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DETERMINING THE VALIDITY OF A NEW CYCLE

ERGOMETER PROTOCOL FOR ESTIMATING VO$_2$MAX

by

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ABSTRACT

DETERMINING THE VALIDITY OF A NEW CYCLE ERGOMETER PROTOCOL FOR ESTIMATING VO$_2$MAX

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The current American College of Sports Medicine (ACSM) submaximal cycle ergometer protocol has been evaluated by several researchers for its validity in estimating maximal oxygen consumption (VO$_2$max). It has been found that the ACSM protocol overestimates VO$_2$max by 28% on average (Swain and Wright, 1997). It is felt that the short stage duration, only 3 minutes, of the ACSM protocol is largely responsible for this overestimation. The new submaximal cycle ergometer protocol evaluated here utilizes a 6-minute stage in an attempt to reduce the overestimation of VO$_2$max while increasing the overall test validity.

Methods

All subjects were between 18 and 44 years old, and met the definition of " low risk" by ACSM guidelines. The subjects performed a submaximal cycle ergometer test at a cadence of 60 rpm. A protocol was designed that consisted of 1-minute stages of gradually increasing intensity culminating in a 6-minute stage that was intended to elicit 65-75% of heart rate reserve (HRR; i.e., a percentage of the difference between resting and maximum HR). At the conclusion of the submaximal test, the intensity was increased in 1-minute stages until the subject reached maximal effort, in order to measure the actual VO$_2$max. The HR recorded during the 5th and 6th minute of the final stage of the submaximal test was used with the power attained during that stage to estimate

VO_2max. This estimate was based on the known relationship of HRR to VO_2 Reserve. For comparative purposes, VO_2max was also estimated from the same data by the Astrand method.

Results

A regression performed on actual VO_2max vs. the VO_2 Reserve method of VO_2max estimation showed an r-value of 0.89, and an SEE of 3.97 $ml\cdot min^{-1}\cdot kg^{-1}$. The mean value of actual VO_2max was 36.9 $\pm$ 8.8 $ml\cdot min^{-1}\cdot kg^{-1}$, while that for the VO_2R estimated VO_2max was 36.7 $\pm$ 8.4 $ml\cdot min^{-1}\cdot kg^{-1}$. A regression performed on actual VO_2max vs. the Astrand estimate of VO_2max showed an r-value of 0.82, and an SEE of 5.09 $ml\cdot min^{-1}\cdot kg^{-1}$. The mean value for the Astrand estimate of VO_2max was 39.8 $\pm$ 11.1 $ml\cdot min^{-1}\cdot kg^{-1}$.

Conclusions

The new cycle ergometer protocol did not over- or underestimate VO_2max, and was found to be highly valid, attaining higher r-values and lower SEE values when compared to previous research on the current ACSM cycle ergometer protocol. Furthermore, estimating VO_2max by the VO_2R method provided higher validity than the Astrand method of estimation. For low risk individuals from 18-44 years old, this cycle ergometer protocol provides a better estimate of maximal oxygen consumption than either the current ACSM or the Astrand method. Future research is needed to expand these findings to the population outside of the parameters of this research.

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Chapter 1
INTRODUCTION

Problem Description

Maximal oxygen consumption (VO_2max) has been the standard of aerobic fitness for several decades. It has been used to determine the functional capacity in regard to the oxygen transport system, and in determining the maximal workload a person is capable of performing. There are several factors that limit the feasibility of VO_2max testing. Expensive laboratory equipment, excessive administration time, and its appropriateness for the elderly and those with coronary risk factors are all limiting factors in regard to VO_2 max testing. Submaximal testing was created to estimate a person's VO_2max without the use of expensive laboratory equipment, and without the subject exercising to exhaustion. Submaximal testing is the most convenient, inexpensive, and practical way to estimate the VO_2max of the general public. Submaximal testing uses a heart rate at one or more workloads, and compares it to a set of norms for the given intensity. This gives one a fairly accurate estimate of VO_2max.

In regard to the submaximal cycling test, there are two popular methods: the Astrand and Rhyming single stage test (Astrand and Rhyming, 1954) and the ACSM multistage test (ACSM, 2000). The Astrand and Rhyming protocol uses a single 6-minute submaximal stage. The VO_2max is predicted based on the heart rate (HR) of the subject at a given workload. The workload is measured in wattage (W) with 75-100 W used for females, and 100-150 W for males. Variations are allowed to elicit a heart rate between 130-150 bpm. Once a target HR is achieved, the single HR and the W used are compared against previous data to estimate the subject's VO_2max. The Astrand test had

a low validity however, particularly with lower workloads. The usual measures of validity, r and SEE, were not reported. However, the accuracy of the VO_2max estimation was indicated as the standard deviation for the difference between actual and estimated values, which were as high as 14.4% for females, and 10.4% in males with workloads of 600 and 900 kg·m·min^{-1} respectively (Astrand and Rhyming, 1954).

In its fourth edition Guidelines text, the American College of Sports Medicine (ACSM) published a submaximal cycle protocol that utilized three or four (typically) two-minute stages designed to elicit a heart rate of roughly 70% of age predicted maximum (ACSM, 1991). Greiwe et al. (1995) evaluated this protocol and found that the estimated VO_2max values were 26% greater than the actual value on average. Greiwe et al. attributed these findings to the inaccuracy of using an age-predicted maximal heart rate, and to the short stages not allowing for the heart rate to reach steady-state.

In the ACSM's fifth edition, the protocol was modified to include 3 minute stages, and the test termination heart rate was increased from 70% HR_{max} to 70% HRR (ACSM, 1995). Swain and Wright (1997) evaluated the new protocol and found that the actual VO_2max was overestimated by 28% on average.

The inclusion of 3-minute stages in the newest ACSM protocol does not seem to have affected the overestimation of a person's VO_2max. This may be in part due to the assumption that a steady-state HR has occurred if the HR from the second to the third minute has not increased by more than six bpm. However, if the HR has increased by 6 bpm during this time, then it is quite possible that it would continue to increase if the stage were prolonged, i.e., a steady state probably has not been reached. If the stages were increased in duration and the HR was allowed to reach steady state, the estimated

VO_2max would be lower. With this information, it would seem prudent to develop a new protocol that utilized a longer (perhaps six minutes) final stage. To limit the total duration of the test, the subject could move quickly through the preliminary stages until nearing the test termination HR.

Recent research by Bennett et al. (2000) utilized an initial 3-minute stage at 50 W. At the end of the 3-minute stage, the heart rate was recorded and used to calculate the workload for a final 6-minute stage. The average of the heart rates at the 5th and 6th minutes was used to estimate maximal workload based on the equivalence of HRR and VO_2 reserve, as established by Swain and coworkers (Swain and Leutholtz, 1997; Swain et al., 1998). The estimated maximal workload was then converted to an estimated maximal VO_2 using the ACSM's cycle VO_2 equation (ACSM, 2000). The results were that the new protocol produced a highly valid estimation of VO_2max ($r = 0.91$; SEE = 3.4 ml·min^{-1}·kg^{-1}). The heart rate achieved at the end of the 6-minute stage averaged 78% of HRR, with several subjects exceeding 80%. The researchers concluded that, although the protocol produced accurate estimations of VO_2max, the final workload elicited a higher heart rate than desired. Thus, a new protocol is needed to determine the appropriate intensity for the 6-minute stage.

Statement of Purpose

The purpose of this research is to test the validity of a new submaximal cycle ergometer protocol for estimating VO_2max in low risk subjects in the 18-44 year old range. The protocol will increase in 1-minute stages, with some variation for the subject's activity level and body mass, culminating in a final six-minute stage that is intended to elicit a heart rate no greater than 75% HRR. VO_2max will be estimated from the submaximal

test data on the basis of the relationship between heart rate reserve and VO_2 reserve established by Swain and coworkers (Swain and Leutholtz, 1997; Swain et al., 1998). After the conclusion of the submaximal cycle test, the subject will immediately perform a maximal cycle test to determine the actual VO_2max. The data will then be compared to see if the proposed protocol provides a valid estimate of VO_2max. The Astrand-Rhyming nomogram will also be used to estimate VO_2max, so that a comparison can be made between the validity of the new protocol and that of the nomogram.

Hypotheses

1a. There will be a statistically significant positive correlation between the estimated VO_2max obtained by the protocol used in this design and the actual VO_2max.

1b. There will be a statistically significant correlation between the estimated VO_2max obtained by the Astrand-Rhyming protocol and the actual VO_2max.

2a. There will not be a statistically significant difference between the mean value of the estimated VO_2max of the subjects derived from the new protocol and the mean value of the actual VO_2max.

2b. There will not be a statistically significant difference between the mean value of the estimated VO_2max of the subjects derived from the Astrand-Rhyming nomogram and the mean value of the actual VO_2max.

