1994

Frequency of Attainment of Plateau in Maximal Oxygen Consumption in Differentially Trained Athletes

Jeffrey Michael Seda

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FREQUENCY OF ATTAINMENT OF PLATEAU IN MAXIMAL OXYGEN

CONSUMPTION IN DIFFERENTIALLY TRAINED ATHLETES

(TITLE)

BY

JEFFREY MICHAEL SEDA

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

MASTER OF SCIENCE

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
CHARLESTON, ILLINOIS

1994

YEAR

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ABSTRACT

A plateau in oxygen consumption during exercise testing has been considered a requisite indicator of achievement of true maximal oxygen consumption. The wide range of reported percentages of subjects revealing a plateau (7 to 80 percent) indicates that closer analysis of factors that may influence plateau attainment is necessary. This study examined the frequency of plateau attainment in two groups of differentially trained subjects. One group (TR) of 12 males (ages 18-36) were trained runners and the other group (WL) of 12 males (ages 18-31) consisted of trained weight lifters. The subjects participated in a series of maximal exercise tests performed on a cycle ergometer equipped with toe straps.

Subjects first completed a continuous graded exercise test which started at a power output of 720 kgm/min and increased every two minutes until exhaustion. Subjects then completed a series of daily discontinuous supramaximal exercise tests, which consisted of maintaining a preset power output (beginning the a next higher power output than the highest power output obtained on the continuous test) for at least 90 seconds. The subsequent constant power outputs were increased until the subject could no longer perform the power output for at least 90 seconds. The pedal frequency was increased for the higher discontinuous power outputs.

The criteria for determination of a plateau was less than a 0.15 L/min increase in oxygen consumption between the peak VO_2 obtained on a continuous test and the mean of the peak values obtained on each of the supramaximal discontinuous tests.

The results showed 92% (11) of trained runners and 83% (10) of trained weightlifters attained a plateau in oxygen consumption. The calculated Chi Square value was not statistically significant ($p < .05$). The results reveal a high percentage (88%) of subjects attaining a plateau in oxygen consumption with no significant difference between the differentially trained groups under the conditions studied.

ACKNOWLEDGEMENTS

I would like to take this opportunity to acknowledge the people who helped make this thesis possible.

First I would like to thank Ben Timson Ph.D. for his help as a principle investigator and as an advisor.

I would like to thank the members of my thesis committee: Phyllis Croisant, Ph.D., Thomas Woodall Ph.D., and Russell Fisher PhD. for their patience and understanding in allowing me to complete this project.

I would like to thank Eastern Illinois University for the invaluable education and unforgettable experiences.

I would like to send special thanks to my family (Denise, Matthew, and Sarah), and to my parents James and Mary Seda for their love and support.

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CHAPTER I

INTRODUCTION

Maximal oxygen consumption is probably the single most commonly measured parameter in exercise physiology. It is generally considered to be the best physiological criterion for measuring the capacity for energy expenditure during heavy muscular work (Robinson, 1938; Taylor et al., 1955; Astrand, 1959; Balke and Ware, 1959). One of the most fundamental beliefs in exercise physiology is that performance during maximal exercise of relatively short duration is limited by the inability to deliver oxygen at a rate sufficient to fuel energy production by the active muscle mass. This belief was initially formed as a result of the original studies of Hill and Lupton (1923), (cited in Noakes, 1988) and Hill, Long and Lupton (1924) (cited in Noakes, 1988) and has been supported by studies of Taylor et al. (1955), and more recently by Wyndham et al. (1969, 1966). The evidence of such a condition can best be demonstrated in the graph of power output vs. oxygen consumption relationship. Oxygen consumption increases linearly with power output until agiven point, which may be different for each individual. At this point oxygen consumption no longer increases with an increase in power output. This point where there is no further increase in oxygen consumption, referred to as the "plateau phenomenon", is classically defined as maximal oxygen consumption (Hill and Lupton, 1923 (cited in Noakes, 1988); Hill, Long and Lupton, 1924 (cited in Noakes, 1988); Taylor, 1955). Taylor et al. (1955) identified 108 of 115 subjects as having attained a plateau in oxygen consumption. Wyndham et al. (1959, 1966), using different criteria, concluded that in none of their subjects was a true plateau in oxygen consumption reached. Mitchell (1958) failed to show a plateau in oxygen consumption in 28% of subjects. Cumming and Borysyk (1972) reported that only 43% of their subjects showed evidence of a plateau. Cumming and Friesen (1967) and Cunningham et al. (1977) reported a plateau in less than 50% of young boys, whereas Sidney and Shepard (1977) demonstrated a plateau in approximately 75% of elderly subjects. Froelicher et al. (1974) observed a plateau in VO_2 in only 7%, 17%, and 33% of subjects using three different treadmill protocols. Pollock et al. (1976) reported a plateau in 69 to 80% of subjects using four different protocols. Katch et al. (1982) demonstrated a plateauing in 61% of tests performed. Davies (1984) showed that 74% of trained runners were able to obtain a plateauing of VO_2 with 94% attainment in all subjects. Freedson et al. (1986) found less than 40% of 301 adults undergoing maximal exercise testing reached a plateau in oxygen consumption. Recently Noakes (1988) proposed an interpretation for the absence of the plateau phenomenon during a VO_2 max test. He suggested that a test without a plateau was limited by muscle power of the subject rather than by the ability of the heart to deliver oxygen to the working muscle. The implication is that if the muscles were able to perform at a greater power output, the heart would be able to respond with a greater cardiac output. One way to test this hypothesis would be to perform VO_2 max tests on a group of individuals with a high relative cardiovascular fitness to muscle power ratio (trained distance athletes) and on a group of individuals with a high relative muscle power to cardiovascular fitness ratio (trained weight lifters). A low number of individuals obtaining a plateau in the former group and a high number of individuals obtaining a plateau in the latter group would support the hypothesis that in individuals unable to obtain a plateau, VO_2 max is limited by muscle power rather than oxygen delivery.

Purpose of the Study

The purpose of the present study is to compare whether a difference in frequency of attainment of a "plateau" in oxygen consumption can be observed in the power output vs. oxygen consumption relationship in highly trained endurance athletes versus highly trained strength athletes.

Null Hypothesis

There will is no significant difference in the frequency with which an oxygen consumption plateau is exhibited by endurance trained athletes compared to weight trained athletes.

Delimitations

The subjects consisted of trained distance runners and trained weight lifters. The trained distance runners were 11 members of the Eastern Illinois University cross country team and one additional trained runner. Ten members of the Eastern Illinois University football team and two additional trained weight lifters, formed the weight lifting group.

Definitions

Power Output

A predetermined unit of power (kgm/min) that remained constant for a given time period and either remained constant or was progressively increased during a testing procedure to elicit a given power output.

VO_2 Peak

The highest value of oxygen consumption obtained during either the continuous test or any one discontinuous test for an individual.

Plateau

Less than a 0.15 increase in peak VO_2 with an increase in power output.

CHAPTER II

RELATED LITERATURE

Introduction

The purpose of the present study was to compare whether a difference in frequency of attainment of a "plateau" in oxygen consumption can be observed in trained endurance athletes versus trained strength athletes.

This review of the related literature will focus on the following areas:

1. Brief history of the concept of a plateau in oxygen consumption
2. The criteria for defining a plateau in oxygen consumption
3. Reproducibility and reliability in measuring maximal oxygen consumption
4. The frequency of attainment of a plateau in oxygen consumption
5. Testing protocols used affecting plateau attainment in oxygen consumption
6. Subjects used in testing maximal oxygen consumption
7. Modes in measuring maximal oxygen consumption
8. Muscle mass used in maximal testing
8. Sampling methods in measuring maximal oxygen consumption

Brief History

Maximal oxygen consumption is the single most commonly used measurement in exercise physiology. This is because it is considered to be the best physiological criterion for the ability to sustain heavy muscular work (Robinson 1938, Taylor et al. 1955, Astrand 1959, Balke and Ware 1959). The earliest investigations to measure oxygen consumption during exercise in athletes were conducted by Lindhard (1915, 1920) (cited in Noakes, 1988) at the University of Copenhagen, Liljestrand and Stenstrom (1920) (cited in Noakes, 1988) at the Karolinska Institute in Stockholm and Herbst (1928) in Berlin (cited in Noakes, 1988). These studies reported that oxygen consumption increased with running (Herbst, 1928) (cited in Noakes, 1988), Liljestrand et al. 1920 (cited in Noakes, 1988) or swimming speed (Liljestrand et al. 1920 (cited in Noakes, 1988) and that the fastest runners had the highest values for oxygen consumption (Herbst, 1928) (cited in Noakes, 1988). Herbst (1928) (cited in Noakes, 1988) also showed that the rate of oxygen consumption when running on a treadmill was greatest at 280 steps per minute which first implicated a defined maximal rate.

The concept of an oxygen consumption plateau was first introduced by Hill and Lupton in 1923. They concluded that "Oxygen consumption reaches a plateau during exercise of progressively increasing intensity". Since then more recent studies of Taylor (1955), and Wyndham et al. (1959, 1966) have also examined the concept of an oxygen consumption plateau during exercise.

Criteria for Defining Plateau in Oxygen Consumption

The point where there is no further increase in oxygen consumption with progressively increasing work (plateau phenomenon) is classically defined as maximal oxygen consumption (VO_2 max) (Hill and Lupton 1923 (cited in Noakes, 1988), Hill et al. 1924 (cited in Noakes, 1988), Taylor et al. 1955). Taylor et al. (1955) defined an oxygen consumption plateau as an increase in oxygen consumption of less than 0.15 l/min with an increase in workload. Mitchell et al. (1957), used a criteria of less than a 0.54 liter increase in O_2 consumption with successive workloads. Wyndham et al. (1959, 1966) proposed that the VO_2 max value should be taken as the mean of three values falling on the plateau, provided they did not differ by more than 0.15 l/min. Cumming and Borysyk (1972) used a criteria of less than 90% of oxygen consumption below the expected value in studying males above 40. Stamford (1976) used changes in VO_2 of less than .112 ml/min between successive stages to be indicative of a "Leveling off" of VO_2. Others have simply suggested either the use of similar values, no increase or no decline in VO_2 with an increase in exercise intensity (Davies et al. 1984, McMiken and Daniels 1976, Shephard et al. 1968).

Reproducibility and Reliability of VO_2 max

A number of investigators have discussed or directly investigated the variability of VO_2 max values. The variability of VO_2 max for an individual can be classified into several sources: technological error and biovariation (biological fluctuation). The technological error is computed for each piece of equipment as the standard deviation of multiple trials and included the variable error of the instruments used to measure and calculate VO_2 max, uncontrolled environmental factors, reading errors, and other unidentified errors. The biological variation is reflective of the inherent biological variation of the organism and was computed as the standard deviation for the VO_2 max values for each individual, after subtracting the net technological error.

Taylor et al. (1955) analyzed the variance in five duplicate tests on 12 subjects, in 28 duplicate determinations of VO_2 max they found that the difference between individuals was highly significant while the trend over time was not. The coefficient of variation for the means over time was 2.4%. In their group it was estimated that 18.7% of the variability was random, 80.5% was accounted for by differences between individuals, and less than 1% was accounted for by day-to-day variability or technological error.

In an earlier investigation, Taylor (1944) reported that 30% of the total variability could be accounted for by biological variation and less than 1% was due to technological error. Katch et al. (1982), using repeat testing on the same subjects revealed a combined source (technological and biological) of variance of ± 5.6%. Biological variability accounted for 90% or more of the combined variability while technological error accounted for less than 10%. They suggested that in light of the magnitude of biological variation, multiple tests may be necessary to secure reliable control values when using measures of VO_2 max.

Frequency of Plateau Attainment

A number of investigations have reported on the frequency of plateau attainment in VO_2max. Taylor et al. (1955) identified 108 of 115 subjects as having attained a plateau in oxygen consumption. A study by Wyndham in 1959 showed that none of his subjects reached a true plateau in oxygen consumption. Mitchell (1958), using essentially the same testing procedure as Taylor et al. (1955), failed to show a plateau in oxygen consumption in 28% of subjects. Cumming and Borysyk (1972) showed that only 43% of their subjects showed evidence of a plateau. Cumming and Friesen (1967) and Cunningham et al. (1977) reported a plateau in less than 50% of young boys, whereas Sidney and Shepard (1977) demonstrated a plateau in approximately 75% of elderly subjects. Pollock et al. (1976) reported a plateau in 69 to 80% of subjects using four different protocols. Of 80 tests performed, Katch et al. (1982) demonstrated a plateauing in 61% of the tests. Davies et al. (1984), showed that 74% of his trained runners were able to obtain a plateauing of oxygen consumption and a plateau was not obtained in only 6% of the total tests performed. Stamford et al. (1978) demonstrated that tests preceded by severe exhaustion did not demonstrate an adequate plateau, even though the VO_2 max values were not different than those obtained when a plateauing was observed. The most recent study relevant to the plateau phenomenon is that of Freedson et al. (1986). They found that less than 40% of 301 adults undergoing maximal exercise testing showed a plateau in oxygen consumption according to the criteria of Mitchell (1958) and Taylor (1955).

Testing Protocols in Maximal O_2 Consumption Studies

Original investigations of maximal oxygen consumption included those by Hill et al. in 1924 (cited in Noakes, 1988), Taylor et al. in 1955, and Mitchell et al. in 1958. These investigators employed discontinuous protocols performed on the same day with rest periods between stages. Shephard et al. (1968) recommended that a continuous test with 2 minute stages be used. Continuous testing protocols were subsequently developed primarily for economy of administrative time in testing large groups of subjects.

Continuous Versus Discontinuous Testing Protocols

A number of studies have compared continuous and discontinuous protocols. In 1971 Maksud and others compared continuous and discontinuous protocols on the treadmill. The continuous protocol began at 7 mph, keeping the speed constant and increasing the grade 2.5% every minute until exhaustion. The discontinuous protocol involved one 3 minute workload per day and began at 7 mph and 2.5% grade with subsequent increases of 2.5% grade each day. Their results showed no significant difference between continuous and discontinuous VO_2 max values. In 1976 Stamford also compared continuous and discontinuous protocols on the treadmill. He used the same continuous protocol as Maksud but with 2 min stages and the same discontinuous protocol but with 10 min rests between stages rather than full days. He also found no significant difference between continuous and discontinuous VO_2 max values. In 1973 McArdle and others looked at continuous and discontinuous protocols using both the treadmill and bicycle ergometer. They used the same continuous and discontinuous treadmill protocols as Stamford, but began at 6 mph. The bicycle ergometer continuous protocol began at a power output of 720 kgm/min with increases of 180 kgm/min in 2 min stages until exhaustion. The discontinuous protocol used the same power outputs, but used 5 minute stages with 10 minutes rest between stages rather than full days. They found no significant difference between continuous and discontinuous tests in either mode, but found approximately 10% greater treadmill max values than bicycle ergometer VO_2 max values.

