TRL)

LOCATE 3, 40: PRINT USING "POWER FATIGUE RATE (W/sec): ##.##";

PFR(TRL)

LOCATE 4, 40: PRINT USING "POWER FATIGUE INDEX (%): ##.##"; PFI(TRL)

LOCATE 5, 40: PRINT USING "TOTAL WORK (KJ): ##.##"; TW(TRL)

LOCATE 8, 23: INPUT "HARDCOPY (1) OR NEXT TRIAL (2)"; HDC

LOCATE 8, 23: INPUT "FULL (1) OR SUMMARY (2) REPORT"; FORS

IF HDC = 1 THEN

LPRINT "-----"

LPRINT " POWER OUTPUT ANALYSIS RESULTS"

LPRINT "-----"

LPRINT " "

LPRINT "SUBJECT: "; S\$

LPRINT " PULSE FILE NAME: "; P\$

LPRINT " FORCE FILE NAME: "; F\$

LPRINT "TRIAL NUMBER: "; TRL

LPRINT "TESTING DATE: "; D\$

LPRINT "COMMENTS/CONDITIONS: "; C\$

LPRINT " "

LPRINT USING "PEAK POWER #####.## Watts"; PP(TRL)

LPRINT USING "TIME TO PEAK POWER #.## sec"; TTPP(TRL)

LPRINT USING "POWER FATIGUE RATE ###.## W/sec"; PFR(TRL)

LPRINT USING "POWER FATIGUE INDEX ##.## %"; PFI(TRL)

LPRINT USING "AVERAGE POWER #####.## Watts"; AP(TRL)

```
LPRINT USING "TOTAL WORK          ##.## KJoules"; TW(TRL)
LPRINT
LPRINT
IF FORS = 1 THEN
  LPRINT "TIME", "POWER", "VELOC."
  LPRINT "(sec)", "(Watts)", "(rpm)"
  LPRINT "----", "-----", "-----"
  FOR I = 1 TO T - 2
    LPRINT PTIME(I) / SFREQ, POWER(I), RPM(I)
  NEXT I
END IF
END IF
NEXT TRL
CLOSE #1: CLOSE #2
END
```

Appendix E
INFORMED CONSENT

Human Performance Laboratory

Division of Health, Physical Education and Recreation
Virginia Polytechnic Institute and State University

Informed Consent

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

Title of the Study:

Relationships Between Sprint Performance, Power Output and Fatigue

Purposes of this experiment include:

The purpose of this research is to use information obtained from a cycle ergometer power output test, namely peak power output, power acceleration, and the rate and magnitude of fatigue, to develop a means to evaluate and model sprint performance. Specifically, these experiments are designed to:

- 1) Determine the individual relationships between sprint performance and each parameter of the power test.
- 2) Determine the best subset of variables to predict performance in each of the selected sprint events.

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

performance of one test of power output consisting of a 15 sec bout of maximal intensity cycle ergometry exercise and performance of track sprints consisting of all out sprints of
55, 100 and 200m.

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

1. Muscle soreness and fatigue due to power and sprint testing.
2. Risk of injury including, but not limited to, tendonitis, bursitis, strains, sprains, and even

the possibility of death. All attending staff will be trained in CPR techniques.

Certain personal benefits may be expected from participation in this experiment. These include:

1. Knowledge of ones ability to generate power and to resist short-term fatigue and ones ability to perform sprints.
2. Knowledge of the relationships between sprint performance and power output.

Appropriate alternative procedures that might be advantageous to you include:

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

Appendix F
DATA SHEET

Data Sheet

Name _____

AGE _____

HEIGHT _____cm

Weight _____kg

PP _____

Ergometer Load _____kg

TTPP _____

Cal Slope _____kg/v

AP _____

Cal Int _____kg

PFR _____

PFI _____

TW _____

Sprint Times

55m _____sec _____sec

100m _____sec _____sec

200m _____sec _____sec

Appendix G

ERGOMETER DIAGRAM
(Williams et al., 1988)

