

COMPARATIVE ANALYSIS OF KARVONEN AND ANAEROBIC THRESHOLD METHODS FOR
PRESCRIBING EXERCISE IN HEALTHY ADULT MALES

by

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Chapter 1

INTRODUCTION

The use of endurance training to develop or maintain cardiorespiratory fitness has been a methodological problem studied by many exercise physiologists. The development of this endurance program is dependent upon the assessment of the individual's aerobic capacity from which an accurate and effective exercise prescription is derived. This assessment can be made by various modes in which the most common are the bicycle ergometer test, treadmill test and step tests. According to Taylor et al (1955) and Davis et al (1975), the most objective method for assessing an individual's aerobic capacity is oxygen consumption and heart rate measurements recorded during a submaximal or maximal graded exercise test. These two measurements are the most widely used physiological parameters to help determine an individual's exercise prescription (Davis et al, 1975).

Exercise prescription is a method of devising an exercise program for individuals to improve their cardiovascular fitness. For this improvement to occur, implementation of an accurate method for calculating an individual's exercise prescription is necessary to enable individuals to effectively and efficiently maintain a cardiovascular training stimulus during the exercise period. When devising an individual's exercise prescription, four components are involved. These components are intensity, duration, frequency, and mode of activity. According to several researchers, to obtain maximal benefits from an exercise program, the individual needs to exercise at the proper intensity (Karvonen et al, 1953, Pollock et al, 1978). The intensity compo-

ment in the exercise prescription is determined by the evaluation of the individual's physiological responses (i.e., oxygen consumption, heart rate and anaerobic threshold) resulting from graded exercise testing.

Presently, a more practical and accurate procedure for determining the intensity for cardiorespiratory endurance exercise is the conventional Karvonen method (Davis et al, 1975). To apply the Karvonen method, a graded exercise test must be administered in which the maximal heart rate is attained. This value can then be used to determine the individual's exercise training intensity. However, the Karvonen method has several fallacies. First, if an individual does not reach a maximal heart rate, the exercise prescription may be inappropriate. Secondly, Powles (1979) stated that patients with ischemic heart disease are unable to exercise at a level to attain their true maximal heart rate. Therefore, determining an intensity level for these individuals using the Karvonen method may be inaccurate and could result in cardiovascular complications.

Perhaps a more accurate method to calculate an individual's exercise prescription is based upon a respiratory-metabolic parameter identified as the anaerobic threshold. This procedure can determine an individual's exercise intensity without the use of maximal heart rate value (Smith, 1979; MacDougall, 1977; Weltman et al, 1978; Goss et al, 1979; McLellan and Skinner, 1978). This procedure is achieved by assessing the utilization of oxygen in the muscle. As long as the local circulation provides for adequate oxygen delivery to the working muscle, the energy requirement is sustained by aerobic metabolism. However,

when the oxygen delivery to the muscle is not adequate to meet the oxygen requirement of the work, anaerobic glycolysis will increase to meet the energy demands. The increase in anaerobic metabolism causes an increase in lactic acid which is buffered by the bicarbonate system which elicits an increase in CO_2 production. This increase in CO_2 formed by the buffering of lactic acid results in an increase in $\dot{V}\text{CO}_2$ which stimulates an increase in $\dot{V}_E$ causing the $\dot{V}_E/\dot{V}\text{O}_2$ relationship to become nonlinear (Weltman and Katch, 1979). Wasserman, Whipp, Koyal and Beaver (1973) introduced non-invasive indicators for rapidly determining the onset of arterial lactic acid accumulation which is reflected by rapidly decreasing the plasma pH during nonsteady-state exercise. These non-invasive indicators which reflect changes in respiratory gas exchange have been proposed as sensitive indicators for the onset of arterial lactic acid accumulation (Davis et al, 1976).

Statement of the Problem

To analyze and determine the benefits of an exercise program it is imperative that appropriate intensity and duration components of the exercise prescription be developed to adequately stimulate cardiorespiratory fitness. An accurate prescription is important to ensure that individuals are able to sustain a cardiovascular training stimulus during the duration of the exercise session. The literature indicates that training intensities should exceed 60% of maximal capacity for the individual to receive cardiovascular improvement (Karvonen et al, 1957; Davis et al, 1975; Sharkey et al, 1967; Wilmore, 1974). If the exercise prescription is too low, the individual does not receive the adequate stimulus for improving cardiorespiratory endurance and

aerobic training (Karvonen et al, 1957). In contrast, for individuals who possess coronary heart disease, an exercise prescription that is too high can be potentially dangerous by producing cardiac instability (Pyfer & Doane, 1969; Fletcher & Cantwell, 1978).