Workrate Increase in Maximal Testing

A number of studies have looked at the rate of increase in workrate as a factor in maximal oxygen consumption testing. Froelicher et al. (1974) compared three different treadmill testing protocols using 15 male subjects. They found a statistically significant difference in VO_2 max between the Bruce and the Balke protocols. They also reported a plateauing in 33, 17, and 7 percent of subjects for the Taylor, Balke, and Bruce protocols respectively. Davies et al. (1982) used a continuous ramp protocol on a cycle ergometer and found that the men studied had similar VO_2 max values regardless of the workrate increase. Pollock et al. (1976) analyzed four different protocols for maximal treadmill testing. They noted that VO_2 max values for all four protocols correlated highly with no significant difference between the tests. The investigators reported a plateau effect in 69, 69, 59, and 80 percent of subjects with Balke, Bruce, Ellestad, and Astrand protocols respectively. Zhan et al. (1991) examined the effect of testing protocol on aerobic parameters. They tested eight men using a cycle ergometer with four different protocols of increasing workrate. The different protocols included: ramp; 1 min step; 2 min step; and 3 min step. No significant difference was found among the four workrate protocols. They concluded that parameters of aerobic function during maximal testing were independent of the type or pattern of workrate increase.

Subjects Used in Maximal Testing

A variety of subjects have been used in studies to help identify the frequency of plateau attainment in maximal oxygen consumption (Mitchell et al. 1957, Pollock et al. 1976, Katch et al. 1982, Davies et al. 1984, Freedson et al. 1986). A majority of the subjects have been men and women between the ages of 20 and 40. However there have been few studies that use children and elderly subjects to determine frequency of plateau attainment in O_2 consumption.

Children as Subjects

Cumming and Friesen in 1967 found only 35% (7 of 20) revealed a plateau in oxygen consumption in a group of 12 to 15 year old boys. They concluded that the difference between plateau and non-plateau groups may have been due to factors indicative of anaerobic metabolism. Sheehan et al. (1987) evaluated 10 to 12 year old boys during walking, continuous running, and intermittent running and observed a plateau in 31, 56, and 69, percent of subjects, respectively. Rowland et al. (1992), using 15 subjects (ages 8 to 11) demonstrated 33% having plateaued using a treadmill. They used a plateau criteria of less than a 2.0

ml/kg/min increase in during the "ultimate exercise minute". The authors conclude that because a majority of the children reached a point of exhaustion without a plateau, oxygen uptake may not serve as the limiting factor during treadmill testing. The authors also suggest that attainment of a plateau is independent of subject effort, aerobic fitness, and anaerobic factors.

Elderly as Subjects

Several studies have looked at the frequency of plateau in maximal oxygen consumption attainment in elderly subjects. Cumming and Boresyk (1972) were the first to study the criteria for defining maximal oxygen consumption in individuals over 40. They studied 65 men between 40 and 65 years old using a cycle ergometer. They looked at the frequency of oxygen consumption values that were less than 90% of expected for the workload. They reported only 43% of subjects as having attained their plateau criteria despite nearly 80% of subjects having attained predicted heart rate maximum. Sidney and Shephard (1977) studied a group of men and women ages 60 to 83 and demonstrated a plateau in 69% of males and 66% of females using a cycle ergometer.

Modes in Measuring Oxygen Consumption

The specific mode of exercise used for testing has a definite influence on the VO_2 max response. McConnell et al. (1984) found that the VO_2 max obtained on a motorized treadmill was 10.2, 26.4, and 28.6% higher than that obtained during upright leg ergometry, supine leg ergometry and arm ergometry, respectively. McArdle & Magel (1970) found that subjects had a 9.9% lower VO_2 max during leg ergometry than during treadmill testing. Of their subjects, the only two who had higher VO_2 max values during leg ergometry were heavy recreational cyclists. Other investigators have shown similar differences between treadmill and leg ergometry testing ranging from 5 to 11% (Astrand 1967; Astrand & Saltin 1961; Diaz et al. 1978; Faulkner et al. 1971; Glassford et al. 1965; Hammond & Froelicher 1984; Harrison et al. 1980; Hermansen & Saltin 1969; Hermansen et al. 1970; Kamon & Pandolf 1972; McArdle et al. 1973; McKay & Banister 1976; Miles et al. 1980; Neiderberger et al. 1974; Shephard et al. 1968; Smodlaka 1982; Stamford 1975, 1976).

Muscle Mass Used in Maximal Testing

Several studies have emphasized the importance of the size of working muscle mass used in obtaining VO_2 max. In subjects having normal arm and shoulder mass, maximal arm work produces a VO_2 max averaging approximately 70% of treadmill VO_2 max.(Bevgard, et al. 1967; Stenburg, 1966; Stenburg et al. 1967). Gollnick et al. (1972) demonstrated however, that when these muscles are extremely developed by specialized use (for example, in weight lifters or competitive canoers) combined arm and shoulder mass may be sufficient to reach 79-97% of VO_2 max. Peak VO_2 on a bicycle ergometer has been shown to be 11% less than peak VO_2 while running up a grade on a treadmill (Astrand et al., 1961; Faulkner et al., 1971; Hermansen et al., 1970; 1969, Kamon et al., 1972; Miyamura et al., 1972). This differernce has been attributed to the smaller muscle mass used in cycling. The treadmill is generally regarded as providing a true measure of VO_2 max, as it is not increased by addition of extra muscle groups. Kamon et al. (1972) reviewed the literature and experimentally reexamined this point. They noted that vigorous exertion employing both arms and legs combined raised peak VO_2 above values measured on the bicycle but not on the treadmill. They concluded that the lower peak in arm and bicycle exercise may result either from utilization of less than the 50% of the total muscle mass necessary to elicit max or from the high intramuscular pressures in maximal cycling, which could restrict muscle blood flow. Secher et al. (1974) looked at maximal O_2 consumption in arm, leg and combined arm plus leg exercise compared to treadmill values. They reported that mean VO_2 max during combined arms and legs exercise was 6% greater than leg exercise and equal to that found with treadmill running. Shephard et al. (1988) studied 8 men and 8 women using four types of ergometry. They tested each subject while using 2 legs, 1 leg + 1 arm, arms and shoulders, and arms only while breathing room air and while breathing 12% oxygen. They reported a plateau in oxygen consumption in only 2 (25%) of the men and 4 (50%) of the women. They also showed a linear relationship between active muscle mass volume and maximal oxygen intake.

Specificity of Training

The more closely a laboratory can simulate during the test the specific muscular action involved in training, the more objective and valuable the VO_2 max assessment (Davies et al. 1984). Corry & Powers (1982) demonstrated the importance of using specifically trained muscle groups by comparing trained runners to trained swimmers. They found that the runners had significantly higher VO_2 max values during treadmill exercise (70.2 ml/kg/min) when compared with swimmers (60.0 ml/kg/min). But, when an arm pulling motion similar to that of swimming was used, the swimmers obtained significantly greater values than runners (47.1 ml/kg/min vs 37.4 ml/kg/min). Pechar et al. (1974) examined the specificity of training in subjects using a treadmill and a bicycle ergometer. They tested subjects (20) on both the treadmill and the bicycle ergometer for maximal oxygen consumption before and after training on both modes. They showed that after 8 weeks of treadmill training the improvement of VO_2 max was independent of the mode used to measure VO_2 max. However, the VO_2 max improvement for the bike trained group differed significantly depending on the mode of VO_2 max evaluation. McArdle et al. (1978) found that following a running program individuals improved their treadmill max by 6.3%, while their swimming VO_2 max improved by only 2.6%. Earlier, they had demonstrated that swim training did not significantly improve VO_2 max values obtained during a running test (Magal et al. 1975).

Sampling Methods in Measuring Maximal O_2 Consumption

The introduction of automated in-line sampling of expired gases (Beaver et al. 1973, Auchincloss et al. 1971) has greatly improved the precision with which to measure oxygen consumption during exercise testing. However, several studies have recently suggested that different sampling methods have an effect on maximal oxygen consumption values (Matthews et al. 1987, Myers et al. 1989) and the ability to detect a plateau. Matthews et al. (1987) compared several automated systems to the more traditional non-automated system. They tested 12 men (age 26-41) on a cycle ergometer using a 25 watt/min ramp protocol. Different sampling intervals (10 to 60 seconds) were used to analyze the same data for each individual's test. They reported differences of up to 20% for maximal values. The 60 second interval was the most comparable to the non-automated system. Walsh et al. (1989) examined the variability of O_2 consumption values using different sampling techniques. They tested 10 subjects performing steady state exercise at 50% of VO_2 max on a treadmill. During 5 minutes of testing they sampled data using a variety of sampling intervals (10 to 60 seconds) and three different moving averages. They observed a high variability (4.5 ml/kg) associated with small sampling intervals and less variability (0.8 ml/kg) in both larger sampling intervals and the moving averages. Meyers et al. (1990) looked at the effect of sampling variability and plateau attainment during maximal treadmill testing using six subjects. They used an eight breath moving average to sample data. They examined the slope of the change in oxygen consumption and found that only two of the subjects revealed a plateau in oxygen consumption using the criteria of Taylor (1955).

Summary

The classical concept of maximal oxygen consumption (Hill and Lupton 1923) assumed that as power output was increased a plateau of oxygen consumption would be reached. Taylor et al. (1955) established that a plateau in oxygen consumption had been reached when there was less than 0.15 l/min of an increase in oxygen consumption with a subsequent workrate. The reported frequency of attainment of this plateau ranges from 7% to as high as 96% of subjects (Hill et al. 1923; Mitchell 1958;Cumming and Borysyk 1972; Cummming and Friesen 1967; Cunningham 1977; Sidney and Shephard 1977; Katch et al. 1982; Davies et al. 1984; Stamford 1976; Pollock 1977; Stamford et al. 1978; Freedson et al. 1986). A number of factors may affect whether or not a plateau in oxygen consumption can be observed. These include criteria for plateau, protocols used, subjects used, modes used, muscle mass used, and sampling methods used.

CHAPTER 3

METHODS

Introduction

The purpose of the present study is to compare whether a difference in frequency of attainment of a "plateau" in oxygen consumption can be observed in the power output vs. oxygen consumption relationship in highly trained endurance athletes versus highly trained strength athletes. This chapter will present the methodology used in this study. It will be divided into areas of: subject selection, testing procedures, and procedures for treating the data.

Subjects

The subjects consisted of 24 male volunteers divided into two groups of 12. The group of trained runners (TR), aged 18-36 years, included eleven Eastern Illinois University cross country team members and one other runner. None of the runners were involved in any form of weight training activity. The group of weight lifters (WL) included individuals (ages 18-31) who had been involved regularly with weight training for more than one year and had not been involved in any other form of regular exercise. Table 1 describes the physical characteristics of each group of subjects,including age, height, and weight.

Table 1

Physical Characteristics of The Subjects

Group	Age (yrs)	Height (cm)	Weight (kg)
Weight Lifters	22.1 ± 1.4	180.3 ± 5.5	92.4 ±18.0
Trained Runners	20.6 ± 2.2	179.1 ± 3.9	66.1 ±17.0

Testing Procedures

The study was conducted in the Human Performance Laboratory at Eastern Illinois University in the fall of 1989. The subjects read and signed an informed consent (Appendix A) to participate in the study. The subjects participated in a series of maximal oxygen consumption exercise tests performed on a Monark cycle ergometer equipped with toe straps. Subjects first completed a continuous graded exercise test which started at a workrate of 720 kgm/min and was increased every two minutes until the subject could not maintain the required 50 rpm. Subjects then completed a series of daily discontinuous supramaximal exercise tests, which consisted of maintaining a preset workrate for at least 90 seconds.

The subsequent constant power outputs for the discontinuous tests were determined from the initial continuous test as one higher than the final power output attained and were increased each day until the subject could no longer perform the workrate for 90 seconds (Table 2).

All subjects were allowed a period of three to five minutes in which to warm up before each exercise test. The pedal frequency was increased to attain the higher power outputs for the discontinuous tests.

Oxygen consumption was measured using an open circuit spirometry system. Expired air was sampled every 15 seconds from a baffled mixing chamber to determine the fractional components of oxygen (Applied Electrochemistry Analyzer S-3A) and carbon dioxide (Applied Electrochemistry Analyzer CD-3A). Ventilation (STPD), oxygen consumption, carbon dioxide production, and respiratory exchange ratio were calculated using an on-line computer system with Rayfield software. Prior to each exercise testing session both the oxygen analyzer and carbon dioxide analyzer were calibrated to both ambient air and a standard gas mixture. The bicycle ergometer was calibrated between tests to ensure correct power outputs.

Table 2

Power Outputs Used In Maximal Tests

Power Output (kgm/min)	Pedal Rate (rpm)	Tension (kp)
720	60	2
1080	60	3
1440	60	4
1800	60	5
2025	75	4.5
2250	75	5
2400	80	5
2640	80	5.5
2805	85	5.5

Procedures for Treating the Data

Peak oxygen consumption (Peak VO_2) during the last 30 seconds of each power output was plotted against time to attempt to illustrate whether or not a plateau was attained.

Oxygen consumption vs. power output values for each subject were analyzed to determine if an oxygen consumption plateau occurred. A plateau was identified if there was less than a 0.15 L/min increase in oxygen consumption between the peak VO_2 obtained on a continuous test and the mean of the peak VO_2 values obtained on the supramaximal discontinuous tests (Taylor, 1955).

CHAPTER 4

ANALYSIS OF THE DATA

Introduction

The purpose of the present study is to compare whether a difference in frequency of attainment of a "plateau" in oxygen consumption can be observed in the power output vs. oxygen consumption relationship in highly trained endurance athletes versus highly trained strength athletes. One group (TR) of 12 males (ages 18-36) were trained runners and the other group (WL) of 12 males (ages 18-31) consisted of trained weight lifters. The subjects participated in a series of maximal exercise tests performed on a cycle ergometer equipped with toe straps.

Subjects first completed a continuous graded exercise test which started at a power output of 720 kgm/min and increased every two minutes until exhaustion. Subjects then completed a series of daily discontinuous supramaximal exercise tests for at least 90 seconds.