Independent Variables

- The independent variables were the four slightly different proposed cycle ergometer protocols.

Dependent Variables

- The dependent variables were the actual VO_2max when compared to the estimated VO_2max.

Operational Definitions

HRR (Heart Rate Reserve): The difference between the resting heart rate and the maximal heart rate.

VO_2max (Maximal Oxygen Consumption): The highest attained VO_2 value over any continuous 60-second time period during an incremental exercise test, with a respiratory exchange ratio (RER) ≥ 1.10.

Respiratory Exchange Ratio (RER): The ratio between the amount of carbon dioxide produced and the amount of oxygen consumed by the body during exercise. During an incremental exercise test, the highest attained value over any continuous 60-second time period is defined as maximal RER.

$VO_2Reserve$: The difference between resting VO_2 and the maximal VO_2.

Validity: The extent to which a measurement tool actually measures the intended trait or attribute.

Limitations

Due to safety constraints regarding the elderly and those with coronary risk factors, the subjects will be limited to those 18-44 years old with a low risk of coronary artery disease. Hence, the findings of this study will not apply to older or younger individuals, or those who have a higher risk of coronary artery disease. Although both high and low fit subjects will be tested, a convenience sample will be used, thus limiting the external validity of the findings.

Delimitations

An external threat to validity would occur in the classification of active and inactive subjects (for the purpose of selecting the submaximal cycle ergometer protocol). The administrator of the submaximal test has to determine if the subject fits the active classification (as defined by this study) through questioning of the subject. If the subject were borderline inactive/active, the administrator would have to decide which protocol to have the subject perform.

Chapter II
LITERATURE REVIEW

The many limitations of VO_2max testing (expensive, time consuming, risky) have led

exercise physiologists toward submaximal testing, particularly for the general public.

Submaximal testing does not require exercising at extremely high intensities, which is an

additional benefit for those that are not athletes or highly motivated. Numerous

submaximal tests have been performed using cycling exercise to predict VO_2max. This

literature review will examine these submaximal tests, and their relevance to this study.

Factors to consider when developing a cycling protocol

Several factors should be considered when developing a cycling protocol:

- The length of the test: if the test stages are too short, a steady-state HR may not be
  achieved and the data may not be of any importance. If the total duration of the
  test is too long, subjects may get excessively fatigued.

- The cadences of various cycling protocols have ranged from 40 to 80 rpm, so
  what would be an appropriate cadence?

- Both male and female subjects from a wide range of fitness levels and ages need
  to be able to follow the protocol.

- The test must have a high validity.

Astrand and Rhyming

The Astrand and Rhyming nomogram for estimating a person's VO_2max was created in

the early 1950's. The study utilized well-trained individuals aged 18-30 years old

(Astrand and Rhyming, 1954). The key development from the research was the

nomogram could estimate a person's VO_2max based on a submaximal workload and heart

rate.

The protocol used a 6-minute, single stage cycle ergometer test to estimate VO$_2$max, and used different resistance levels for certain subjects. The resistances were as follows: conditioned males, 100-150 watts, unconditioned males, 50-100 watts, conditioned females, 75-100 watts, and unconditioned females, 50-75 watts. The cadence was set at 50 rpm, and the tester recorded heart rates at approximately one minute and a half, and every minute subsequently until the subject completed the test. Typically, the final two heart rates were averaged to determine the steady state that was used in the calculations for VO$_2$max. The researchers used a "line of best fit" between an average resting heart rate of 61 bpm, and a baseline of zero oxygen consumption along with the measured heart rate (Astrand and Rhyming, 1954).

The research assessed validity by measuring actual VO$_2$max values of 27 well-trained males, and 31 well-trained females, and then comparing the results to the predicted value using the nomogram (Astrand and Rhyming, 1954). As indicated previously, the usual measures of validity, r and SEE, were not reported. However, the accuracy of the VO$_2$max estimation was indicated as the standard deviation for the difference between actual and estimated values, which were 6.7% for males, and 9.4% for females when using the 1200 kg·m·min^{-1} workload. The lower workrate (600 kg·m·min^{-1} for females and 900 kg·m·min^{-1} for males) showed a difference of 14.4% for females, and 10.4% for males. The researchers acknowledged that the study was limited in its ability to predict VO$_2$max in populations that were younger or older then the subjects used (Astrand and Rhyming, 1954).

Astrand and Rodahl (1977) found that when using the nomogram, the low VO$_2$max values were underestimated, and the high VO$_2$max values were overestimated

for the highly trained. These early findings led to numerous studies to find a more accurate way of predicting VO$_2$max through submaximal testing.

Fox (1973) developed a single stage submaximal bicycle test that used 87 healthy untrained college males. The VO$_2$max was predicted by comparing the heart rate during the fifth minute of a cycle test at 150 W. The data were compared to their actual VO$_2$max by performing a series of exhaustive cycle tests (60-rpm) with 10-minute rest periods between sessions. The workload was continually increased until the subjects could not longer ride for at least 3 minutes at a workload 10-15 W higher than their previous ride. The criteria for attaining VO$_2$max were either volitional exhaustion, heart rate in excess of 190 bpm, or a leveling or decrease in VO$_2$ with increasing workload. The regression equation to identify a relationship between VO$_2$max and heart rate was calculated using the least-squares method: Y= 6,300 – 19.26X, where Y= predicted VO$_2$max (ml$\cdot$min^{-1}), 6,300 = Y intercept (ml$\cdot$min^{-1}), -19.26 = regression coefficient (ml$\cdot$bpm^{-1}), and X = HR$_{sub}$ (bpm) recorded during the fifth minute of exercise at 150 W. The regression (r = +0.76) was statistically significant (P < 0.001) with the standard error of estimate = $\pm$ 246 ml/min ($\pm$ 7.8% of the mean VO$_2$max). The study concluded that this method was valid, accurate, and easy to use; but several shortcomings were apparent. The correlation coefficient was not very high, and the findings only apply to a small range of the male population.

Regression models used for VO₂max prediction

Regression models have been used to estimate the VO_2max of an individual while taking into account various factors. Multiple regression models involve the use of several measurements to help predict a person's VO_2max more accurately.

Mastropaolo (1970) performed a study to improve the accuracy of the submaximal cycle test by utilizing several physiological responses to exercise: heart rate, work rate, systolic and diastolic blood pressure, expired CO_2 and O_2, expired volume, oxygen consumption, carbon dioxide production, and respiratory exchange ratio. The research included 13 men aged 43-61 years old who exercised to maximal VO_2 on a cycle ergometer. The data were analyzed at approximately 300, 600, and 900 $kg\cdot m\cdot min^{-1}$ by a stepwise multiple linear regression. As expected, the multiple regression predicted VO_2max significantly better (r= 0.93, SEE 0.172 $L.min^{-1}$, p< 0.05) when compared to the simple regression described by Astrand (1954). These findings demonstrate the accuracy of VO_2max predictions using multiple regression, but the expensive laboratory equipment used in the protocol would be inconvenient and expensive for use on the general public.

Gender with regard to the submaximal cycling test

Females have been included in numerous submaximal cycling studies, and the validity of the estimated VO_2max has varied greatly. In regard to females, Siconolfi et al., 1982, Siconolfi et al., 1985, and Zwiren et al., 1991, all found that VO_2max could be overpredicted, sometimes by as much as 31%.

A study by Hartung et al. (1985) focused exclusively on the prediction of VO_2max of females through submaximal treadmill and cycle ergometer testing. For the purpose of this research, only cycle testing will be reviewed. Thirty-eight healthy female

subjects participated in two submaximal cycle ergometer tests and one maximal test with each test being at least one week apart from each other. The subjects performed an initial workload for three minutes at a cadence of 50 rpm, and the heart rate was recorded and entered into a computer. If applicable, an adjustment in workload was given so that a steady state rate of 120-150 bpm could be accomplished at the end of a six-minute exercise bout. To verify steady-state had been reached, the heart rates at the end of the 5th And 6th minute were compared. If they varied by more than three beats, the test continued at one-minute intervals until steady-state was achieved. The results showed that the test was very reliable in regard to retest (r= 0.92), but it found an overestimation of VO_2max by 18.5%. The SEE was 0.34 L min^{-1}, and the correlation coefficient (r) was 0.72 for the cycle ergometer test. The researchers concluded that VO_2max was overpredicted due to the higher fit subjects' values, and that the overestimation in VO_2max in females was contrary to the Astrand and Rhyming study that found an underestimation in VO_2max in males.

Fitness levels on the submaximal cycle test

In analyzing the data from the Astrand and Rhyming test, it is important to note that the nomogram was created by using healthy, well-trained subjects. This specialized subject population led other researchers to develop a submaximal test that could be used on a wider range of fitness and age levels.