Currently, there has been little research conducted using anaerobic threshold as a procedure to determine an individual's exercise prescription. One apparent reason is that there is great difficulty in obtaining blood lactic acid samples during a graded exercise test. Also, the research of Davis and Convertino (1975) has validated the Karvonen method against the criterion measurement of work intensity ($\dot{V}O_2$), thus, making this procedure more attractive. However, Katch and others (1978) investigated the relative training intensities utilizing percent oxygen intake, heart rate and metabolic acidosis at 60, 70, and 80% of maximal heart rate on a bicycle ergometer test. The results indicated that at 60 and 70% of the maximal heart rate, one subject was above the metabolic stress level. However, at 80% of the maximal heart rate, 17 subjects were working above their metabolic stress level. Therefore, it was concluded by Katch and others, that when all subjects were working at the same relative percent of their maximal heart rate, 18 subjects were working at a level above the point of "metabolic acidosis" (anaerobic threshold). The implications of this investigation would indicate that if exercise intensities are based on maximal heart rate concept, then cardiorespiratory endurance activities could be impaired as a result of an inaccurate exercise prescription.

To support a similar finding, Goss et al (1978) investigated the utilization of anaerobic threshold to determine the exercise prescription.

Goss and his co-workers reported that in 17 of 18 cases, the anaerobic threshold fell within 60-85% of the exercise heart range derived by the Karvonen method. However, much individual variability was noted (i.e., subject range = 52-85%) and was concluded by Goss and co-workers that perhaps the anaerobic threshold method was more sensitive to individual differences and not dependent on true maximal heart rate values attained during the graded exercise test.

Research Hypotheses

H_0 : There are no significant differences in the subject's ability to exercise at a prescribed level using the Karvonen and anaerobic threshold methods in young, healthy male adults with respect to:

- a. the duration that the prescribed training heart rate is maintained in continuous exercise;
- b. the level of oxygen uptake required during the exercise period in which the prescribed heart rate is maintained;
- c. the level of perceived exertion (RPE reported during the exercise period in which the prescribed heart rate is maintained.

H_0 : There are no significant differences in the subject's capacity to perform continuous exercise using the Karvonen and anaerobic threshold methods in young, healthy male adults with respect to:

- a. the duration that continuous exercise is maintained before fatigue is expressed;
- b. maximal heart rate attained at the end of exercise;
- c. respiratory exchange values during continuous exercise;
- d. the subject's perceived exertion (RPE) of the intensity during continuous exercise.

Delimitations

The following delimitations are inherent in the design of this study:

1. Only 10 male subjects (22-26 years old) attending Virginia Tech served as subjects;
2. Non-invasive measurements were used to estimate the anaerobic threshold.

Limitations

The following limitations restrict the generalizability of the findings:

1. Applicability of results should be limited to a young male population;
2. Since invasive measures (e.g., blood lactic acid) were not used to determine anaerobic threshold, the validity of the $\dot{V}_E$ responses from which anaerobic threshold was estimated could not be established.

Definitions and Symbols

1. Aerobic metabolism: The process in which oxygen is available and utilized to resynthesize adenosine triphosphate in the muscle.
2. Anaerobic Threshold (AT): The point during exercise at which there is an accumulation in blood lactic acid as a result of elevated muscle metabolism. When this accumulation reaches two millimoles of lactate, the rise is considered to reflect the anaerobic threshold (Skinner and McLellan, 1980).
3. Carbon dioxide production ($\dot{V}CO_2$): The minute volume of CO_2 eliminated from the lungs during gaseous exchange.

4. Exercise Prescription: Exercise prescription is a method of devising an exercise program for individuals to improve cardiorespiratory fitness. Intensity, duration and frequency are the components of exercise prescription. The prescription is determined by evaluation of physiological variables resulting from the graded exercise test.
5. Graded Exercise Test (GXT): A subject is evaluated on a treadmill measuring various physiological parameters. While the subject is being tested on the treadmill, measured speed and grade increments are applied until functional exercise capacity is attained.
6. Lactic Acid: The by-product of glycolysis, formed by the addition of H^+ to pyruvic acid (Astrand & Rodahl, 1977).
7. Metabolic Equivalent (MET): One MET represents an oxygen uptake of approximately $3.5 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, i.e., resting metabolism. METS are used in conjunction with the graded exercise test to describe fitness classification.
8. Minute Ventilation ($\dot{V}_E$): The volume of air inspired or expired from the lungs, expressed in liters per minute.
9. Oxygen Uptake ($\dot{V}O_2$): The minute volume of oxygen consumed and utilized by body tissues.
10. Rate of Perceived Exertion (RPE): The subjects' ability to rate the intensity of the exercise by utilizing perceptual cues as the primary source of information (Borg et al, 1974).