This chapter will serve to identify:

1. The graphical treatment of the data.
2. The statistical treatment of the data.
3. The results.

Graphical Treatment

The graphs and tables of oxygen consumption for each power output for the trained runners (TR) are contained in

Appendix B. The graphs and tables of the oxygen consumption for each power output for the trained weight lifters (WL) are contained in Appendix C. The tables for each subject include Group, Power Output, VO2, as well as the type of test in which the power output was performed and whether or not the individual plateaued.

Statistical Treatment

A 2 x 2 contingency table was used to classify the number of subjects in each group who achieved a plateau in maximal oxygen consumption. Chi Square was calculated in order to determine if there was a difference in frequency of attainment of a plateau between the TR and WL groups (Appendix D).

Results

The peak VO_2 values for each maximal test for the weight lifters (WL) and the trained runners (TR) are contained in Table 4 and Table 5, respectively. The tables contain the peak VO_2 values for the continuous test and all discontinuous tests performed. The difference of the continuous VO_2 values and the mean of the discontinuous VO_2 values is included and was used in determining whether or not a plateau in maximal oxygen consumption occurred.

Table 3

Peak VO_2 Values For Each Test (WL)

Group	Subject	Test	VO2 (l/min)	Difference (l/min)
WL	1	CONT.	5.31	0.14
		DISC. 1	5.22	
		DISC. 2	5.12	
WL	2	CONT.	4.50	0.44
		DISC. 1	4.56	
		DISC. 2	4.83	
		DISC. 3	5.17	
		DISC. 4	5.21	
WL	3	CONT.	4.78	0.14
		DISC. 1	4.79	
		DISC. 2	4.97	
		DISC. 3	5.01	
WL	4	CONT.	4.80	0.04
		DISC. 1	4.75	
		DISC. 2	4.93	
WL	5	CONT.	4.76	0.07
		DISC. 1	4.80	
		DISC. 2	4.73	
		DISC. 3	4.96	
WL	6	CONT.	4.46	0.05
		DISC. 1	4.41	
		DISC. 2	4.59	
		DISC. 3	4.43	
		DISC. 4	4.62	
WL	7	CONT.	4.63	0.26
		DISC. 1	4.55	
		DISC. 2	5.04	
		DISC. 3	5.09	
WL	8	CONT.	5.22	0.05
		DISC. 1	5.14	
		DISC. 2	5.40	
WL	9	CONT.	3.80	0.14
		DISC. 1	4.09	
		DISC. 2	3.79	
WL	10	CONT.	4.52	0.01
		DISC. 1	4.53	
		DISC. 2	4.49	
WL	11	CONT.	4.90	0.02
		DISC. 1	4.92	
WL	12	CONT.	4.00	0.05
		DISC. 1	4.08	
		DISC. 2	4.02	

Table 4

Peak VO_2 Values For Each Test (TR)

Group	Subject	Test	VO2 (l/min)	Difference (l/min)
TR	13	CONT.	4.73	0.07
		DISC. 1	4.94	
		DISC. 2	4.69	
		DISC. 3	4.77	
TR	14	CONT.	4.66	0.02
		DISC. 1	4.68	
		DISC. 2	4.63	
		DISC. 3	4.67	
		DISC. 4	4.73	
TR	15	CONT.	4.50	0.13
		DISC. 1	4.47	
		DISC. 2	4.70	
		DISC. 3	4.73	
TR	16	CONT.	4.53	0.04
		DISC. 1	4.53	
		DISC. 2	4.61	
TR	17	CONT.	4.59	0.03
		DISC. 1	4.44	
		DISC. 2	4.57	
		DISC. 3	4.68	
TR	18	CONT.	4.68	0.14
		DISC. 1	4.83	
		DISC. 2	4.59	
		DISC. 3	4.98	
		DISC. 4	4.89	
TR	19	CONT.	4.59	0.09
		DISC. 1	4.60	
		DISC. 2	4.77	
		DISC. 3	4.59	
		DISC. 4	4.72	
		DISC. 5	4.72	
TR	20	CONT.	4.26	0.13
		DISC. 1	4.26	
		DISC. 2	4.51	
TR	21	CONT.	4.77	0.33
		DISC. 1	4.68	
		DISC. 2	4.91	
		DISC. 3	5.19	
		DISC. 4	5.61	
TR	22	CONT.	4.39	0.11
		DISC. 1	4.39	
		DISC. 2	4.68	
		DISC. 3	4.46	
		DISC. 4	4.46	
TR	23	CONT.	4.26	0.03
		DISC. 1	4.30	
		DISC. 2	4.28	
TR	24	CONT.	4.73	0.03
		DISC. 1	4.69	
		DISC. 2	4.67	
		DISC. 3	4.73	

The frequency of attainment of a plateau in oxygen consumption for the two groups is shown in Table 5. The Chi Square of 0.381 (Appendix D) was not statistically significant (p< .05) (Cohen, L, & Holliday, M. 1979). A plateau in oxygen consumption was attained in 88% (21) of all subjects, and in 83% (10) of the weight trained group and 92% (11) of the trained runners.

Table 5

Frequency Of Plateau Attainment

		Plateau	No Plateau
Group	WT	10	2
	TR	11	1

Discussion

A plateau criteria used similar to the one originally used by Taylor et al. (1955) was used for this study because it is probably the most frequently used criteria in the study of maximal exercise.

The cycle ergometer was chosen in an effort to remove possible bias towords the trained runners. Using a treadmill for maximal tests might have influenced plateau attainment in trained runners because of possible specificity of training factors (Davies et al., 1984; Corry & Powers 1982).

The use of toe clips may also have served to allow a greater muscle mass to be employed and to increase the ability to sustain the high power outputs performed.

A continuous-discontinuous protocol was employed in an effort to obtain as many supramaximal peak O_2 consumption values as possible. The discontinuous tests served to decrease the effects of possible cumulative fatigue that may accompany continuous tests.

Pilot studies performed on similar trained subjects indicated that in order to terminate the continuous tests in 7 to 10 minutes (Pollock 1977), the two minute stages had to start at 720 kgm/min. This was mainly a result of the subjects in this study being trained rather than sedentary.

The sampling interval of 15 seconds has been shown to produce a small sampling variability comparable to other intervals in sampling (Myers et al. 1990). However, this sampling interval may have been a factor in those individuals who failed to show a plateau in VO_2. It is seems possible that the variability in sampling may have affected the mean value of the discontinuous tests, thus affecting plateau attainment.

Because there was no significant difference between the groups, this study does not support Noakes's (1988) argument for a muscle power limitation to VO_2 max. If there had been a disproportionate number of subjects in the trained runners group who did not attain a plateau in oxygen consumption compared to the weight lifters this would have supported Noake's hypothesis of some type of "muscle power" limitation. Although the present study serves to underscore the classical concept of a "plateau in maximal oxygen consumption", the results may not apply to other populations and conditions studied.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

It was the purpose of the present study to determine whether a "plateau" in oxygen consumption is observed in the power output-oxygen consumption relationship in trained endurance athletes less often than in strength trained athletes.

The subjects consisted of 24 male volunteers with 12 in each group. One group included Eastern Illinois University cross country team members and other experienced runners (ages 18-36) who were not involved in any form of weight training activity. The other group included individuals (ages 18-31) who had been involved regularly with weight training for more than one year and had not been involved in any other form of regular exercise.

The subjects, after signing an informed consent, participated in a series of maximal oxygen consumption exercise tests performed on a Monark cycle ergometer equipped with toe straps. Subjects first completed a continuous graded exercise test which started at a workload of 720 kgm/min and increased every two minutes until exhaustion. Subjects then completed a series of daily discontinuous supramaximal exercise tests, which consisted of maintaining a preset power output (beginning at the next higher workrate than the highest power output obtained on the continuous test) for at least 90 seconds. The subsequent constant workloads were increased until the subject could no longer perform the workrate for 90 seconds. Pedal frequency was increased with the higher discontinuous workrates.

Oxygen consumption was plotted against time (at each 15 second interval) for each workrate. Frequency of plateau attainment was analyzed using a 2 x 2 contingency table in calculating the Chi Square value (0.381). A plateau in oxygen consumption was attained in 88% (22) of all subjects (24), and in 83% (10) of the weight trained group and 92% (11) of the trained runners. The Chi Square Test indicated that there is no statisticallly significant difference between the groupsm in frequency of attainment of a plateau during maximal testing.

Conclusions

Based upon the results of this study the null hypothesis is accepted. There is no statistically significant difference between the number of subjects attaining a plateau in oxygen consumption in groups of endurance trained athletes vs. strength trained athletes. Under the conditions of the present study 91% (22 of 24) of all subjects were shown to have attained a maximal oxygen consumption plateau.

Recommendations

Further investigations involving examination of frequency of attainment of a plateau in oxygen consumption should utilize methods that will enable subjects to perform at maximal work levels for longer periods of time. Methods to accomplish this may include utilization of legs and arms during maximal tests to enable the subject to perform fixed severe workloads for longer periods of time by employing a greater muscle mass (Gutin et al. 1988).

These studies should include trained as well as sedentary individuals for plateau frequency comparison. The studies should also test groups of subjects using different modes (ie. treadmill, cycle ergometer etc.).

Protocols similar to that used in the present study (a continuous test followed by a series of discontinuous tests) may also be employed to more precisely determine a plateau in oxygen consumption. Future studies should seek to compare different homogeneous groups of subjects in helping to identify factors which may affect the demonstration of a plateau in oxygen consumption.

Studies in which maximal oxygen consumption is measured should identify the criteria used for maximal oxygen consumption as well as report the actual number of subjects who plateau.

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APPENDIX A: INFORMED CONSENT

INFORMED CONSENT

The subject is being asked to participate in a research study being conducted by Jeff Seda, a graduate student at Eastern Illinois University. The purpose of the study is to determine whether or not there is a difference between trained runners and trained weight lifters in showing a "plateau" in oxygen consumption.

To be included in the study the subject will be required to maintain regular training (weight training or run training) and will be ask not to participate in the opposite type of training, i.e. runners should not weight train and weight lifters should not participate in aerobic training.

The study requires that the subject perform a series of maximal exercise tests using a bicycle ergometer. The first test will be one in which the subject will be required to pedal at a given revolutions per minute (rpm) with the workrate being increased every 2 minutes, until the subject can no longer maintain the rpms. The subsequent tests will be performed on separate days and will require the subject to pedal at a workrate higher than the previous day. The testing will end when the subject can no longer maintain the required power output for at least 90 seconds.

The subjects may withdraw from the study for any reason at any time upon notifying the investigators.

I understand that the results of the study may be published in the medical literature and my identity will not be disclosed.

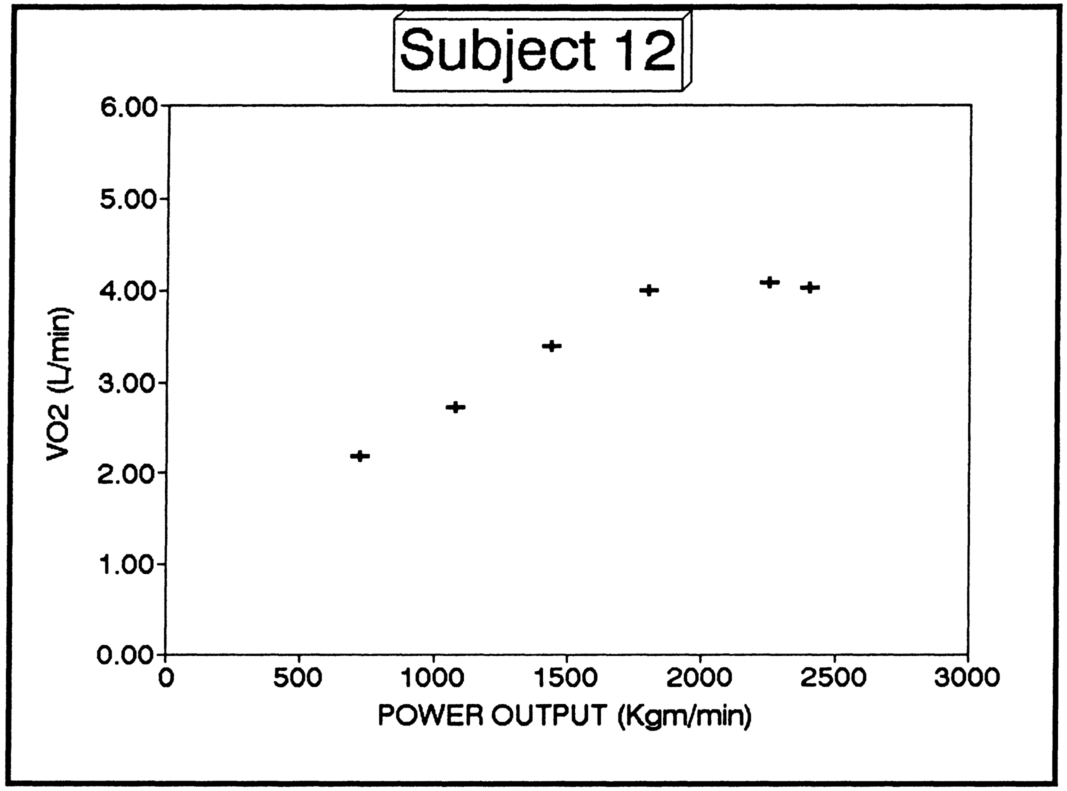
I have read the attached description and have had any questions regarding the study answered. If I have further questions regarding the study, I may have them answered at any time by the investigators.