Siconolfi et al. (1982) designed a protocol that could account for age and gender by testing 113 males and females from age 20-70 years. Fifty subjects were randomly assigned to a test group while the remaining 63 served as a validity group (tested the validity of the derived equations). The subjects were also broken up into five groups

based on age for the purpose of data analysis. In this protocol, all females and males over 35 years of age started out at an initial workload of 150 kg·m·min^{-1}, as opposed to the 300 kg·m·min^{-1} in the Astrand-Rhyming protocol. The exercise rate was increased by 150 kg·m·min^{-1} every 2 minutes until the subject reached the target heart rate of 70% HR$_{max}$. For men under the age of 35, the initial workload was kg·m·min^{-1}, and was increased by 300 kg·m·min^{-1} every 2 minutes if the HR was less than 60% of the predicted maximum. If the HR was between 60 and 70% of the predicted maximum, the workload was increased by only 150 kg·m·min^{-1}. For all exercise protocols, once the final workload was reached, the subjects continued at the same workload until a steady-state heart rate was achieved. This was assumed to be present when consecutive heart rates (taken every minute) differed by less than 5 bpm. A maximal test was then performed with the resistance being increased by 150 kg·m·min^{-1}, each minute until the subject could no longer continue and/or reached a plateau in VO$_2$. VO$_2$max was then estimated using the Astrand-Rhyming nomogram, which used the average of the last two heart rate readings and the final workload. The age-correction factor developed by Astrand-Rhyming was not used in this study. Separate regression equations for males and females were developed from the test group with the directly measured VO$_2$max as the dependent variable, and the VO$_2$max from the Astrand-Rhyming nomogram and age as the independent variable (Siconolfi et al., 1982). The results showed that the overall correlation coefficient (r) was 0.94 between the estimated and the measured VO$_2$max of the subjects. The SEE for the five groups ranged from 9.5-13.1%, while the standard error in predicting the directly measured VO$_2$max was $\pm$ 248 ml·min^{-1}. The researchers concluded that the protocol was effective in providing estimated VO$_2$max in low-fit

adults over a wide age range. The researchers also conclude that the subjects in this study were mainly inactive adults, so the validity is unknown for children or well-fit individuals.

Selecting the proper cycle cadence

Various cadences have been used in the administration of cycle ergometer tests, with the standard being either 50 rpm (Astrand and Rhyming, 1954) or 60 rpm (Fox, 1973). Some experts believed that the low rpm was uncomfortable for some experienced cyclists, and may have an adverse effect on data collection. Swain and Wright (1997) sought to determine the optimal cycling cadence by testing 58 subjects including 30 experienced cyclists (16 male and 14 female) and 28 inexperienced subjects (15 males and 13 females). Each subject participated in two incremental cycle tests with randomly ordered cadences of 50 or 80 rpm. For the inexperienced subjects, the protocol called for 3-minute stages with a beginning workload of 40 W, and an increase in 40 W every three minutes thereafter. The experienced cyclist protocol began with an initial workload of 80 W, and then advanced to 160 W for the second stage. All other workload increases were 40 W. The test was terminated due to exhaustion or if the subject could no longer maintain the prescribed cadence. The correlation between the actual and predicted VO_2max with the 50-rpm protocol was 0.79 with a SEE of 8.2 $ml\cdot min^{-1}\cdot kg^{-1}$. The results for the subjects at 80 rpm were 0.81 (r) with a SEE of 7.4 $ml\cdot min^{-1}\cdot kg^{-1}$. The researchers found the there was no significant difference in validity when comparing the 50 or 80 rpm. They did however; find a trend for better validity for the experienced cyclists when using the 80-rpm cadence. The researchers also noted that VO_2max was significantly overestimated by approximately 28% on average.

Evaluating the ACSM cycle ergometer test

The ACSM cycle ergometer protocol, as published in the 4th edition (1991), was evaluated by Greiwe et al. in 1995. The study used fifteen male and female subjects aged 21-54 years old. The testing involved a maximal test, and two submaximal tests using the ACSM protocol. Heart rates were recorded during the last 15 seconds of each two-minute stage, and the test was terminated at the end of the fourth stage, or when the subject reached 65-70% of age predicted HR_{max}. The study found good reliability as indicated by a correlation coefficient (r) between the estimated VO_2max values from the two submaximal tests of 0.863. However, the test overestimated the actual VO_2max by approximately 26%. The researchers identified several reasons why the VO_2max was so overpredicted. The first possible reason was the relatively short stages (two-minutes), which would not allow a steady-state heart rate to be achieved. The second reason was the termination point of only 70% of age-predicted HR_{max}, which would not allow the subjects to reach a high enough workload. Another possible error is the use of a conversion factor of power to VO_2. The ACSM has only validated their equation for converting power to VO_2 for power from 50 to 200 W, so any subject who exceeded 200 W might not receive an accurate estimated VO_2max. In light of the potential problems with the ACSM submaximal cycle ergometer protocol, Greiwe et al. (1995) concluded that the ACSM protocol should not be used when accurate estimations of VO_2max are needed.

The ACSM modified the protocol in their 5th edition (ACSM, 1995) by increasing the stage duration from two to three minutes and increasing the upper limit of the exercise intensity for the test from 70% HRmax to 70% HRR. As described above in the

cadence section of this review, Swain and Wright (1997) found that these modifications did not reduce the overestimation of VO_2max.

As demonstrated in the research by Swain and Leutholtz (1997), %HRR does not correspond to the equivalent values of %VO_2max during cycling exercise, but is instead equivalent to values of % VO_2R. The study by Swain et al. (1998) reinforced the findings of Swain and Leutholtz, this time during treadmill exercise. In the 1997 cycle ergometer study, the line of identity was indistinguishable when comparing %HRR to %VO_2R, and was only slightly different from the line of identity when using a treadmill in 1998. The researchers also identified three advantages to prescribing exercise based on %VO_2R rather than %VO_2max. The close relationship between %HRR and %VO_2R provide a more accurate estimate of the target heart rate. The use of VO_2max in prescribing exercise intensities in a wide range of fitness levels does not work nearly as well as using %VO_2R. And third, exercise prescriptions based on %VO_2R (rather than %VO_2max) are more directly translated into caloric expenditure for the purpose of weight loss. A further use of the relationship of %HRR to %VO_2R might be in the estimation of VO_2max from submaximal HR data.

Bennett et al. (2000) attempted to devise a submaximal cycle test that would eliminate the overprediction of VO_2max. The researchers felt that a 6-minute final stage would allow the heart rate to reach a steady-state, thus providing a more accurate estimation of VO_2max. The relationship between %HRR and VO_2R would then be used to estimate a maximal VO_2 from the single submaximal stage, as suggested by Swain and Leutholtz (1997).

The protocol used 59 subjects (29 males and 30 females) all between 18 and 45 years old, and had met the definition of "apparently healthy" by the American College of Sports Medicine guidelines. All subjects begin to cycle at 60 W at a cadence of 60 rpm. During the last 15 seconds of the third minute, heart rate was recorded and used to calculate the workload for the six-minute test. The workload was intended to elicit approximately 70% HRR using the following equation: Workload= 0.70 (HRmax – HRrest)/(3rd minute HR at 60 W) – HRrest. The workload was rounded off to the nearest ¼ kg, and the subjects continued to pedal at 60 rpm. Heart rate was measured during the last 15 seconds of the third minute. If the heart rate was within 10 bpm of the target heart rate, the workload was not increased, and the subject completed a final, six-minute stage. If the heart rate was at least 10 bpm away from the target heart rate, the workload was increased by ½ kg, and this new workload was performed for the final, six-minute stage. A maximal exercise test followed the submaximal protocol.

A regression performed on actual VO_2max vs. VO_2R showed the r-value was 0.91 with a SEE of 3.4 $ml \cdot min^{-1} \cdot kg^{-1}$. The regression performed on the Astrand estimate of VO_2max vs. actual VO_2max values showed an r-value of 0.83, and a SEE of 5.4 $ml \cdot min^{-1} \cdot kg^{-1}$. The researchers concluded that the high r-values indicated were most likely in response to the 41% of subjects who were working at a high level ($\geq$ 80% HRR) during the submaximal testing.

CHAPTER III
METHODS

Subjects

All subjects were between 18 and 44 years old, and met the definition of " low risk" in

the American College of Sports Medicine guidelines: i.e., the subjects did not have two

or more major coronary risk factors, any signs or symptoms of cardiopulmonary disease,

nor any known cardiopulmonary or metabolic disease (ACSM, 2000). All subjects

provided informed consent consistent with institutional guidelines for research with

human subjects.

Fifty-seven subjects initially participated in the study (29 males and 28 females).

Three male subjects and two female subjects were excluded due to failure to reach the

criteria for VO_2max (RER was not ≥ 1.10), and another male subject was excluded due to

equipment failure. One female's heart rate went above 75% HRR during the submaximal

test, and because a retest could not be scheduled, she was also excluded from the data.