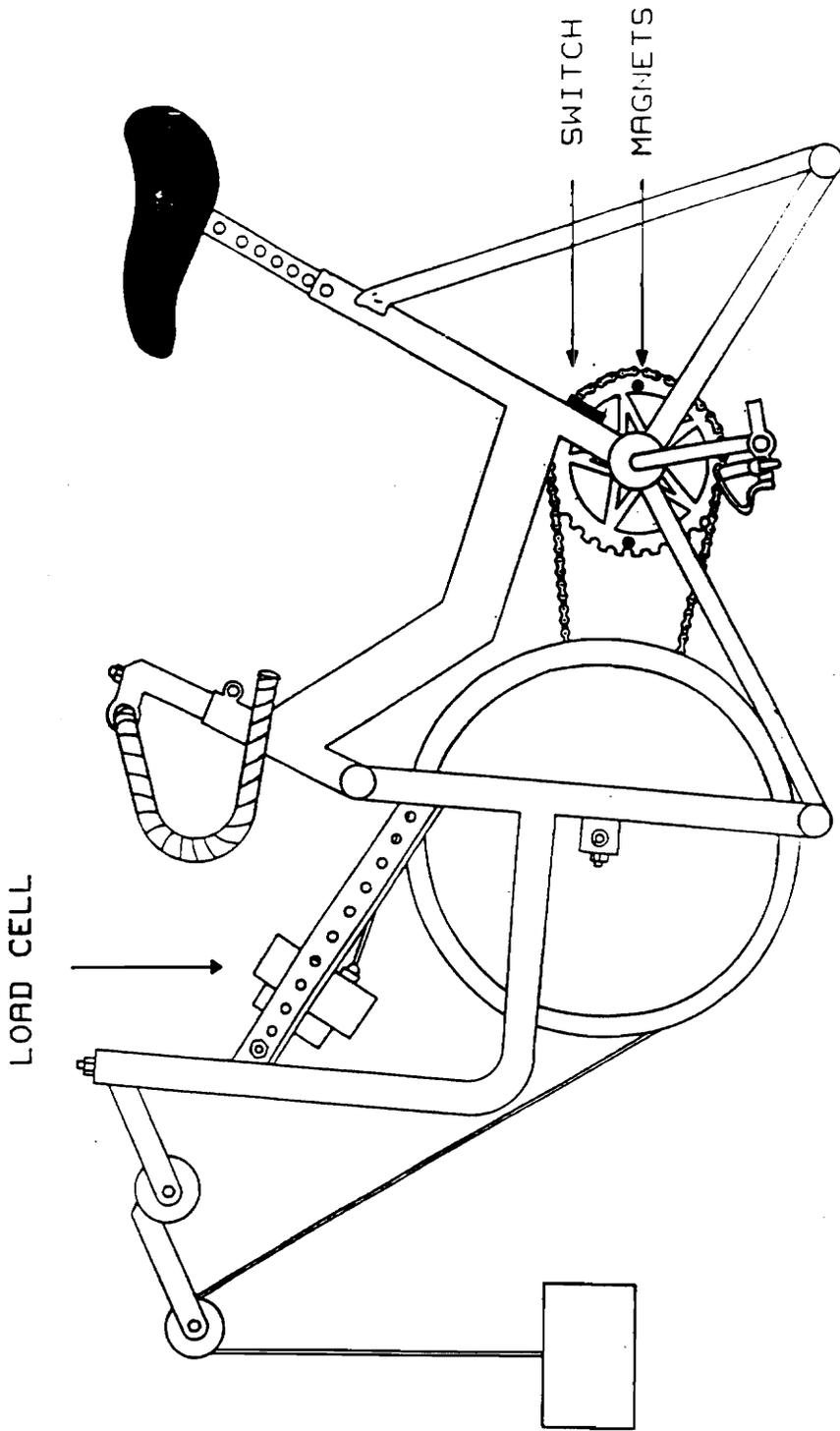


Figure 10

VITA

James Shorten was born March 14, 1967 in Manassas Virginia to Mrs. Marcia A. Shorten and Mr. James E. Shorten. He has one older sister, Mary Ann Shorten, currently residing in Virginia Beach. He has two younger brothers, Mike Shorten who is beginning his final year at Radford University, and Bill Shorten who will be a senior at Stonewall Jackson Senior High School in Manassas VA. this fall. Jim grew up in Manassas Va and graduated from Stonewall Jackson Senior High School in 1985. Jim then attended Virginia Tech and graduated with a B.S. in exercise science in August, 1989. In August of that same year he started the masters of science in exercise physiology program at Virginia Tech.

Jim was a Graduate Assistant Athletic Trainer for the Virginia Tech Athletic Department this past year where he was involved in all aspects of athletic training. After completing his masters degree Jim hopes to get his athletic trainers certification and work in the area of sports medicine. Jim hopes to continue his education and eventually enter medical school. In his spare time Jim enjoys weight training, running, fishing, and mountain biking.

A handwritten signature in cursive script, appearing to read "James Shorten". The signature is written in dark ink and is positioned in the lower right quadrant of the page.