_________________________ _________________________

Volunteers's Signature Investigators
Signature

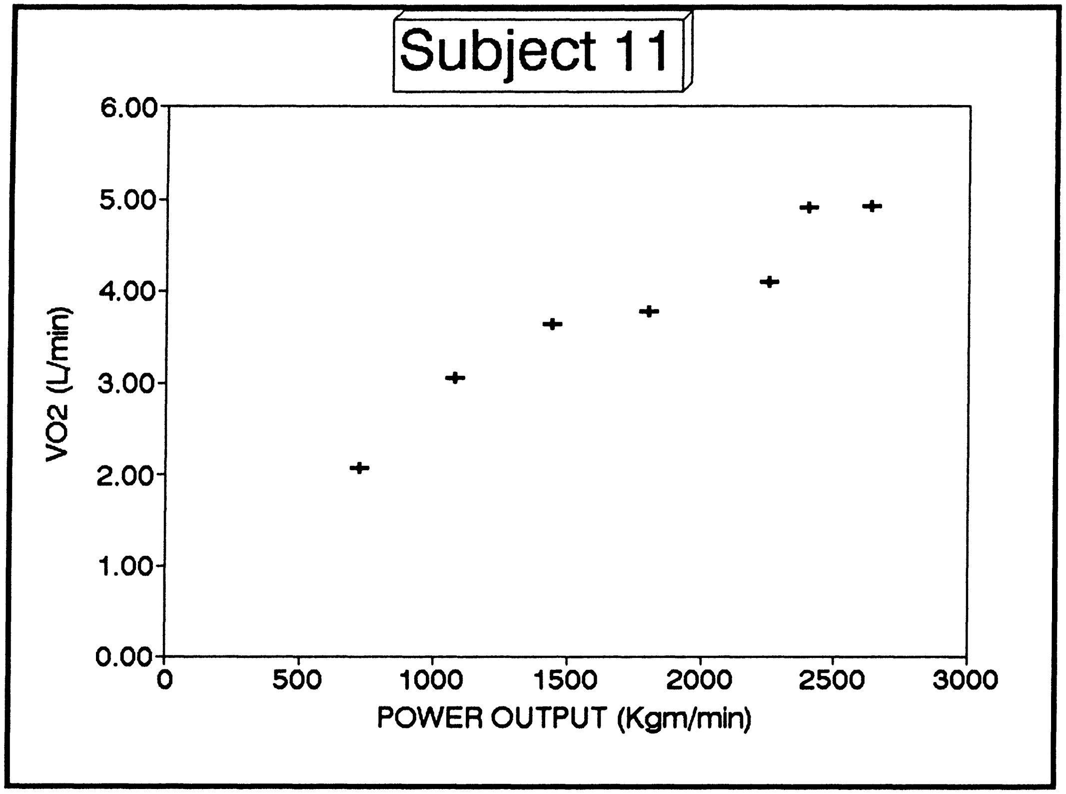
APPENDIX B: GRAPHS-VO2 VS POWER OUTPUT (WL)

Figure 12



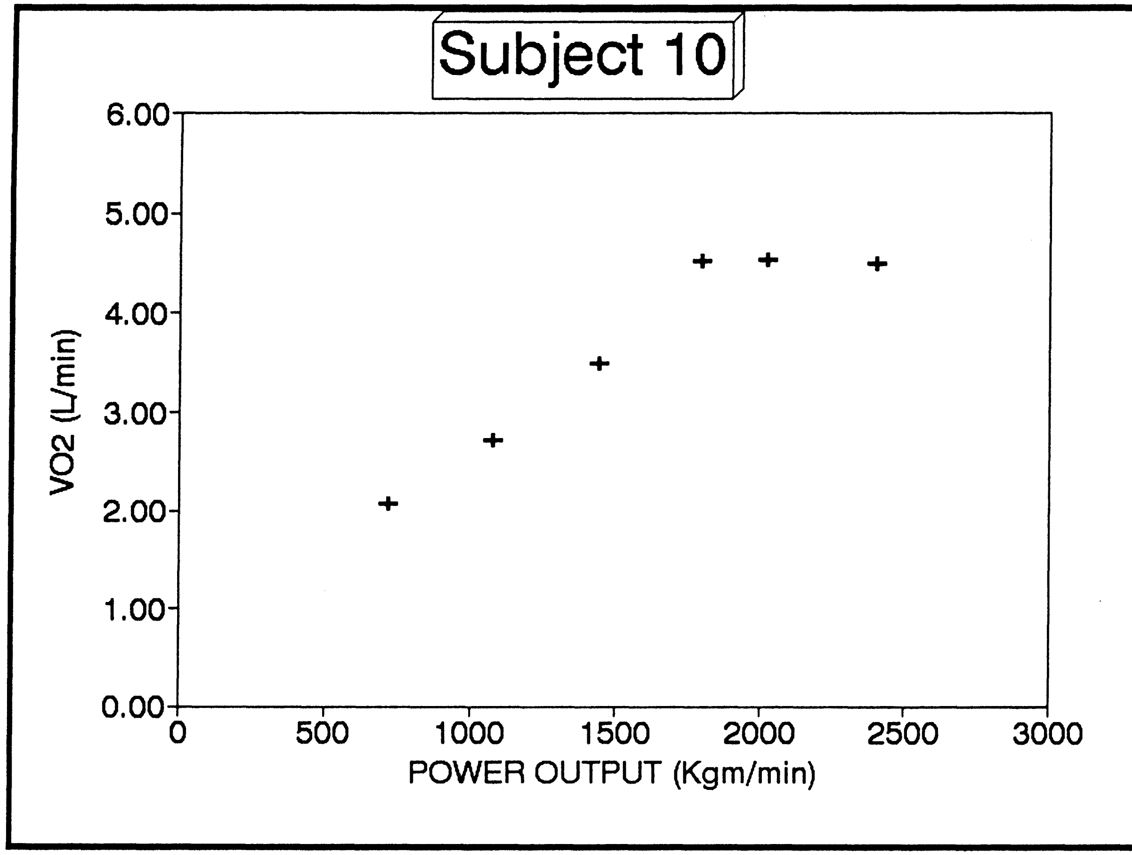
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
12	WL	CONT	720	2.19	
		CONT	1080	2.73	
		CONT	1440	3.40	
		CONT	1800	4.00	
		DISC	2250	4.08	
		DISC	2400	4.02	YES

Figure 11



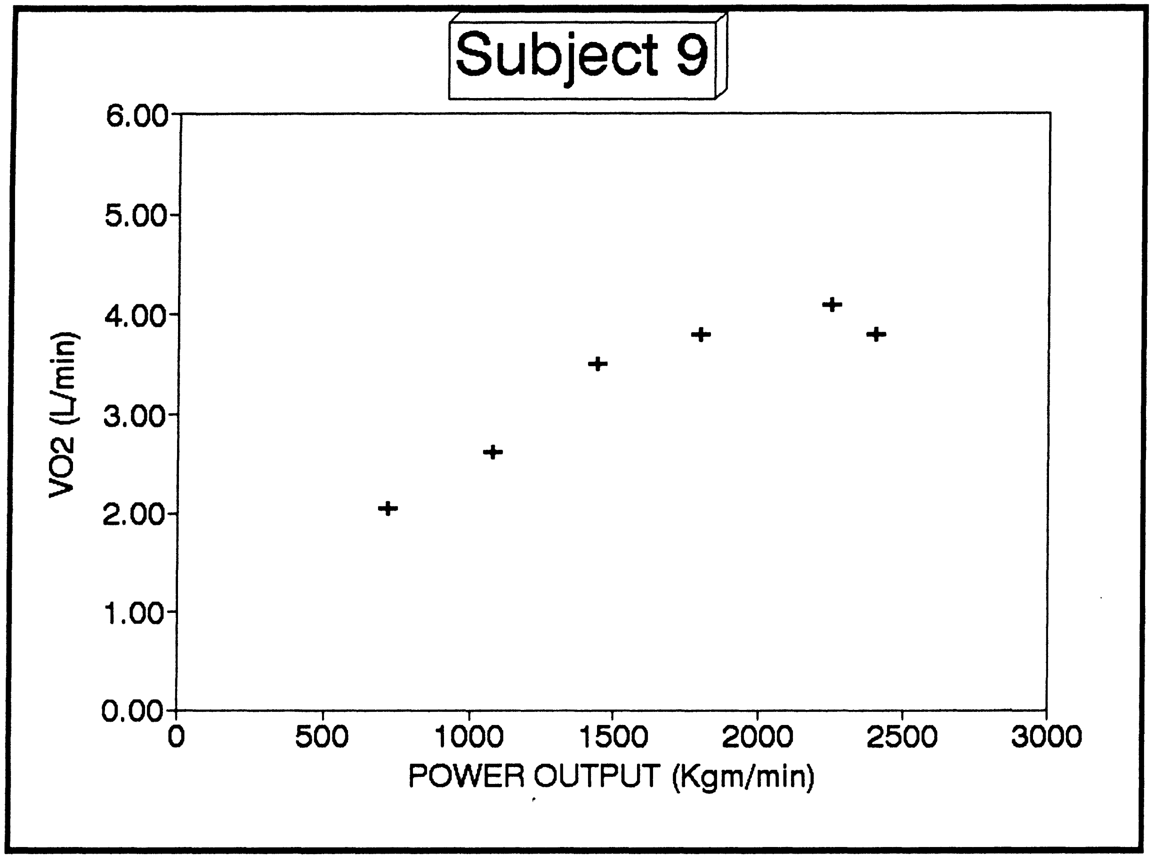
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
11	WL	CONT	720	2.07	
		CONT	1080	3.05	
		CONT	1440	3.64	
		CONT	1800	3.78	
		CONT	2250	4.10	
		CONT	2400	4.90	
		DISC	2640	4.92	YES

Figure 10



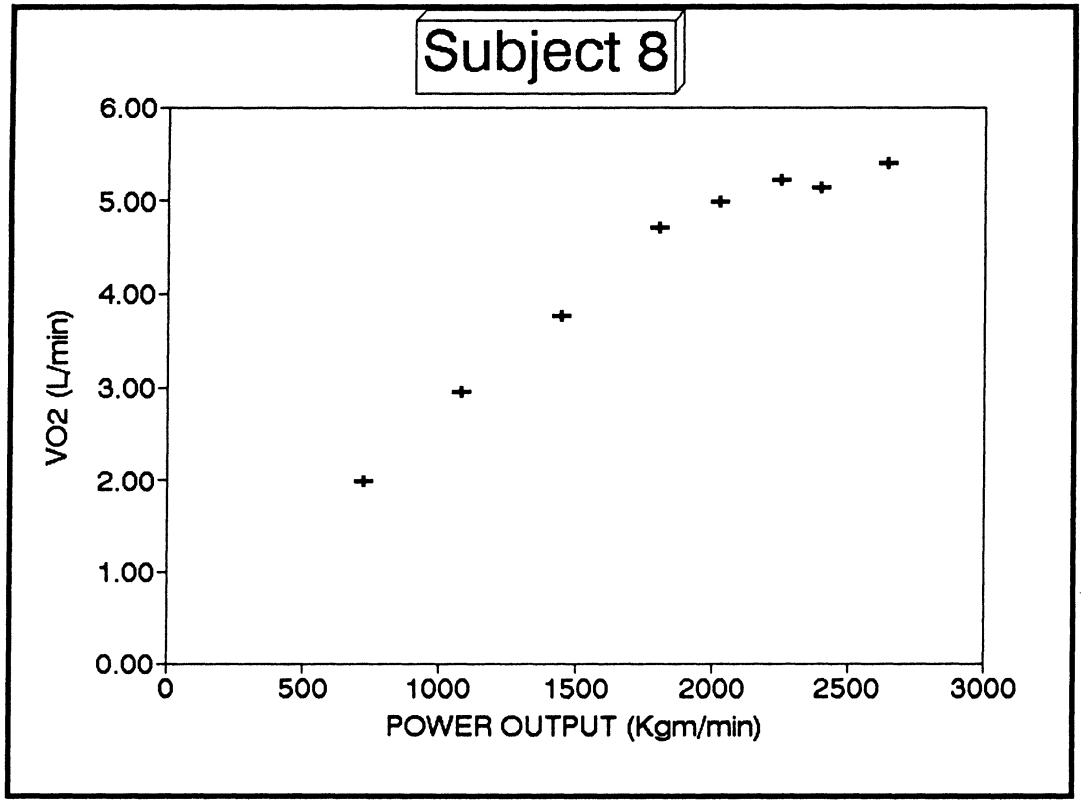
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
10	WL	CONT	720	2.07	
		CONT	1080	2.71	
		CONT	1440	3.48	
		CONT	1800	4.52	
		DISC	2025	4.53	
		DISC	2400	4.49	YES

Figure 9



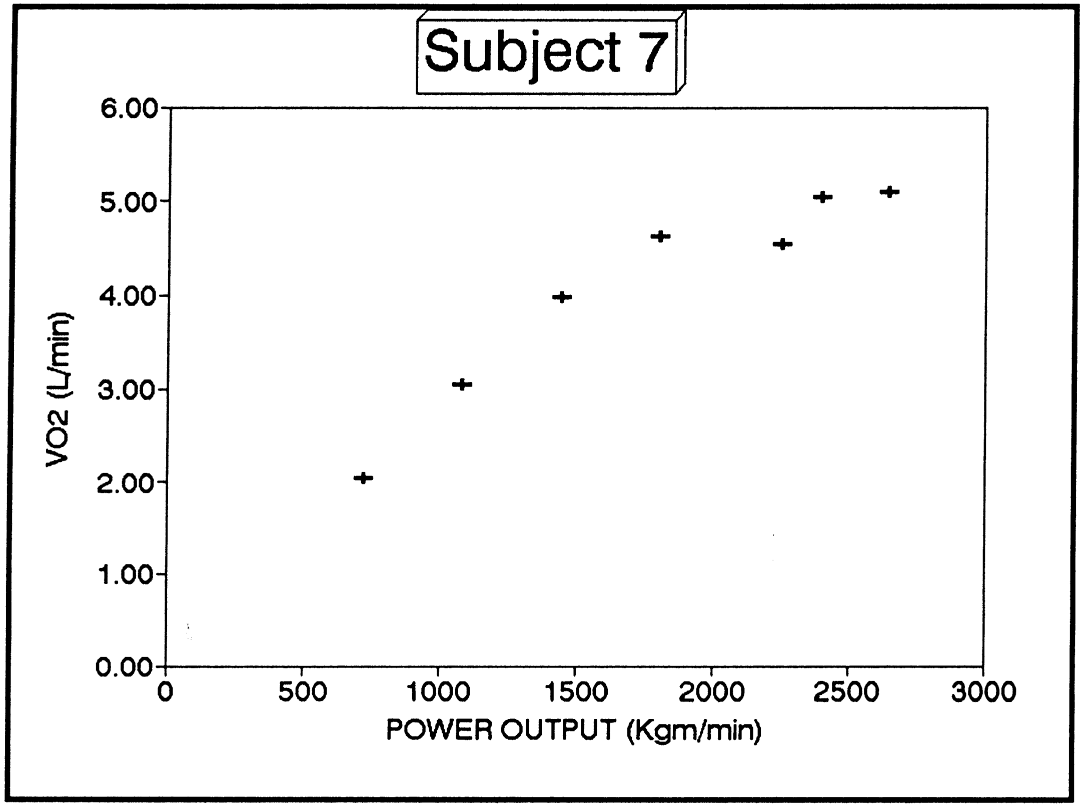
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
9	WL	CONT	720	2.04	
		CONT	1080	2.60	
		CONT	1440	3.50	
		CONT	1800	3.80	
		DISC	2250	4.09	
		DISC	2400	3.79	YES