Subsequently, 25 males and 25 females provided data that could be used in the final

analysis.

Protocol

Subjects were asked to abstain from alcohol, caffeine, and other drugs 24 hours prior to

testing, and to avoid eating for one hour prior to testing. Once the subjects were screened

and informed consent obtained, each subject's height and weight were recorded. A chest

strap heart rate monitor (Polar) was used to determine the resting heart rate as the

subjects sat quietly for six minutes. An average of the last 15 seconds of the 5th and 6th

minute were obtained and reported as the resting heart rate. Maximum heart rate was

estimated as 220-age.

The subjects were then asked to sit on a calibrated Monark 828e cycle ergometer, and the seat was adjusted to provide a slight bend (approximately 5°) in the knee at full extension. Pedal straps were used to allow a fluid circular motion while pedaling. The ambient temperature was approximately 21° C during testing, and a fan was directed at the subjects during exercise to enhance cooling. Each subject performed a submaximal cycle ergometer test at a cadence of 60 rpm. The initial resistance depended on the subject's weight (i.e., ¼ kg for subjects < 90 kg, ½ kg for subjects ≥ 90 kg). The resistance increased every minute by ¼ kg for subjects < 90 kg, and ½ kg for subjects ≥ 90 kg. To be classified as active, the subjects must have been on a regular aerobic exercise routine for at least 3 months prior to testing, and fall into one of the two following categories. Category one, subject must perform at least 90 minutes of moderate-vigorous physical activity per week (indicated by having a more difficult time talking while exercising). Examples include, but not limited to, running, vigorous cycling, competitive basketball, soccer, etc. Category two, subject must perform at least 120 minutes of moderate physical activity per week (indicated by being able to talk while exercising). Examples include, but are not limited to, brisk walking, moderate cycling, etc. Subjects who did not exercise regularly, as defined above, were classified as aerobically inactive.

Throughout the submaximal test, the heart rate was recorded during the last 10 seconds of every minute. For the inactive subject, once he/she reached 45% HRR, the workload remained the same for an additional two minutes. If the heart rate reached 55% HRR or greater during the additional two minutes, the subject continued at the same workload for an additional three minutes to complete a six-minute stage. If the heart rate

did not reach 55% HRR, the resistance continued to increase by ¼ kg per minute until the

heart rate reached 55% HRR. When this occurred, the subject performed an additional 5

minutes to complete a final six-minute stage at that workload. For the active subject, the

resistance was increased every minute (by ¼ kg for subjects <90 kg, by ½ kg for subjects

≥ 90 kg) until the subject reached 55% HRR. Once the subject reached 55% HRR, he/she

performed an additional 5 minutes to complete a final six-minute stage. At the

conclusion of the submaximal test, the subjects pedaled against very light resistance and

were fitted with a mouthpiece, and the final preparations were made for conducting the

incremental test to maximal effort for the measurement of the VO_2max. The initial

resistance was that which the subject last completed during the submaximal test. The

subject pedaled at that resistance for 2 minutes at 60 rpm. Resistance was then increased

by ¼ kg every minute until the subject reached volitional exhaustion, or was unable to

maintain the prescribed cadence. Once the maximal test was completed, the resistance

was reduced and a cool-down occurred.

Data Collection and Analysis

Heart rates were recorded during the last 10 seconds of each minute during the

submaximal test. The average values for the 5th and 6th minutes of the final stage were

used for the estimation of VO_2max. During the maximal incremental test, expired gases

were collected continuously and analyzed for the determination of oxygen consumption

(VO_2) and respiratory exchange ratio (RER) using a metabolic cart (SensorMedics

2900c). The O_2 and CO_2 analyzers of the metabolic cart were calibrated prior to each test

against known gas concentrations, and its flowmeter were calibrated prior to each test

using a 3.0-L syringe. Maximal oxygen consumption was defined as the highest VO_2

obtained over any continuous 60-s time period, provided the RER was ≥ 1.10. Maximal

heart rate was similarly defined as the highest recorded value over any continuous 60-s

period during exercise.

Once the submaximal data were recorded, the VO_2max was estimated in two

ways: first, using the relationship of %HRR to VO_2R, and second, using the Astrand-

Rhyming nomogram. Both methods are described below.

VO_2Reserve method:

Step 1: Determine the workload for the 6-minute test

(test resistance setting in kg)(6m)(60 rev/min)($9.81m/s^2$)= _____ Watts

Step 2: Determine the % HRR for the six-minute test

(HR average $_{5-6}$ – HR_{rest})/(est. HR_{max} - HR_{rest})= _____ %

Step 3: Estimate the subject's maximal workload

6-minute workload / %HRR= _____Watts

Step 4: Estimate VO_2max from the estimated maximal workload using the ACSM

metabolic equation for cycle ergometry (ACSM, 2000).

VO_2 = (10.8 x Watts / body mass) + 7= _____ $ml\cdot min^{-1}kg^{-1}$

Astrand (Astrand and Rhyming, 1954)

Step 1: Determine the workload for the 6-minute test

(test resistance setting in kg)(6-m)(60 rev/min)($9.81 m/s^2$)= _____ Watts

Step 2: Determine the HR for the 6-minute test

Average HR for the minutes 5-6= _____bpm

Step 3: Look up raw VO_2max from nomogram= _____$L\cdot min^{-1}$

Step 4: Correct the raw VO_2max for age

_____ $L \cdot min^{-1}$ x <u>age factor</u>= _____ $L \cdot min^{-1}$

Step 5: Convert to $ml \cdot min^{-1} \cdot kg^{-1}$

Statistical Analysis

Hypothesis number one, there will be a statistically significant correlation between the estimated VO_2max obtained by the new protocol described here and the actual VO_2max, was tested by performing a linear regression analysis on the actual versus estimated VO_2max values. This analysis was performed for both the Astrand method, and for the new method of estimating VO_2max. The SEE and the correlation coefficient were determined for each regression, and the regressions were tested for significance by a Student-t test for the correlation coefficient.

Hypothesis number two, there will not be a statistically significant difference between the mean value of the estimated VO_2max of the subjects and the mean value of the actual VO_2max, was tested by comparing the actual versus estimated VO_2max values with a paired Student-t test. This was done twice, once for each of the methods described above for estimating the VO_2max.

The significance for statistical tests was set at the 0.05 alpha level.

CHAPTER IV
RESULTS

Table 1 presents characteristics of the 50 subjects who successfully completed all phases of the study.

Table 2 presents exercise test results, including submax wattage, submax HR, %HRR, HR max, and RER max.

Table 3 presents the mean values for the VO_2max in regard to the actual, VO_2R method, and Astrand method.

As seen in Figure 1, the accuracy of the VO_2max estimation using the VO_2R method was very similar for men and women. Thus, results for men and women are combined in all further analysis.

A regression performed on actual VO_2max vs. the VO_2 Reserve estimate of VO_2max showed an r-value of 0.89, and an SEE of 4.0 $ml \cdot min^{-1} \cdot kg^{-1}$ (Fig. 2). A regression performed on actual VO_2max vs. the Astrand estimate of VO_2max showed an r-value of 0.82, and an SEE of 5.1 $ml \cdot min^{-1} \cdot kg^{-1}$ (Fig. 3). Both of these regressions were statistically significant.

To determine the relationship between activity status and accuracy of prediction, regressions were performed on active and inactive subjects separately. For active subjects, the mean estimated VO_2max using the VO_2 Reserve method was 39.8 ± 7.9 $ml \cdot min^{-1} \cdot kg^{-1}$ vs. the actual value of 40.9 ± 7.5 $ml \cdot min^{-1} \cdot kg^{-1}$ with an r-value of 0.88, and a SEE of 3.8 (Fig.4). For inactive subjects, the mean estimated VO_2max using the VO_2 Reserve method was 30.8 ± 6.1 $ml \cdot min^{-1} \cdot kg^{-1}$ vs. the actual value of 30.8 ± 7.0 $ml \cdot min^{-1} \cdot kg^{-1}$ with an r-value of 0.82, and a SEE of 4.1 (Fig. 5).