Significance of the Study

The utilization of AT may prove to be a key concept for determining the exercise prescription and assessing physical fitness. Currently, exercise prescription is based on predetermined percentages of maximal

oxygen uptake and heart rate. However, AT may prove the current procedures to be inadequate. Since maximum oxygen uptake and maximal heart rate values are generally considered to be the standard indicators of cardiorespiratory exercise capacity, AT may offer a more practical alternative (Weltman et al, 1978; McLellan et al, 1978).

The AT method to determine exercise prescription may offer several advantages. First, during the graded exercise test, subjects would not be required to exercise until exhaustion to attain a maximal $\dot{V}O_2$ value or a true maximal heart rate to accurately prescribe a training intensity. The utilization of non-invasive measurements (i.e., $\dot{V}_E$, $F_{E O_2}$ and $F_{E CO_2}$) would allow for predicting the individual's AT during the GXT before exhaustion occurs. Secondly, this procedure would expedite the graded exercise testing time required to accurately determine an exercise prescription. Thirdly, the AT method may allow for a safer method when assessing the exercise tolerance of cardiac subjects, since near-maximal efforts at which there may be a slight increased risk of cardiovascular complications may not be required in the GXT.

Chapter II

REVIEW OF THE LITERATURE

Exercise prescription can be described as being a science and an art that is new in adult fitness and cardiac rehabilitation programs. With increasing importance being placed on accurately prescribing the individual's exercise intensity, a new method of calculating the individual's exercise prescription has been studied. It appears that the utilization of the AT as a criterion measure to more precisely and safely prescribe an individual's intensity may become more popular than the Karvonen method (Davis et al, 1979, McLellan and Skinner, 1978, Weltman et al, 1978, Patton et al, 1979).

The purpose of this chapter is to review the literature as it pertains to the following: components of the exercise prescription; developing the intensity component of the exercise prescription; validity of the Karvonen method; AT method of exercise prescription; transition from aerobic to anaerobic metabolism, validity of detecting AT via respiratory responses; workload durations related to AT; normative values of AT for adults; and validity and reliability of perceived exertion as an indicator of exercise intensity.

Components of the Exercise Prescription

To develop and maintain cardiorespiratory fitness and body composition, the ACSM (1980) has stated that there are four components for developing and maintaining cardiorespiratory fitness and body composition. The four components of the exercise prescription are: 1) mode of activity, 2) frequency of participation, 3) duration of each exercise period, and 4) intensity of the effort.

There are numerous training modes that are available to develop cardiorespiratory fitness. This is best developed through rhythmical, large muscle activities that are endurance in nature. Jogging, running, swimming, walking, cross-country skiing are examples of aerobic type activities that will help obtain cardiovascular improvement (Ribisl, 1980).

The frequency of training refers to the number of exercise sessions per week. The literature supports the theory that there is a direct relationship between frequency of training and cardiovascular fitness (Gettman et al, 1976). According to the literature, training should be a minimum of three days per week and more cardiovascular improvement may occur if the frequency is increased to five days per week (ACSM, 1980, Wilmore, 1972 and Pollock et al, 1978). This is in agreement with the findings of Gettman and co-workers (1976). The purpose of their study was to examine the physiological responses to jail inmates on one, three, and five days per week running program. The training regimens were thirty minute sessions for twenty weeks at an intensity level of 85 to 95% of their maximal heart rate. Gettman and associates reported cardiovascular improvements in all three groups. However, improvements in individuals' $\dot{V}O_{2\max}$ expressed in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ was 8% for one day, 13% for three days, and 17% for five days per week, thus, indicating that there seems to be greater cardiovascular gains when the frequency is increased. Hellerstein and Franklin (1978) reported that once-a-week conditioning is not enough to elicit an increase in $\dot{V}O_{2\max}$ in young men, however, older men or cardiac subjects did have an increase in $\dot{V}O_{2\max}$.