Figure 8



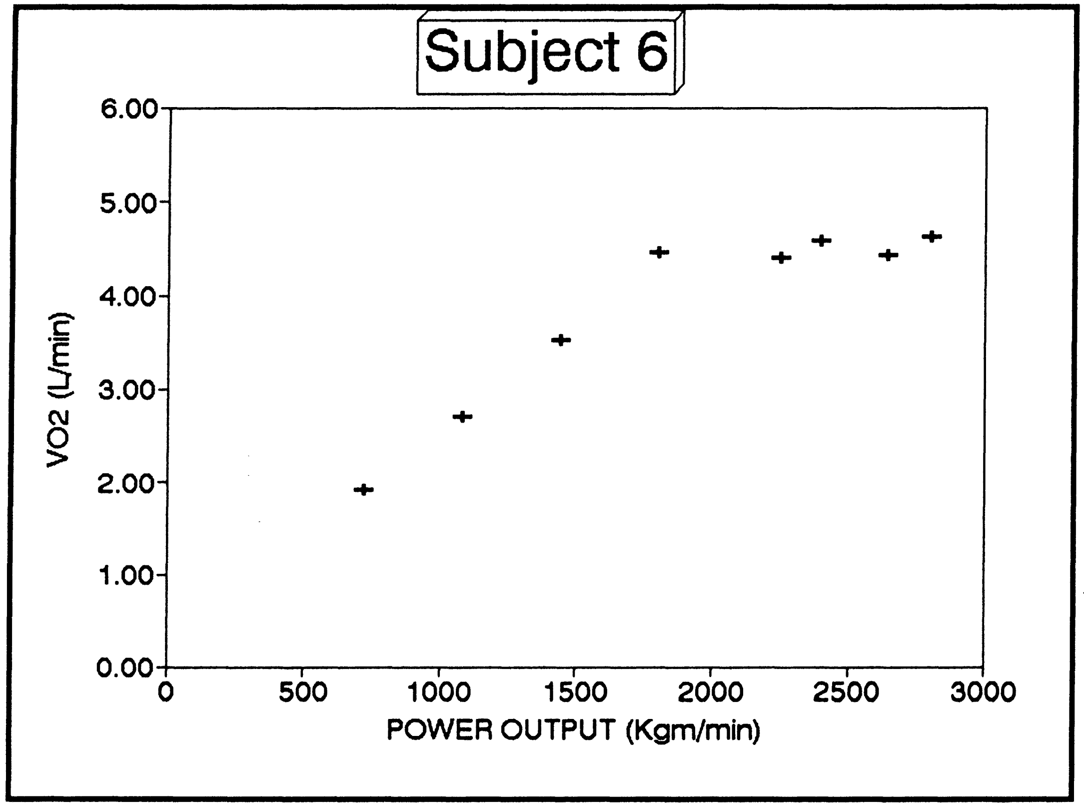
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
8	WL	CONT	720	1.99	
		CONT	1080	2.95	
		CONT	1440	3.77	
		CONT	1800	4.70	
		CONT	2025	4.99	
		CONT	2250	5.22	
		DISC	2400	5.14	
		DISC	2640	5.40	YES

Figure 7



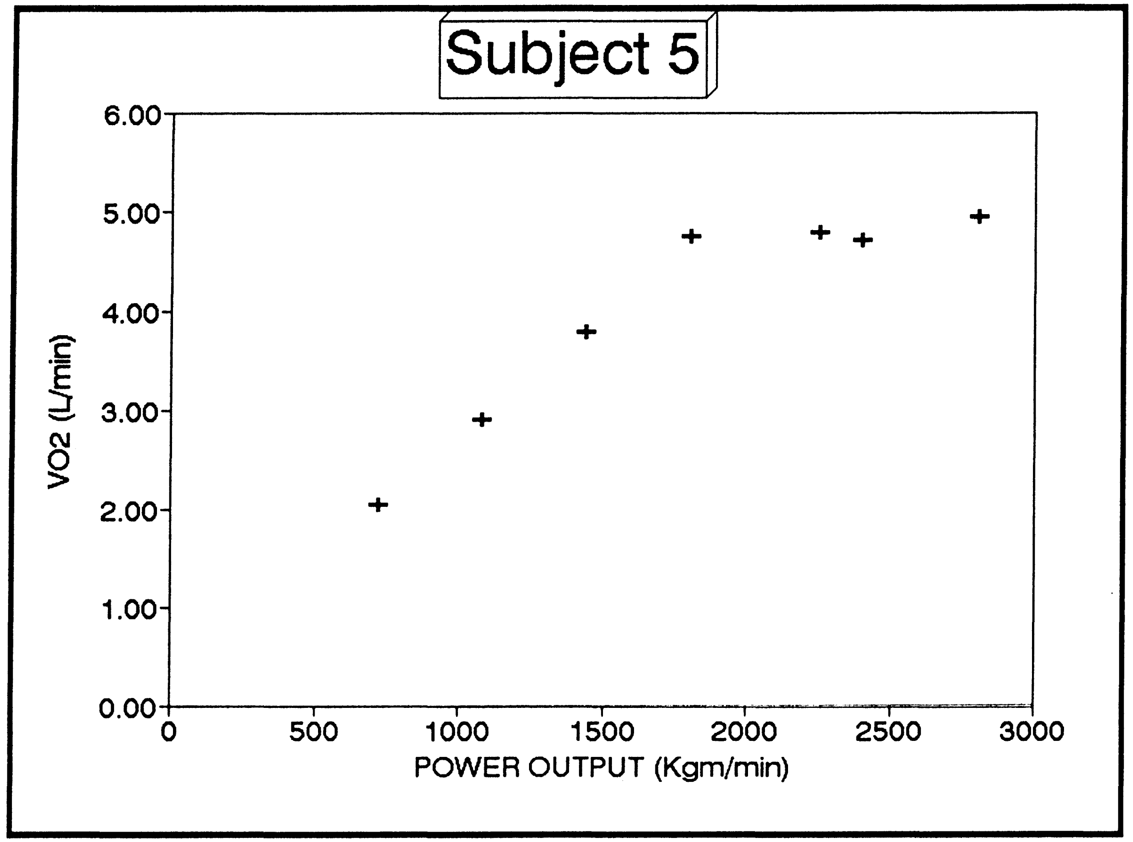
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
7	WL	CONT	720	2.05	
		CONT	1080	3.04	
		CONT	1440	3.98	
		CONT	1800	4.63	
		DISC	2250	4.55	
		DISC	2400	5.04	
		DISC	2640	5.09	NO

Figure 6



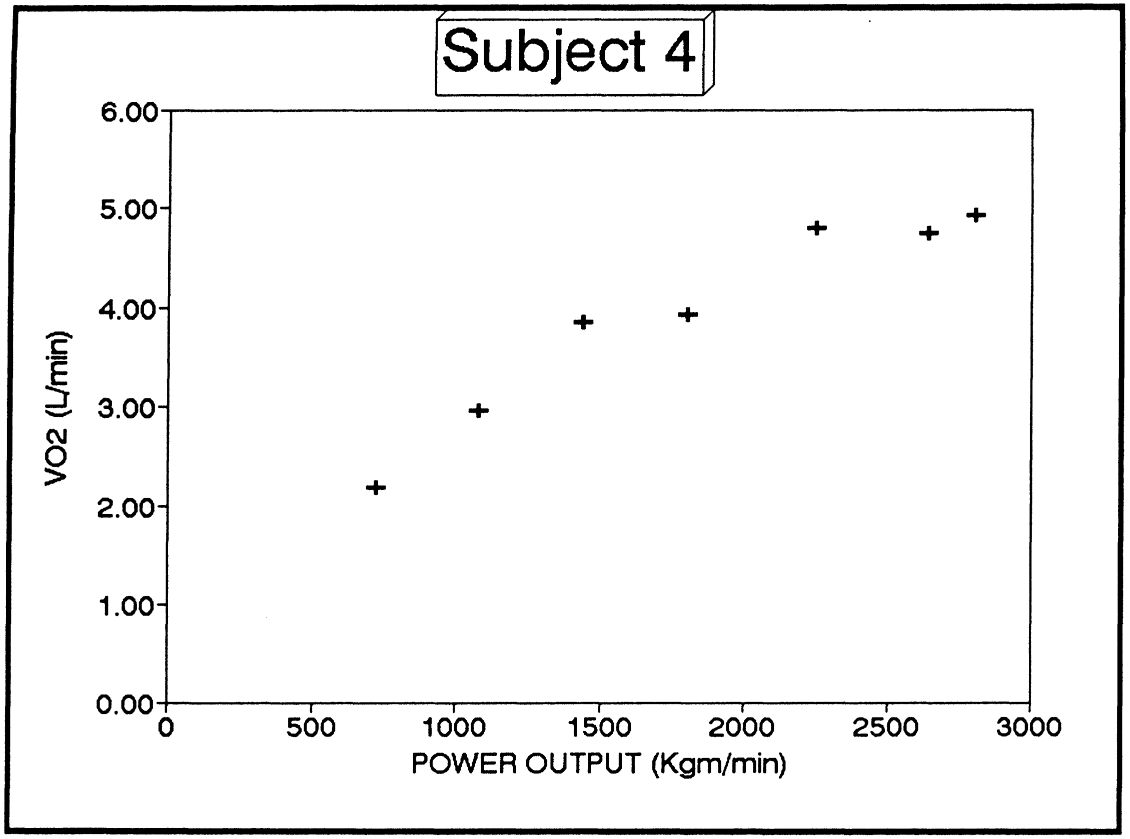
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
6	WL	CONT	720	1.92	
		CONT	1080	2.70	
		CONT	1440	3.53	
		CONT	1800	4.46	
		DISC	2250	4.41	
		DISC	2400	4.59	
		DISC	2640	4.43	
		DISC	2805	4.62	YES

Figure 5



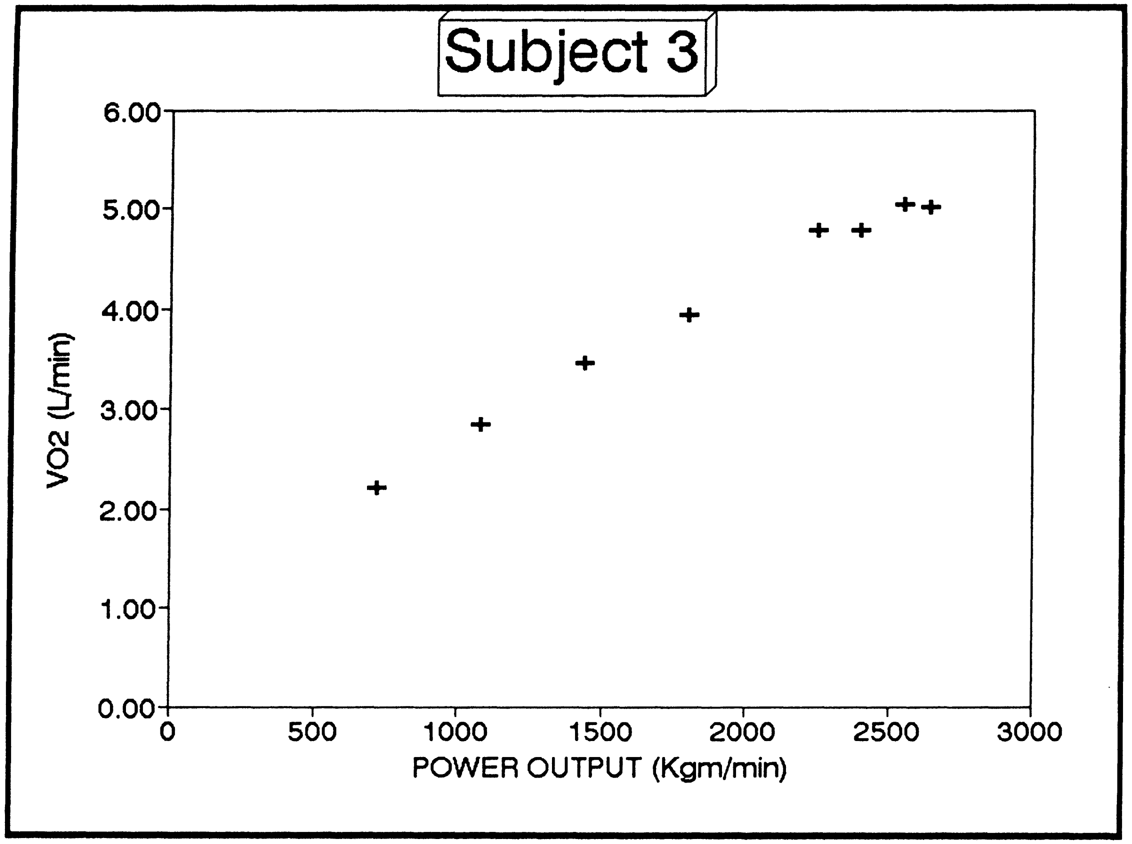
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
5	WL	CONT	720	2.04	
		CONT	1080	2.91	
		CONT	1440	3.79	
		CONT	1800	4.76	
		DISC	2250	4.80	
		DISC	2400	4.73	
		DISC	2805	4.96	YES