TABLE 1

Subject Characteristics

	Age (yr)	Height (cm)	Mass (kg)	HR rest (bpm)
Mean	29	169.3	71.2	70
Standard Deviation	6	8.89	13.22	12
Range	18-44	154-191	47-91.7	46-96

TABLE 2

Exercise test results

	Submax W (wattage)	Submax HR (bpm)	%HRR (heart rate reserve)	HR max (bpm)	RER max (respiratory exchange ratio)
Mean	124	147	64	184	1.20
Standard Deviation	40	9	5	9	0.06
Range	60-240	133-162	48-75	168-196	1.11-1.35

TABLE 3

VO_2max results for all subjects

	Actual VO_2max $(ml \cdot min^{-1} \cdot kg^{-1})$	VO_2R method $(ml \cdot min^{-1} \cdot kg^{-1})$	Astrand method $(ml \cdot min^{-1} \cdot kg^{-1})$
Mean	36.9	36.7	39.8
Standard Deviation	8.78	8.39	11.07
Range	19.9 - 58.0	21.3 - 57.9	19.7 - 64.8

Fig. 1 Comparison of VO$_2$R estimate of VO$_2$max in men and women

Women
$y = 0.83x + 6.5$
$r = 0.87$

Men
$y = 0.87x + 4.3$
$r = 0.88$

Estimated VO$_2$max (ml·min^{-1}·kg^{-1})

Actual VO$_2$max (ml·min^{-1}·kg^{-1})

□ Women
▲ Men
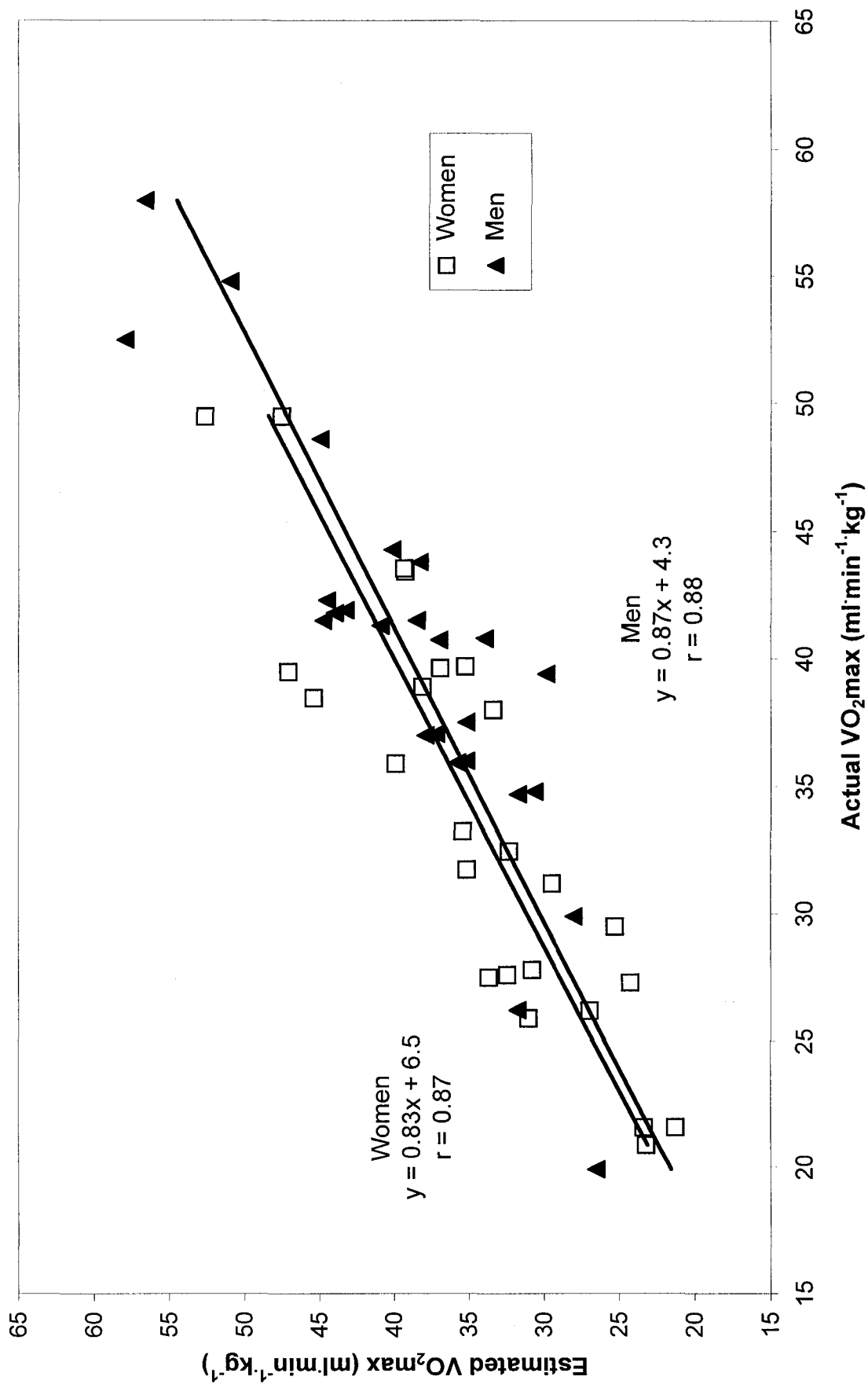
Fig. 2 Validity of VO_2R method for estimation of VO_2max

$y = 0.84x + 5.6$
$r = 0.89$
$SEE = 4.0$

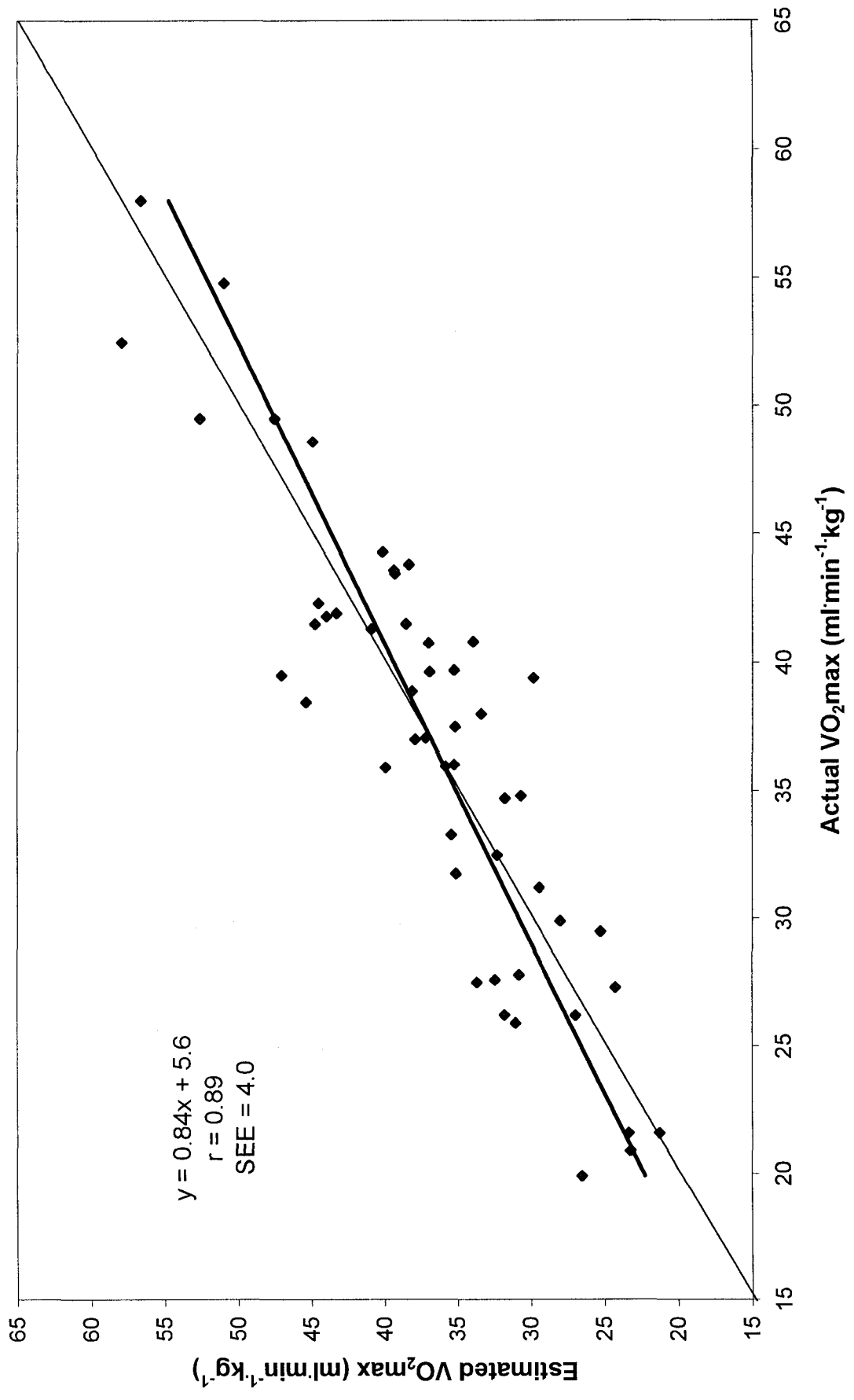Estimated VO_2max (ml·min^{-1}·kg^{-1})

Actual VO_2max (ml·min^{-1}·kg^{-1})