Duration refers to the time an individual trains at a particular intensity. To achieve the desired cardiovascular effect, the subject should perform dynamic exercise for an adequate period to stimulate energy through the aerobic energy pathways (Hellerstein et al, 1978). The duration of effort is interrelated to the intensity of effort and both must be considered simultaneously rather than separately to assess the quality of the training stimulus (Ribisl, 1980). To produce a significant conditioning response, the duration of exercise has an inverse relationship with intensity: the lower the intensity of exercise, the longer the duration. In contrast, the greater the intensity (up to about 80% $\dot{V}O_{2\text{max}}$), the shorter the duration to receive the same benefits (Hellerstein et al, 1978, Pollock et al, 1978). Wilmore and et al (1979) conducted a jogging program for middle-aged men three times per week for ten weeks in which the subjects trained either 12 or 24 minutes per exercise session. Wilmore and co-workers reported that both groups had significant cardiovascular improvement, however, the latter group improved more. The American Heart Association (1975) reported that the training period should last from twenty to sixty minutes while Ribisl (1980) and the ACSM Guidelines (1980) indicated that the optimal duration is between thirty and forty-five minutes a day. Hellerstein et al (1978) stated that training for more than forty-five minutes a day elicited a very slight improvement in aerobic capacity and that the increase in duration may increase the risk of orthopedic complication.

Another factor closely related to the duration of the training session is the caloric expenditure of the individual. Pollock et al

(1971) conducted a study in which sedentary males trained forty minutes, four times per week for twenty weeks. The subject's initial training regimen was walking 2.5 miles per week during the first week and progressing to 3.25 miles during the last five weeks. Pollock reported that the kilocalorie expenditure was 241 to 357 per session depending on the duration of exercise. The caloric expenditure is an important objective of the exercise prescription since it will result in body composition changes of the individual (Pollock, Wilmore and Fox, 1978).

Perhaps the most important component of the exercise prescription is intensity. The intensity is the percent of maximum exertion that is attained during the training stimulus (Ribisi, 1980). Exercise at too low an intensity will not elicit a training effect regardless of the duration and frequency (Pollock et al, 1978). Conversely, too high an intensity can be ineffective or potentially dangerous. The reasons that very high intensity training may be ineffective for most subjects is because exercise cannot be sustained long enough to develop an optimal stimulus. Another concern for high intensity training is the risk involved with those subjects with ischemic heart disease. These individuals may develop cardiovascular complications such as arrhythmias, and myocardial infarction (Hellerstein et al, 1978 and Mead et al, 1976).

A classical study by Karvonen et al (1957) was conducted to determine the effects of different intensities on the resting, working and maximum heart rates of six young male students trained by running on a treadmill for thirty minutes four or five days a week. The training

regimen lasted for four weeks. Karvonen and others reported no significant improvement in maximum working capacity for those individuals who did not sustain a heart rate of $135 \text{ bts} \cdot \text{min}^{-1}$. It was further stated by Karvonen and co-workers that there appeared to be a critical limit at or slightly above the sixty percent training level to produce a training effect. A heart rate of $150 \text{ bts} \cdot \text{min}^{-1}$ which corresponded to seventy percent of the maximal heart rate produced even greater training effects.

A later investigation conducted by Sharkey and Holleman (1967) supports the findings of Karvonen and co-workers. Sharkey and others studied the cardiorespiratory responses of sixteen male subjects that were divided into three different training intensity groups. The subjects exercised three days per week for ten minutes at intensity levels eliciting 120, 150, or 180 heart rates. The researchers concluded the need for more intense rather than light or moderate activity as a training stimulus. This study also supported the theory that heart rates above $150 \text{ bts} \cdot \text{min}^{-1}$ elicited more cardiovascular improvements.

Davis and Convertino (1975) validated the method described by Karvonen et al (1957) which also stated the minimal threshold for improvement in cardiovascular fitness is approximately $130\text{--}135 \text{ bts} \cdot \text{min}^{-1}$ for young persons. However, since there is an inverse relationship between maximal heart rate and age, a training effect of $110\text{--}120 \text{ bts} \cdot \text{min}^{-1}$ may be adequate to elicit a training response in older individuals (ACSM, 1980, Ribisl, 1980).