Figure 4



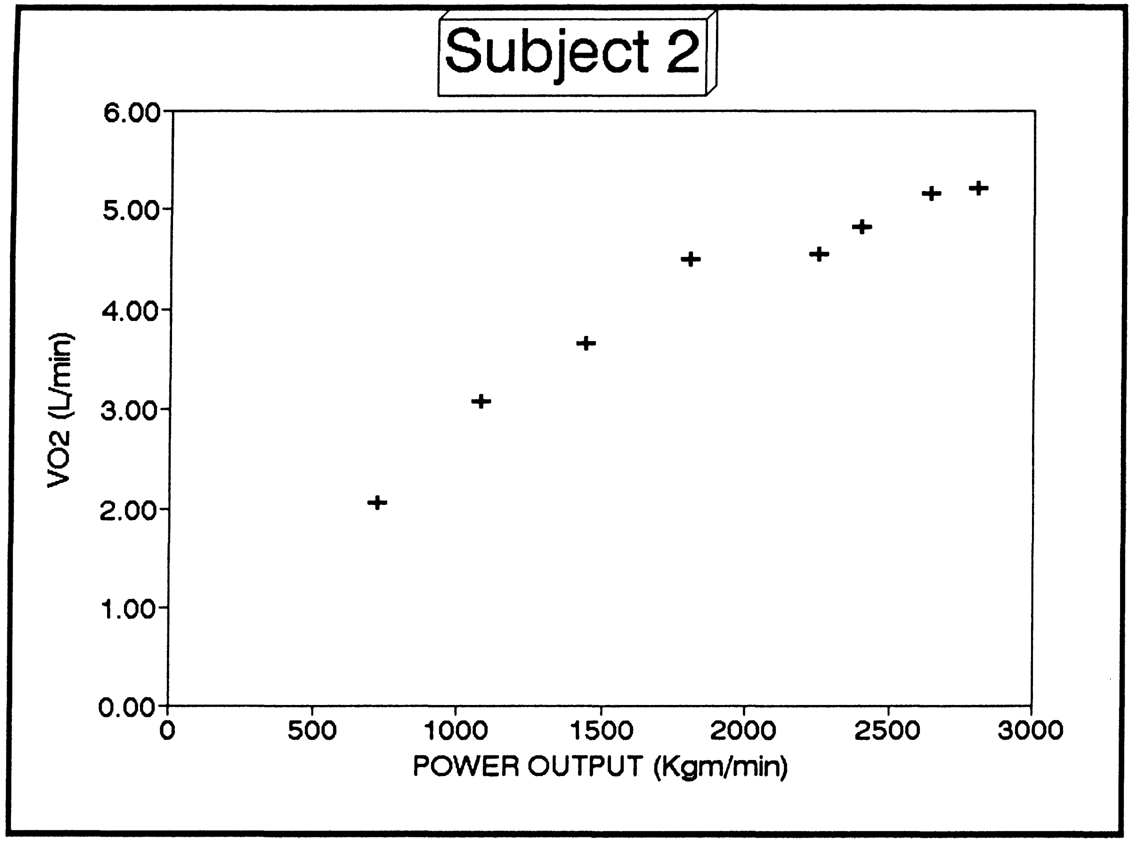
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
4	WL	CONT	720	2.18	
		CONT	1080	2.97	
		CONT	1440	3.85	
		CONT	1800	3.93	
		CONT	2250	4.80	
		DISC	2640	4.75	
		DISC	2805	4.93	YES

Figure 3



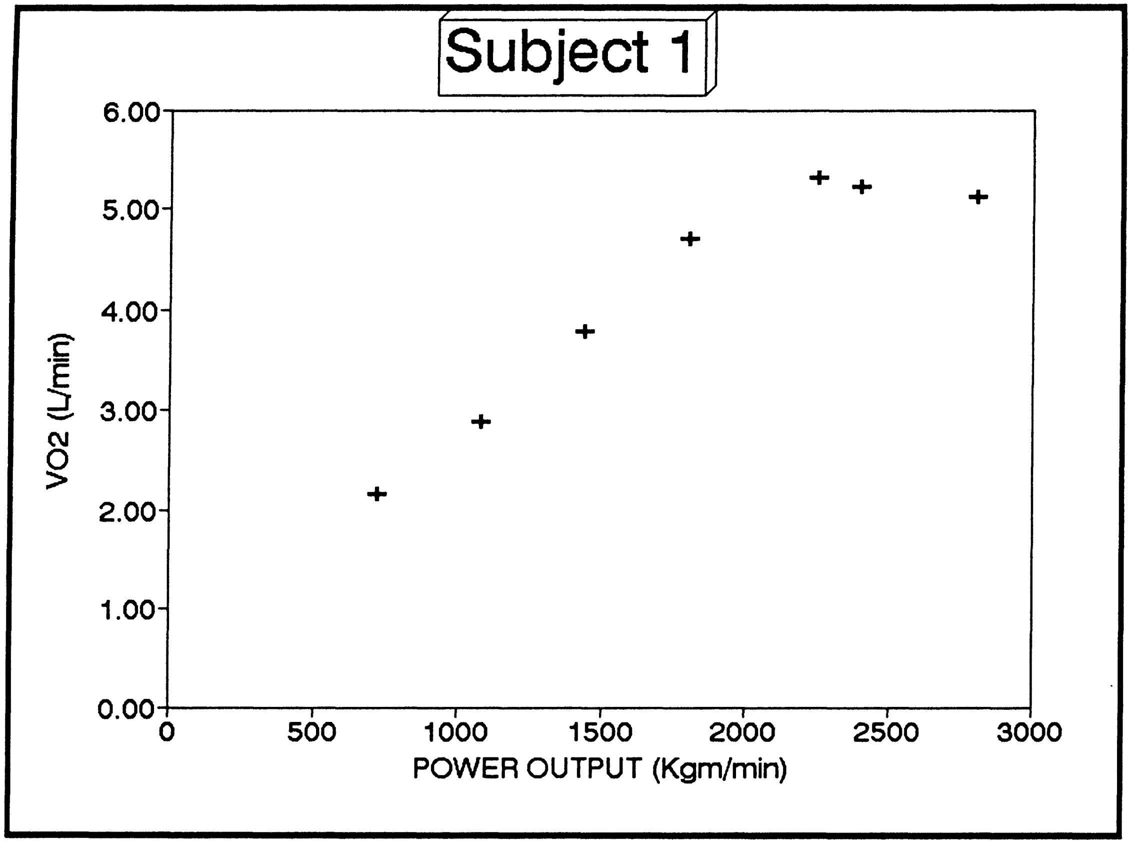
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
3	WL	CONT	720	2.22	
		CONT	1080	2.85	
		CONT	1440	3.47	
		CONT	1800	3.95	
		CONT	2250	4.78	
		DISC	2400	4.79	
		DISC	2550	5.05	
		DISC	2640	5.01	YES

Figure 2



Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
2	WL	CONT	720	2.06	
		CONT	1080	3.08	
		CONT	1440	3.67	
		CONT	1800	4.50	
		DISC	2250	4.56	
		DISC	2400	4.83	
		DISC	2640	5.17	
		DISC	2805	5.21	NO

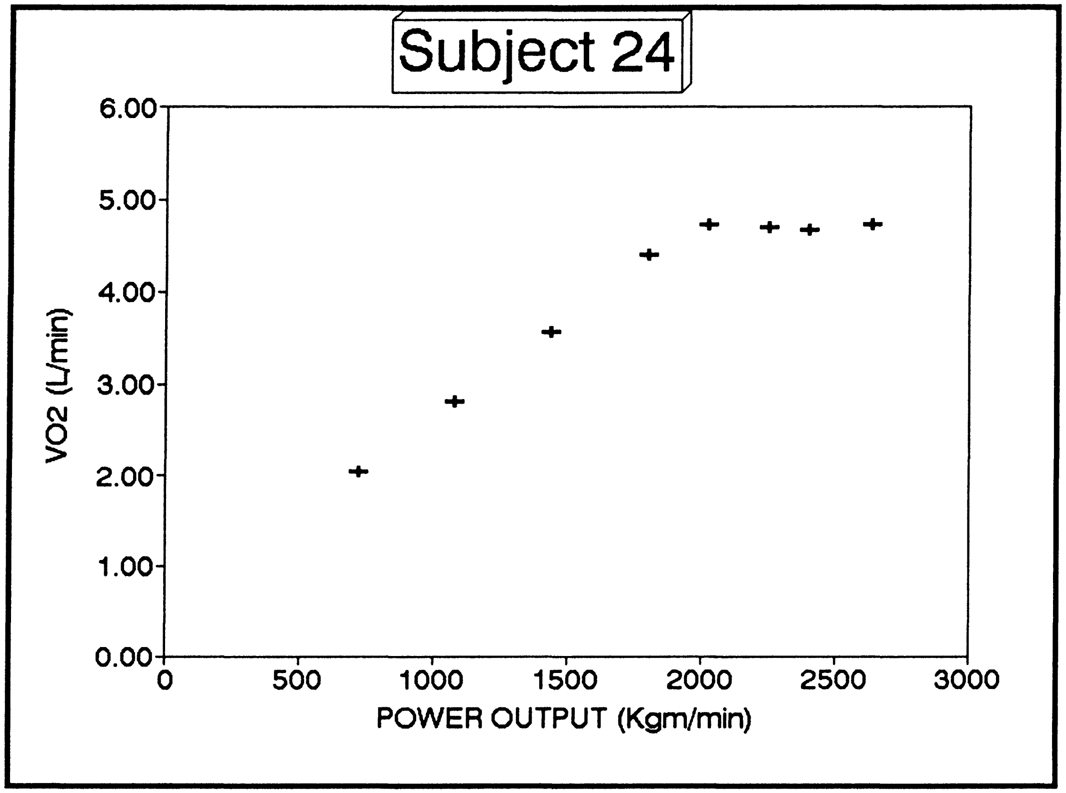
Figure 1



Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
1	WL	CONT	720	2.16	
		CONT	1080	2.88	
		CONT	1440	3.79	
		CONT	1800	4.70	
		CONT	2250	5.31	
		DISC	2400	5.22	
		DISC	2805	5.12	YES

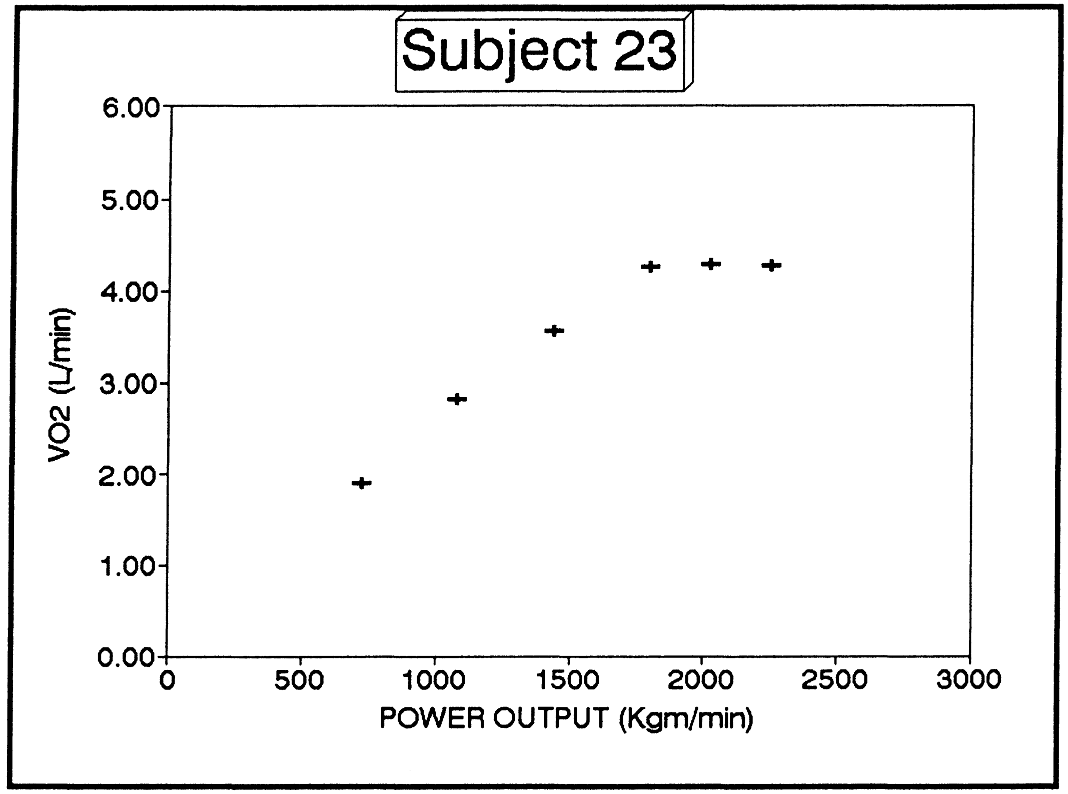
APPENDIX C: GRAPHS-VO2 VS POWER OUTPUT (TR)

Figure 24



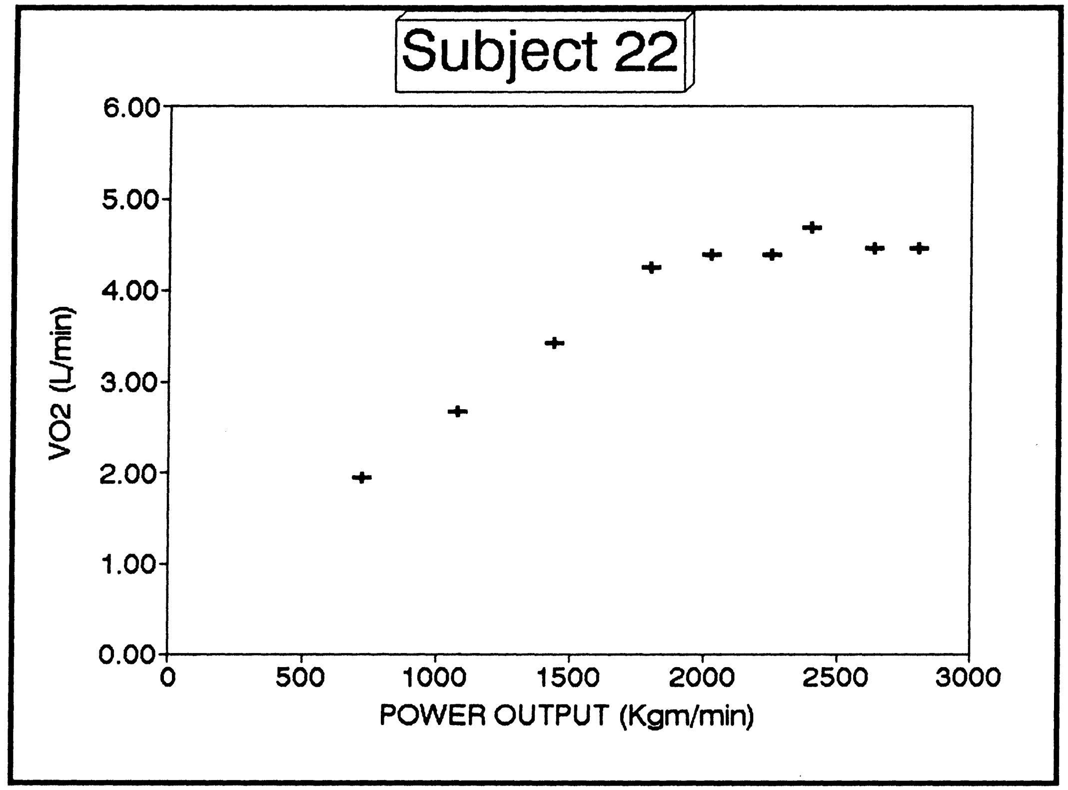
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
24	TR	CONT	720	2.05	
		CONT	1080	2.81	
		CONT	1440	3.57	
		CONT	1800	4.40	
		CONT	2025	4.73	
		DISC	2250	4.69	
		DISC	2400	4.67	
		DISC	2640	4.73	YES