Fig. 3 Validity of Astrand method for estimation of VO$_2$max
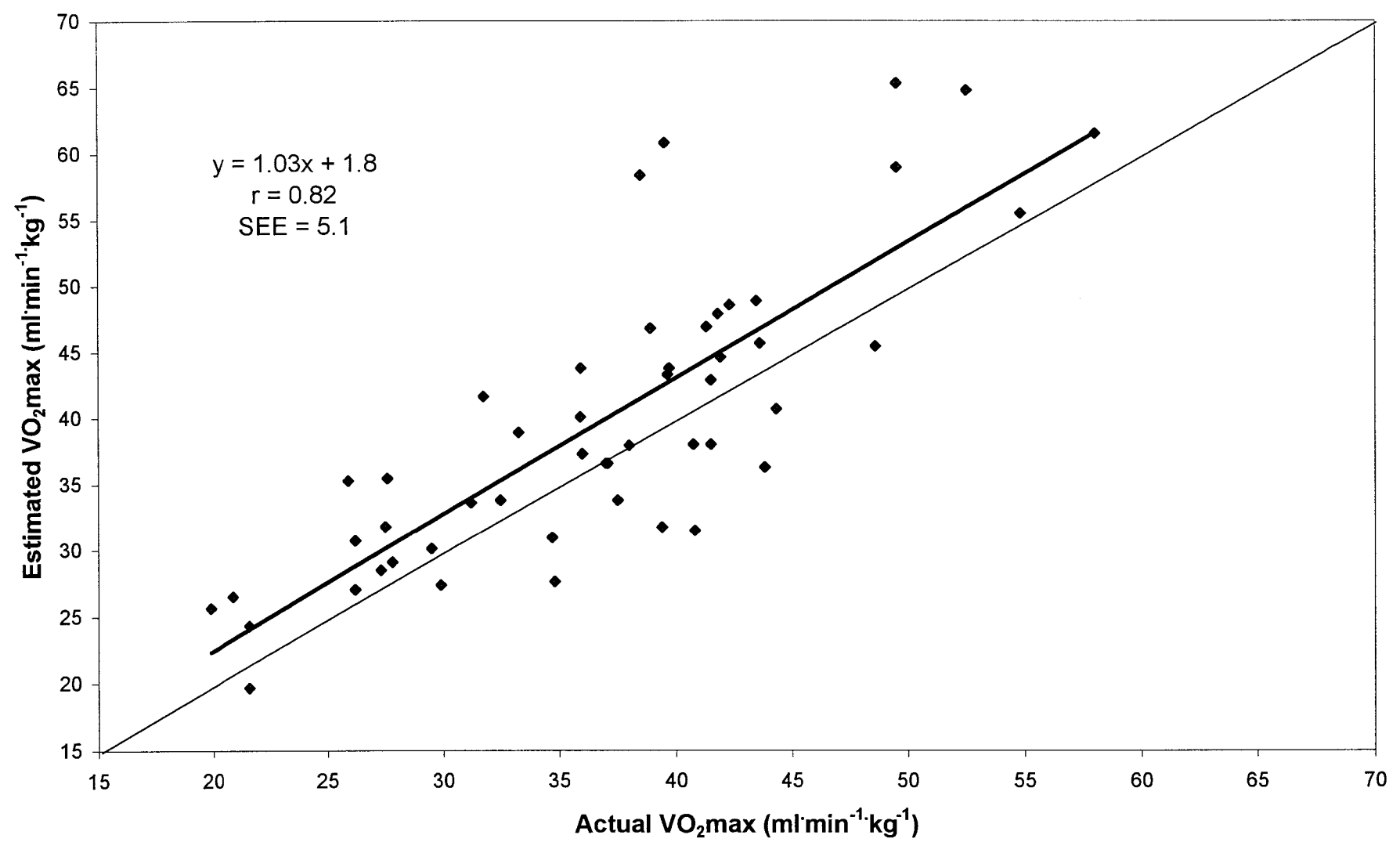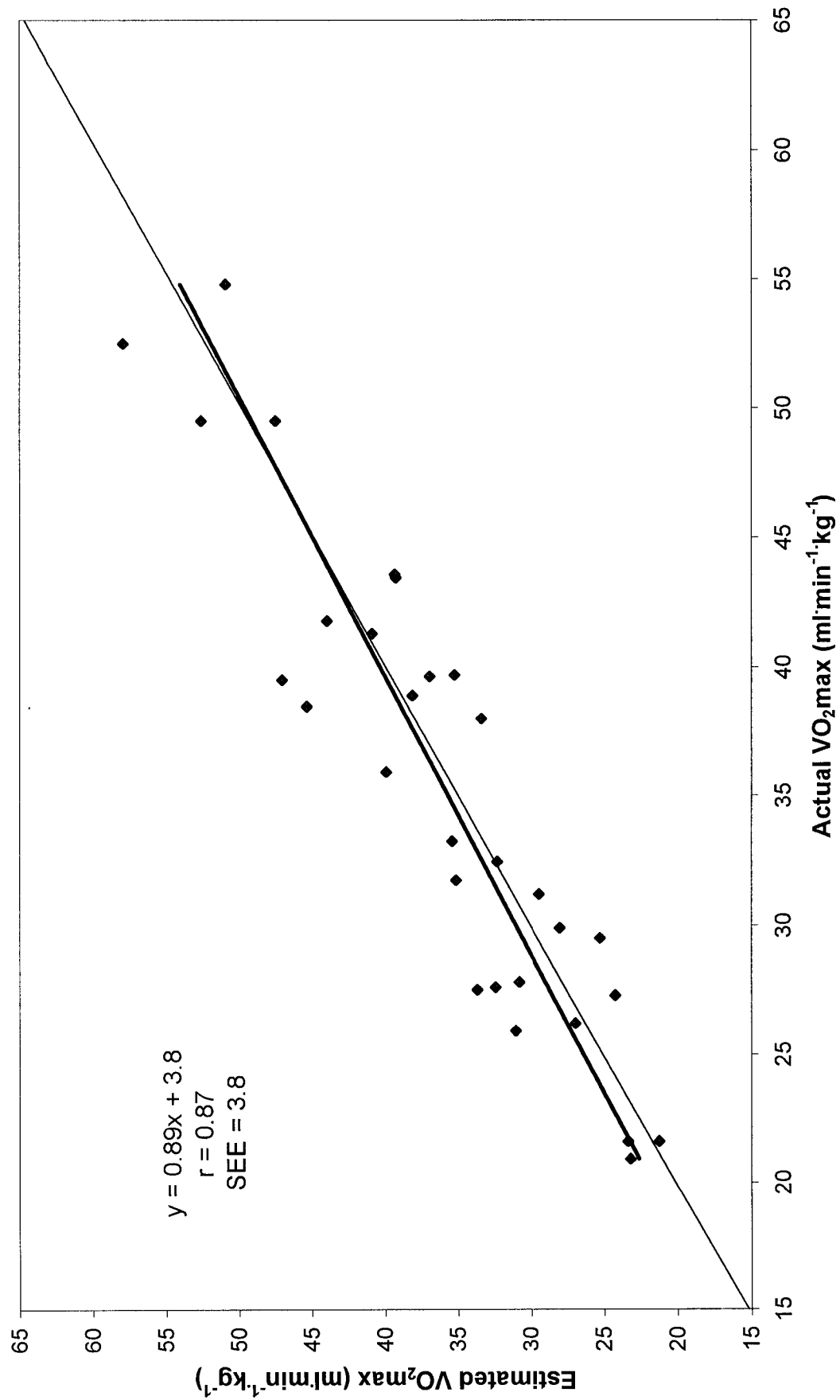
$y = 1.03x + 1.8$
$r = 0.82$
SEE = 5.1

Estimated VO$_2$max (ml·min^{-1}·kg^{-1})

Actual VO$_2$max (ml·min^{-1}·kg^{-1})

Fig. 4 Validity of VO$_2$R estimation of VO$_2$max in active

$y = 0.89x + 3.8$
$r = 0.87$
$SEE = 3.8$

Estimated VO$_2$max (ml·min^{-1}·kg^{-1})

Actual VO$_2$max (ml·min^{-1}·kg^{-1})

Fig. 5 Validity of VO₂R estimation of VO₂max in inactive subjects

Fig. 5 Validity of VO_2R estimation of VO_2max in inactive subjects

$y = 0.72x + 9.3$
$r = 0.82$
$SEE = 4.1$

Estimated VO_2max (ml·min⁻¹·kg⁻¹)

Actual VO_2max (ml·min⁻¹·kg⁻¹)
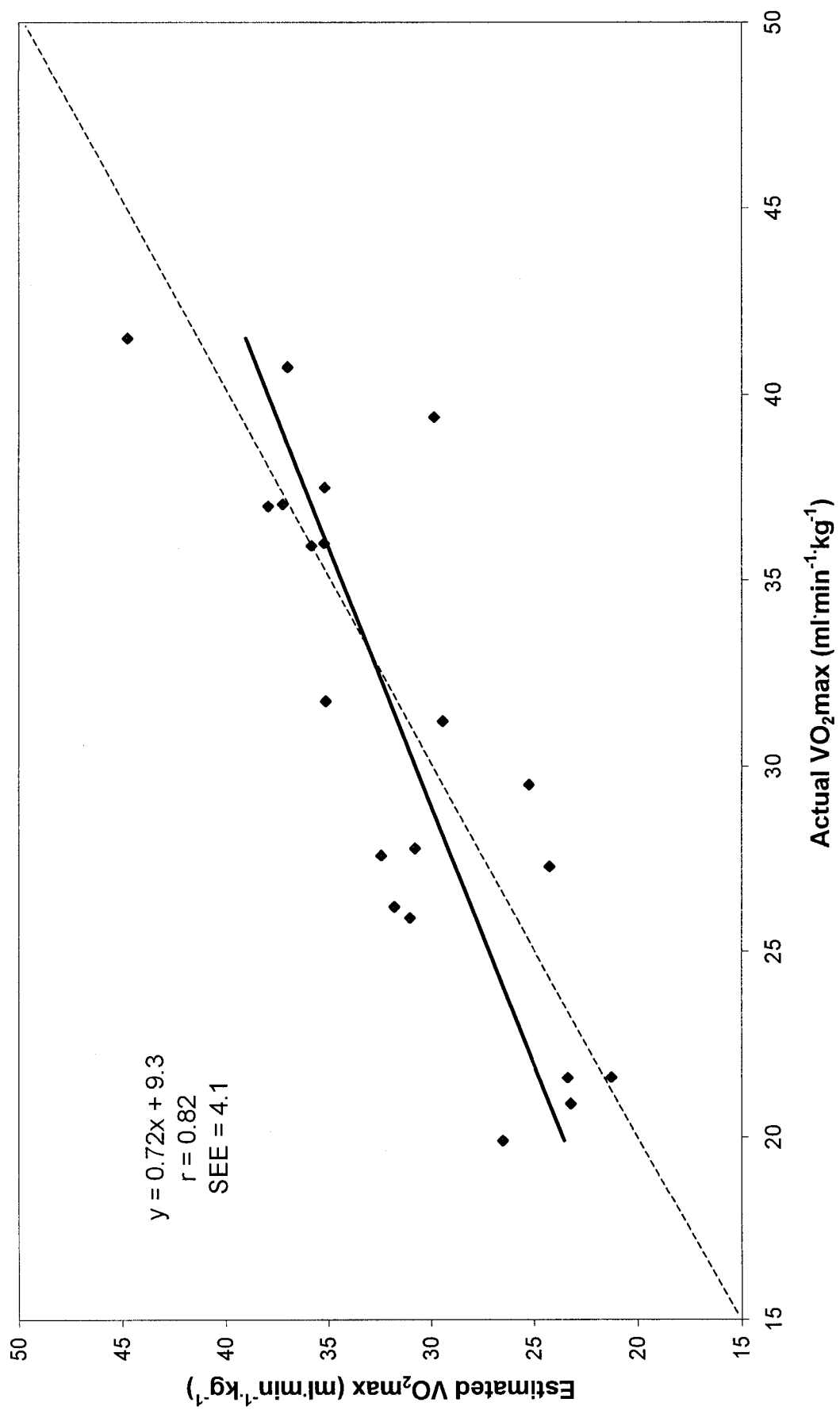
For active subjects, the mean estimated VO$_2$max using the Astrand method as 44.4 $\pm$ 11.2 ml·min^{-1}·kg^{-1} vs. the actual value of 40.9 $\pm$ 7.5 ml·min^{-1}·kg^{-1} with an r-value of 0.76, and a SEE of 5.0 (Fig.6). For inactive subjects, the mean estimated VO$_2$max using the Astrand method was 32.9 $\pm$ 6.5 ml·min^{-1}·kg^{-1} vs. the actual value of 30.8 $\pm$ 7.0 ml·min^{-1}·kg^{-1} with an r-value of 0.77, and a SEE of 4.5 (Fig. 7).

A t-test was performed on the mean values of the estimated and actual VO$_2$max, in order to determine if the actual value was an over- or under-estimation. No significant difference was found when comparing the actual VO$_2$max to the estimate derived from the VO$_2$R method (p = 0.77). However, the Astrand method significantly overestimated the actual VO$_2$max (p = 0.0019).

The submaximal protocol used was designed to elicit a HR of approximately 65-75% HRR at the end of the 6-minute final stage. The average %HRR was 65%, with seven subjects <60% HRR, thirty-seven subjects between 65 and 70% HRR, and six subjects between 70 and 75%HRR. Three subjects attained HRs above 75% HRR, and were retested. These subjects had attained HRs of 78%, 79% and 83% HRR at the end of their first submaximal test and were given retests at one stage lower than their initial test. On the second test, they attained HRs of 64%, 48% and 59% HRR, respectively. Two males with a first submax %HRR of 78% and 79% were retested at a workload of one less then their preliminary submax test. The subject with a 78% HRR completed the retest with a %HRR of 64%, while the subject with a 79% HRR completed the retest with a 48% HRR. One female with a first submax test of 83% HRR completed a retest with a
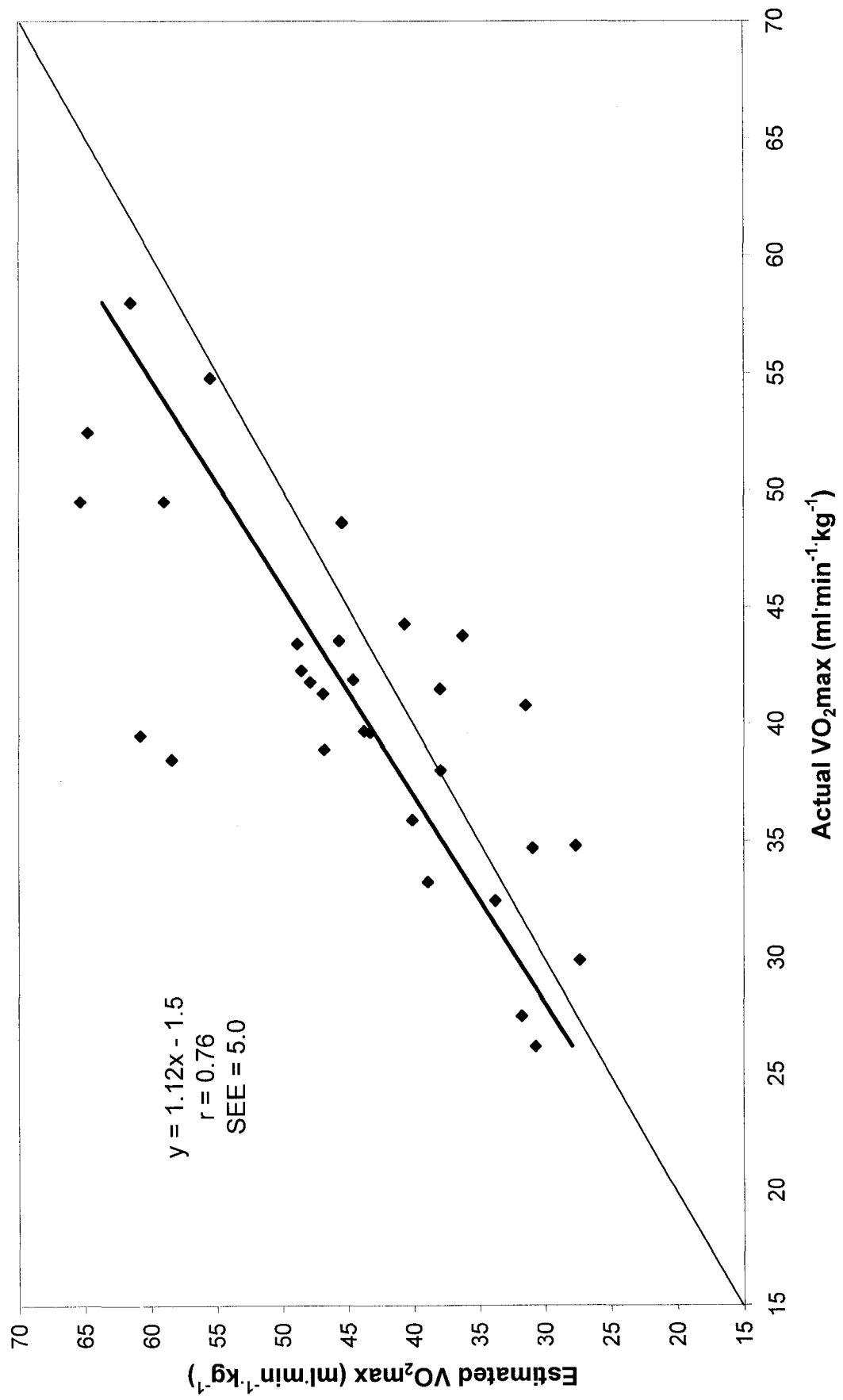
Fig. 6 Validity of Astrand estimation of VO_2max in active subjects