Figure 23



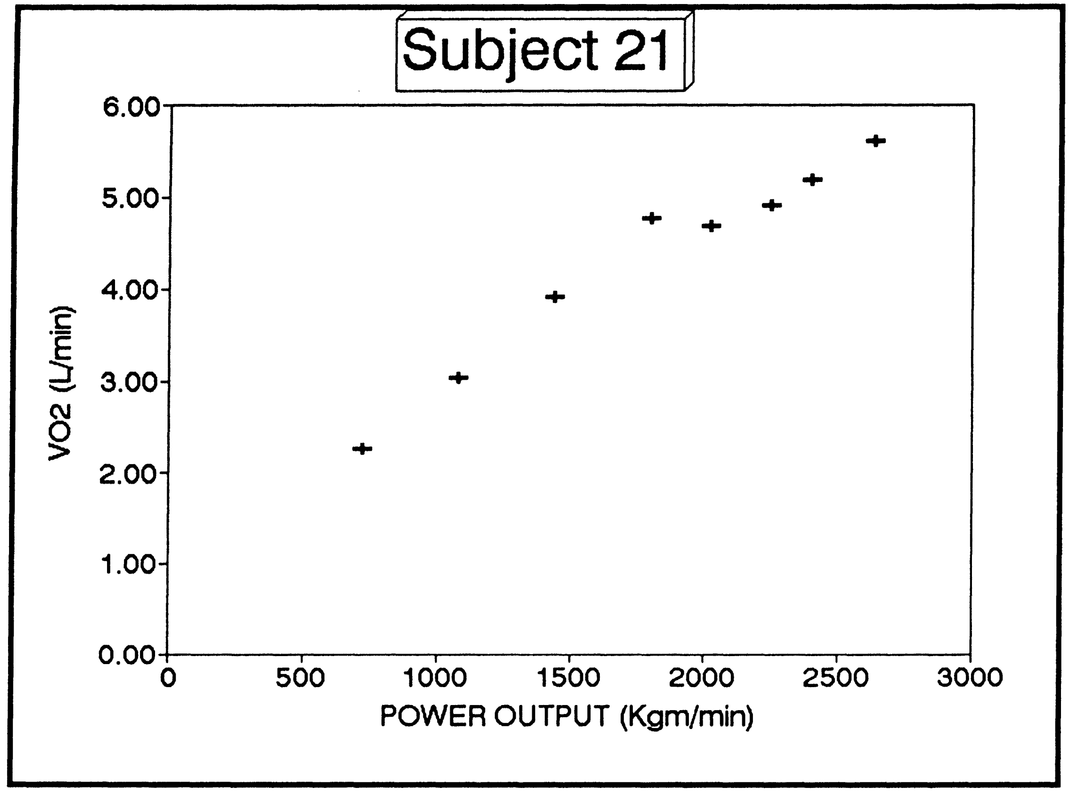
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
23	TR	CONT	720	1.90	
		CONT	1080	2.83	
		CONT	1440	3.57	
		CONT	1800	4.26	
		DISC	2025	4.30	
		DISC	2250	4.28	YES

Figure 22



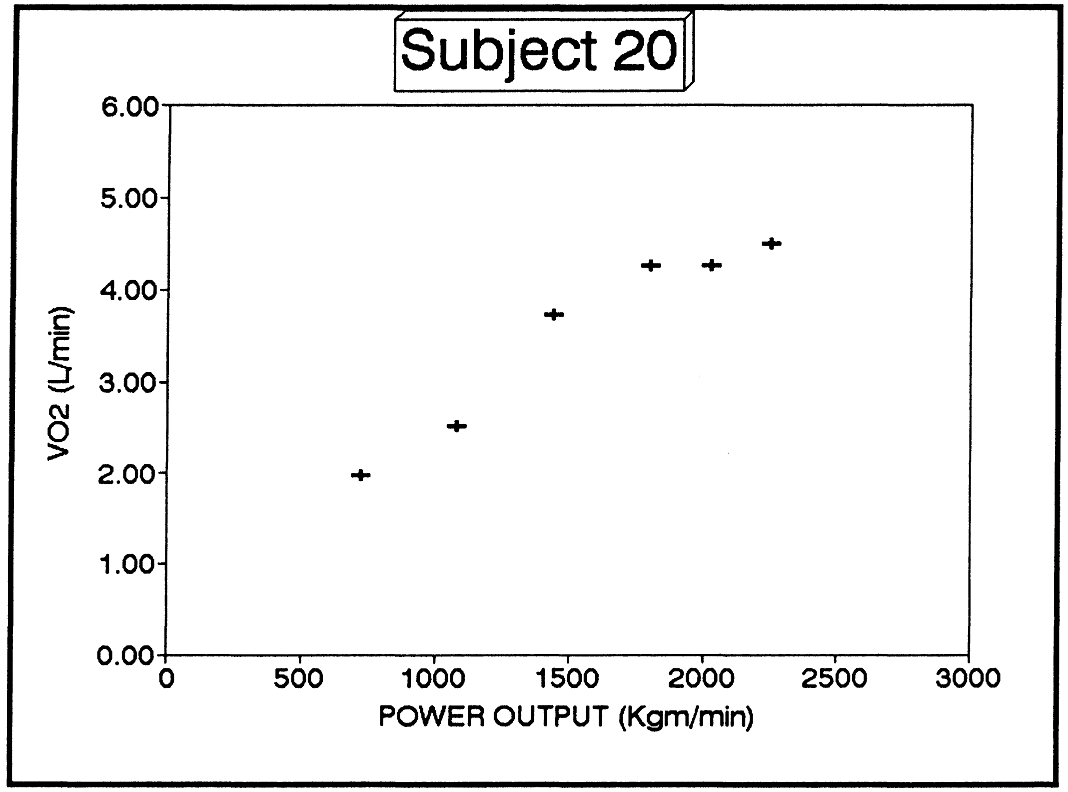
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
22	TR	CONT	720	1.95	
		CONT	1080	2.67	
		CONT	1440	3.43	
		CONT	1800	4.25	
		CONT	2025	4.39	
		DISC	2250	4.39	
		DISC	2400	4.68	
		DISC	2640	4.46	
		DISC	2805	4.46	YES

Figure 21



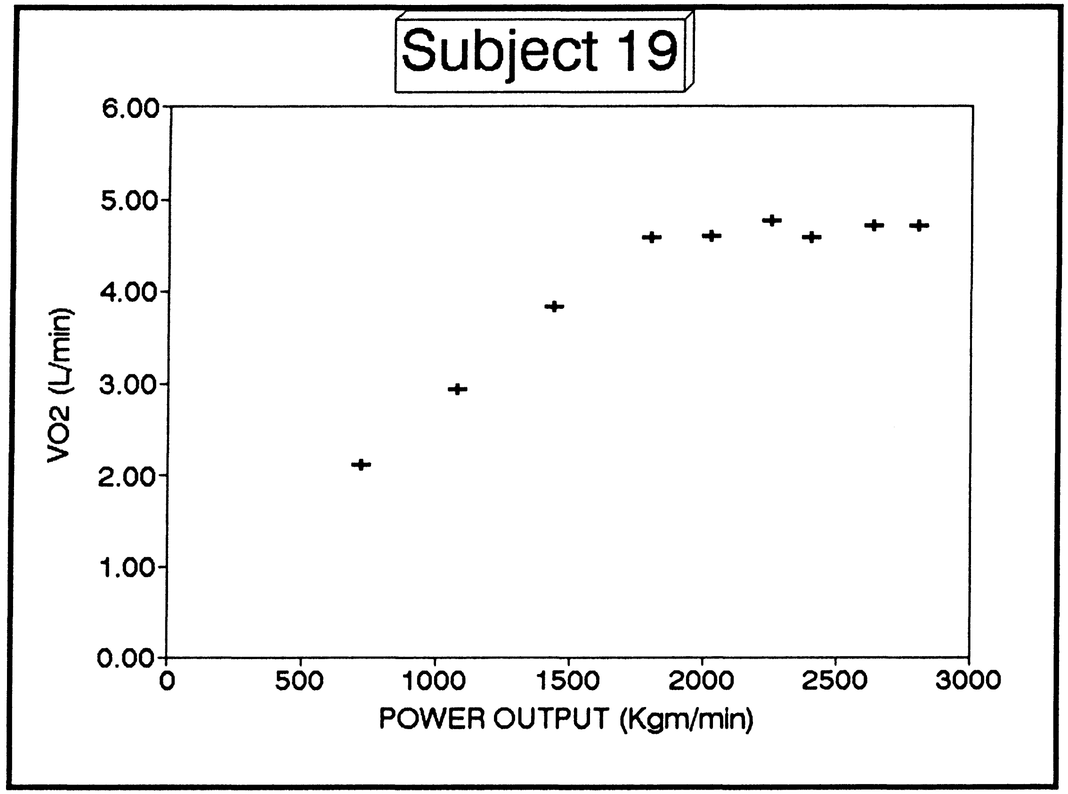
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
21	TR	CONT	720	2.27	
		CONT	1080	3.04	
		CONT	1440	3.92	
		CONT	1800	4.77	
		DISC	2025	4.68	
		DISC	2250	4.91	
		DISC	2400	5.19	
		DISC	2640	5.61	NO

Figure 20



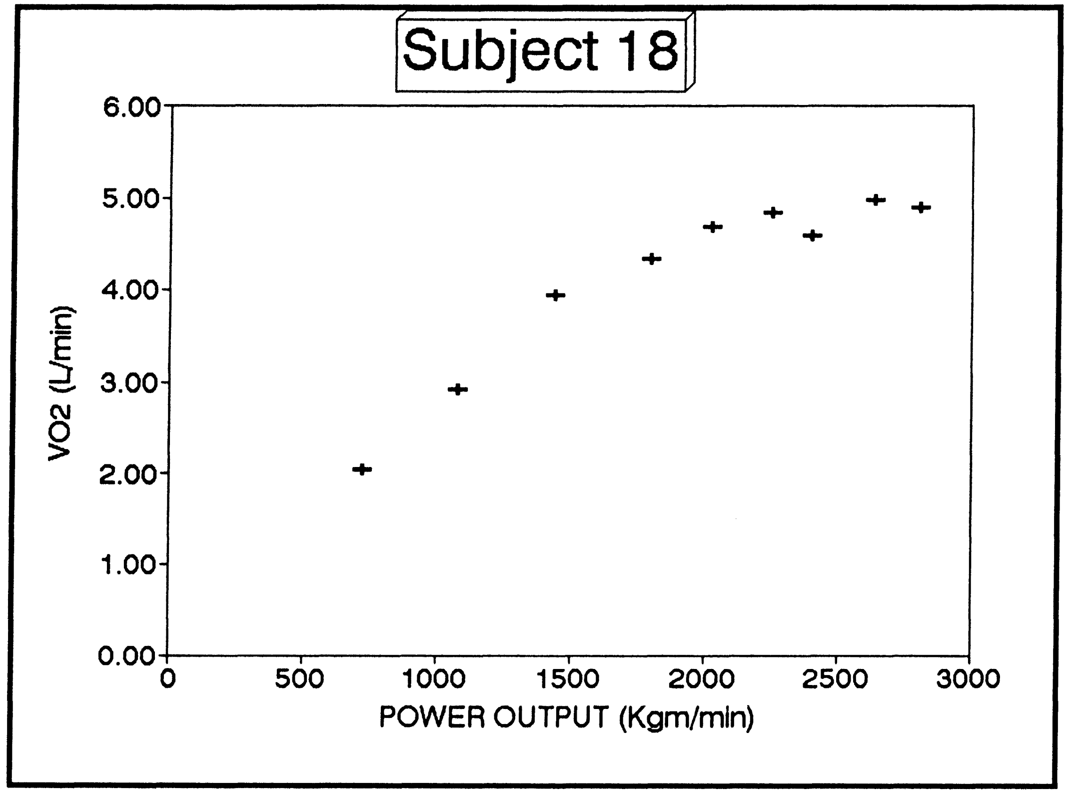
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
20	TR	CONT	720	1.97	
		CONT	1080	2.52	
		CONT	1440	3.73	
		CONT	1800	4.26	
		DISC	2025	4.26	
		DISC	2250	4.51	YES

Figure 19



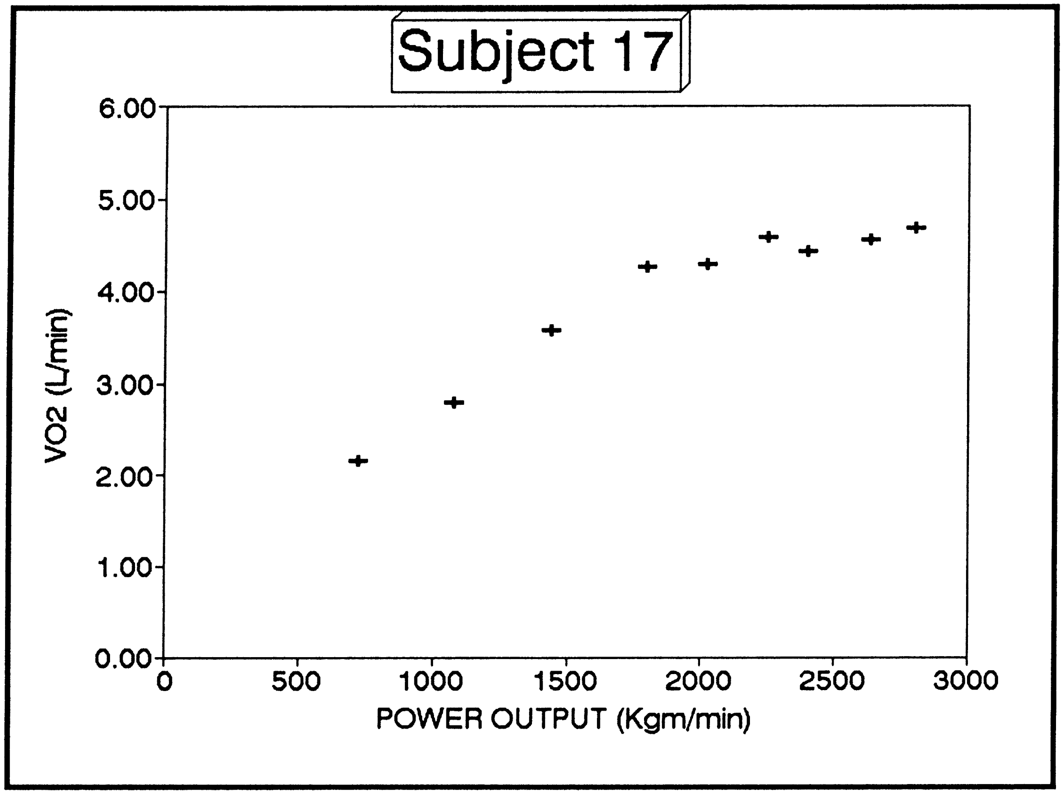
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
19	TR	CONT	720	2.12	
		CONT	1080	2.94	
		CONT	1440	3.84	
		CONT	1800	4.59	
		DISC	2025	4.60	
		DISC	2250	4.77	
		DISC	2400	4.59	
		DISC	2640	4.72	
		DISC	2805	4.72	YES

Figure 18



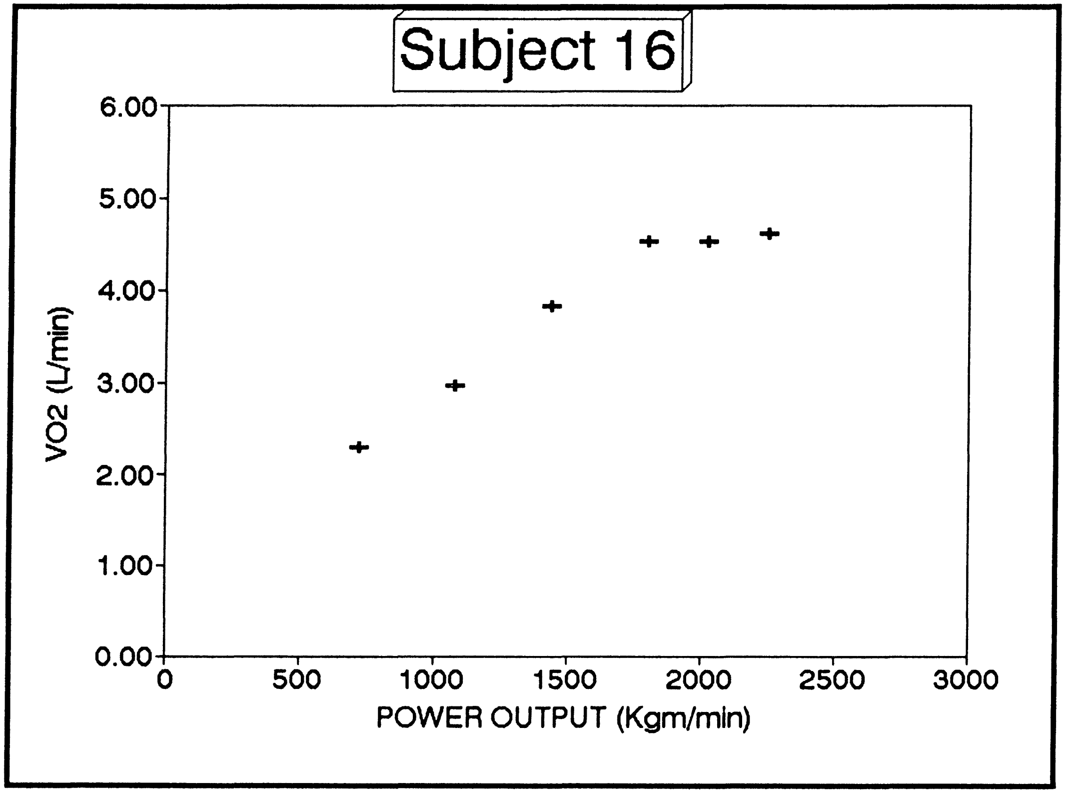
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
18	TR	CONT	720	2.04	
		CONT	1080	2.92	
		CONT	1440	3.94	
		CONT	1800	4.34	
		CONT	2025	4.68	
		DISC	2250	4.83	
		DISC	2400	4.59	
		DISC	2640	4.98	
		DISC	2805	4.89	YES

Figure 17



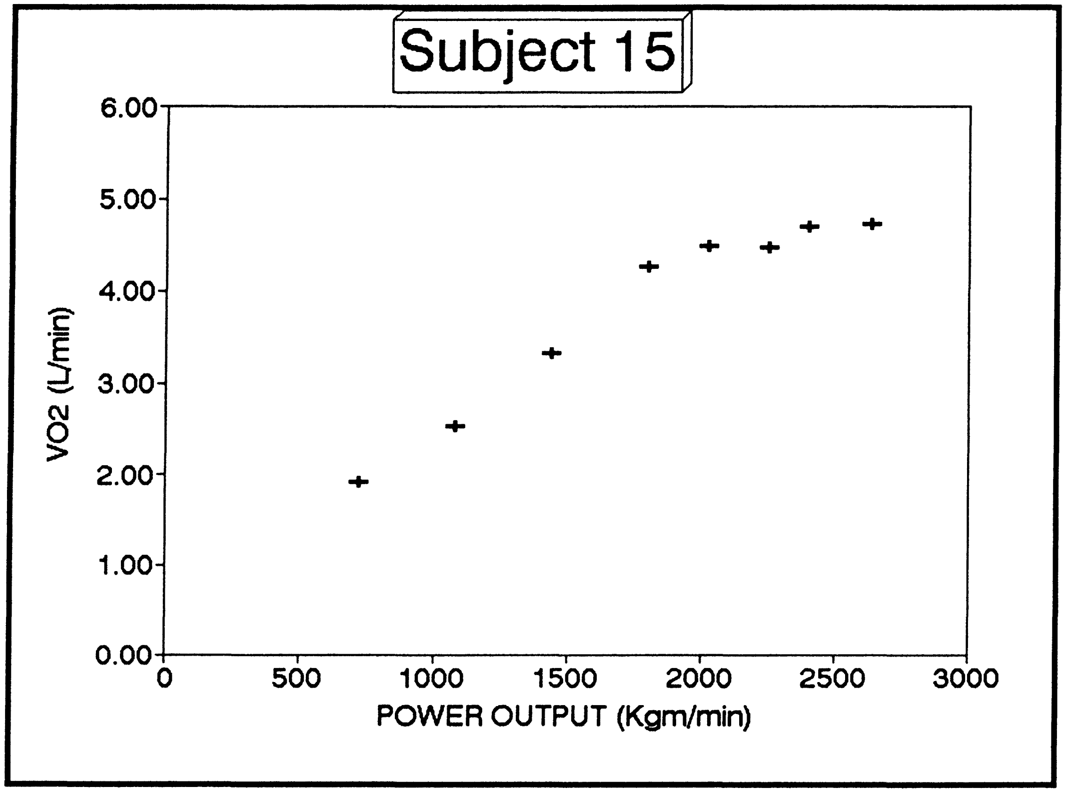
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
17	TR	CONT	720	2.16	
		CONT	1080	2.79	
		CONT	1440	3.58	
		CONT	1800	4.27	
		CONT	2025	4.30	
		CONT	2250	4.59	
		DISC	2400	4.44	
		DISC	2640	4.57	
		DISC	2805	4.68	YES

Figure 16



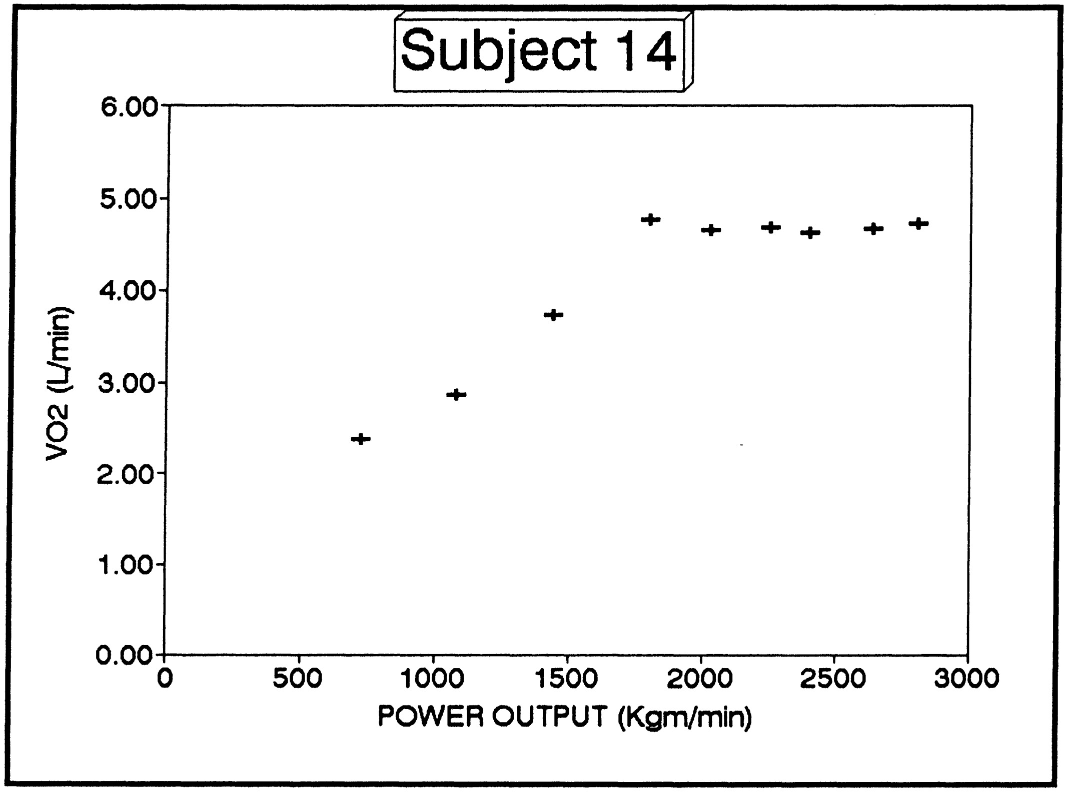
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
16	TR	CONT	720	2.29	
		CONT	1080	2.97	
		CONT	1440	3.83	
		CONT	1800	4.53	
		DISC	2025	4.53	
		DISC	2250	4.61	YES

Figure 15



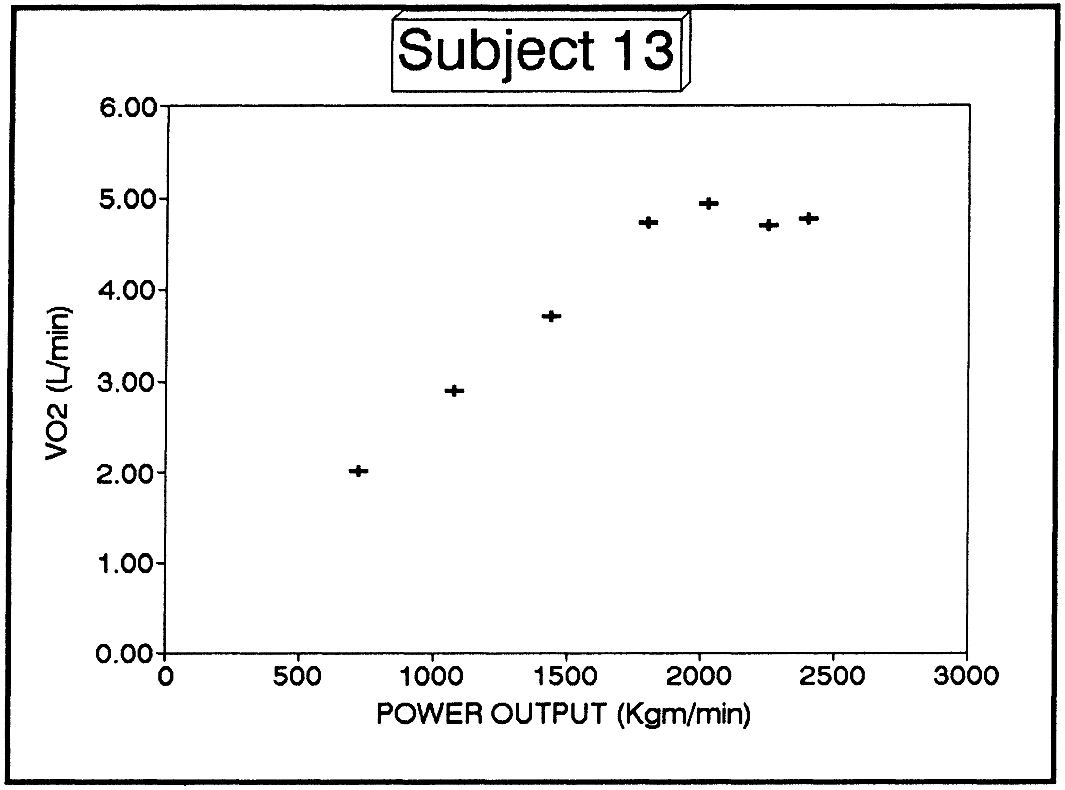
Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
15	TR	CONT	720	1.92	
		CONT	1080	2.54	
		CONT	1440	3.33	
		CONT	1800	4.26	
		CONT	2025	4.50	
		DISC	2250	4.47	
		DISC	2400	4.70	
		DISC	2640	4.73	YES

Figure 14



Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
14	TR	CONT	720	2.37	
		CONT	1080	2.86	
		CONT	1440	3.73	
		CONT	1800	4.76	
		CONT	2025	4.66	
		DISC	2250	4.68	
		DISC	2400	4.63	
		DISC	2640	4.67	
		DISC	2805	4.73	YES

Figure 13



Subject	Group	Test Type	Kgm/min	VO2 (L/min)	Plateau ?
13	TR	CONT	720	2.01	
		CONT	1080	2.90	
		CONT	1440	3.71	
		CONT	1800	4.73	
		DISC	2025	4.94	
		DISC	2250	4.69	
		DISC	2400	4.77	YES

APPENDIX D: CALCULATION OF CHI SQUARE STATISTIC

Table 6

2 X 2 Contingency Table

		Status: Plateau	Status: No Plateau	
Group	WT	10	2	12
	TR	11	1	12
		21	3	24

$$X^2 = \frac{24(10-(11)(2))^2}{(12)(12)(22)(3)}$$

$$X^2 = \frac{3456}{9072}$$

$$X^2 = 0.381$$