$y = 1.12x - 1.5$
$r = 0.76$
$SEE = 5.0$

Actual VO_2max ($ml \cdot min^{-1} \cdot kg^{-1}$)

Estimated VO_2max ($ml \cdot min^{-1} \cdot kg^{-1}$)

Fig. 7 Validity of Astrand estimation of VO₂max in inactive subjects

$y = 0.72x + 10.7$
$r = 0.77$
$SEE = 4.5$

Actual VO₂max (ml·min⁻¹·kg⁻¹)

Estimated VO₂max (ml·min⁻¹·kg⁻¹)
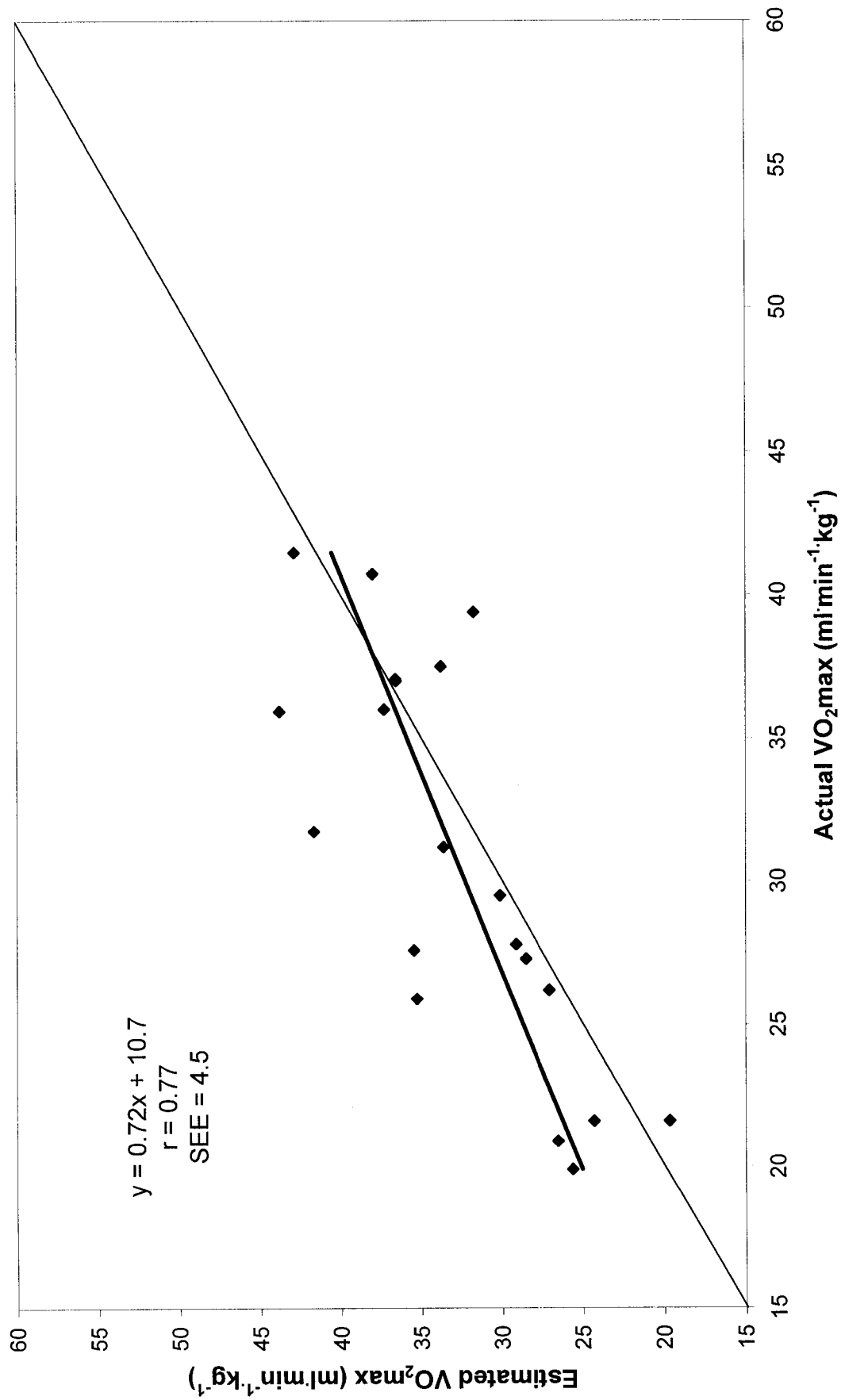
59% HRR. These retest data reveal the fact that no one submaximal protocol can be used for all subjects, and retesting may have to occur if subjects reach too high of a workload.

Chapter V
DISCUSSION

A major problem with the current ACSM submaximal protocol is the overestimation of

VO_2max. It has been surmised that the main reason for the low accuracy in regard to the

prediction of VO_2max when using the ACSM protocol was the insufficient stage length.

This protocol attempted to eliminate the multi-stage (3-min) approach in favor of a final

(6-min) stage to ensure that a steady state heart rate was reached. Furthermore, the

method of estimating VO_2max from the submaximal data was new, utilizing the

relationship between HRR and VO_2R established by Swain and coworkers (Swain and

Leutholtz, 1997; Swain et al., 1998). The new method did not over- or underestimate

VO_2max, yielding a virtually identical mean value, and exhibited very high validity, with

an r of 0.89 and SEE of 4.0 $ml\cdot min^{-1}\cdot kg^{-1}$. In contrast, previous studies of the ACSM

protocol have found that it overestimates VO_2max by more than 25% on average, and has

a lower r and larger SEE (Greiwe et al, 1995; Swain and Wright, 1997). Moreover, the

new method was equally valid in men and women, and in inactive and active subjects.

This study also evaluated the accuracy of the Astrand method of estimating

VO_2max while using the new submaximal testing protocol. The Astrand method had

somewhat lower validity than the VO_2R method, and significantly overestimated

VO_2max on average. This overestimation was specific to the active subjects, as seen in

Figure 6.

Bennett et al. (2000) also utilized the VO_2R method of estimating VO_2max from a

final 6-min stage, but the workload that the subjects completed was considered high (78%

HRR on average). The current protocol tried to elicit a %HRR between 65 and 75%

HRR at the conclusion of the submaximal test. The average HR attained was 65% HRR, and three subjects exceed 75% HRR. These results are to be expected when trying to get subjects into a narrow HRR margin. In this study, the three subjects who exceed 75% HRR were retested. Outside of a controlled laboratory center, it may not be feasible to retest subjects, or they may be unwilling to do so. Experience with the three subjects who exceeded 75% HRR in this study suggests a means of handling such clients in the fitness setting. All three subjects first exceeded 75% HRR at the end of the 5th minute of the 6-min stage. The HRR value for the 5th and 6th minute together was 3% higher than the 5th minute value alone. In a post-hoc analysis, using 3% more than the %HRR of the 5th minute provided a reasonably accurate estimate of VO_2max in these three subjects, similar to what was obtained in their retest at a lower intensity. Thus, clients in a fitness setting who reach 75% HRR should have their test terminated to insure that a safe exercise intensity is not exceeded. If the test is terminated in the 5th minute, 3% should be added to their final HRR value, and this value should be used to estimate VO_2max. Clients who reach 75% HRR earlier than this point should be retested.

In the research done by Bennett et al. (2000), 41% of the subjects went over 80% HRR, and the researchers attained a very high r-value (0.91) and a low SEE (3.4). Clearly, greater accuracy can be attained by having subjects exercise closer to maximum intensity levels, however, such a protocol might not be considered safe for testing the general public.

The cadence used in this study was 60 rpm, which was in part based on the Swain and Wright study (1997) that found no significant differences between cadences of 50 and 80 rpm. This cadence appeared to work very well for most subjects, although those

more experienced in cycling tended to complain that the cadence was uncomfortably slow.

In conclusion, the new submaximal cycle ergometer protocol performed in this study, using the VO_2R method of estimation, did not significantly overestimate, or underestimate VO_2max, and was found to be highly valid. The ACSM protocol in current use has previously been found to overestimate VO_2max, and the Astrand method significantly overestimated VO_2max in the active subjects. Based upon this information, the new submaximal cycle ergometer protocol was a more valid and accurate method for prediction of VO_2max when compared to both the Astrand and the current ACSM submaximal cycle ergometer protocol.

The findings of the current research are limited to relatively young adults (18-44 years old) who are at a low risk of coronary heart disease. Future research is needed to validate its findings to that of older populations, or those that would not be classified as low risk by the ACSM.

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