Developing the Intensity Component of the Exercise Prescription

There are various methods for assigning recommended intensities. Karvonen et al (1957) introduced a new method by designating a target heart rate that corresponds to a certain fraction of the cardiac reserve (i.e., maximal HR minus rest HR). Davis and Convertino (1975) reported that between two methods, a chosen percentage of the maximal heart rate and the Karvonen technique (percentage of the difference between maximal and rest HR values and added to resting HR), the percentage of the measured maximal HR overpredicted the exercise intensity, while the Karvonen technique proved to be accurate. However, Powles and others (1979) reported that the target heart rate procedure may be potentially dangerous. After exercise testing 159 post-myocardial infarction patients, Powles and others (1979) concluded that CHD patients did not achieve heart rate response to that of normal subjects. Consequently, estimating maximal heart rate responses from age-adjusted predicted maximal heart rates or submaximal heart rate responses will grossly overestimate the target heart rate. Hellerstein and others (1978) were in agreement with Powles and associates that the Karvonen technique has limited application to the normal population where the resting and maximal heart rate values can be reliably assessed, rather than estimated.

Perhaps a safer and more accurate method for determining an individual's training intensity is the individual's AT. Recent studies of MacDougall, 1979, Goss et al, 1979, Katch et al, 1978, Kinderman et al, 1979, indicated that an individual's AT may be a critical factor for determining the individual's potential for endurance activities.

Katch and associates (1978) studied thirty-one subjects to determine the level of exercise at which lactic acidosis occurred at different levels of maximum heart range. The purpose of this study was to determine if the training intensities derived from the percent HR_{max} was valid in equating the same physiological intensity among all subjects. Katch and co-workers measured the subject's venous blood lactate at 60 and 70% of maximal heart rate and reported only one subject was at or above his AT. However, seventeen subjects were working at or above anaerobic threshold at 80% maximum heart rate. It was concluded by Katch and others that the subjects may be exercising at the same relative percentage of their training heart rate, but the levels of intensity were different. Katch et al (1978) also stated that the training heart rate concept for equating exercise or training intensity levels needs re-examination.

Goss et al (1979) conducted an investigation to determine if AT was a more accurate parameter for prescribing exercise than the Karvonen method. Twenty-one subjects underwent supervised GXT's before entering an exercise program. The workload consisted of two minute intervals until subjects became exhausted. Heart rates and $\dot{V}_E$ were measured during the second minute of each workload. In this study, the AT in seventeen of the eighteen cases, was reported to fall between 60-85% of the exercise heart range using the Karvonen formula. However, much individual variability was noted, and thus, AT was reported to be more sensitive to individual differences and not solely dependent upon reliability of the true maximal heart rate obtained

during the GXT.

Patton and associates (1979) investigated the theory that target heart rates can be set for training at or above the AT regardless of the individual's fitness level. Five male cross-country runners and six physically active non-runners were exercised until exhaustion on a treadmill test. AT was determined visually as the non-linear point in the $\dot{V}_E$ response. It was determined that the heart rate at the AT for the two groups was not significantly different although the runners reached AT at a greater absolute and relative level of $\dot{V}O_{2\max}$. Patton and associates concluded that absolute heart rate measures are good indicators of intensity level required for AT.

McLellan and Skinner (1978) investigated the use of AT as a training criterion in fourteen sedentary males. The subjects were divided into two groups according to high and low AT values, and high and low values relative to $\dot{V}O_{2\max}$. The high and low AT groups included subjects that had AT values above 55% of $\dot{V}O_{2\max}$ or below 45% of $\dot{V}O_{2\max}$, respectively. In the second group, intensity ranged from 65 to 55% of $\dot{V}O_{2\max}$ for high and low groups, respectively. The groups exercised on a bicycle ergometer thirty to forty-five minutes a day three times a week for eight weeks. The groups that utilized AT as the training criterion had significant increases in $\dot{V}O_{2\max}$. The researchers noted that the percentage improvement in $\dot{V}O_{2\max}$ was related to initial fitness levels, however, variability was not different among the four groups. McLellan and Skinner concluded that utilization of $\dot{V}O_{2\max}$ cannot be justified as the sole criterion used to prescribe intensity and that AT should be considered as an additional criterion to assist in deter-

mining training intensity.

Validity of Karvonen Method

The effectiveness of maintaining and/or developing cardiorespiratory fitness is dependent upon the accuracy of the exercise prescription. One of the most important components of the exercise prescription is the intensity component. As previously mentioned, several researchers (Pollock et al, 1978, Sharkey et al, 1967, Karvonen et al, 1957) have stated that the proper intensity is very important to elicit a cardiovascular training stimulus. There are several methods in which the intensity can be determined. One method is the Karvonen method. Presently, there are very few studies cited that examine the validity of this procedure.

Davis and Convertino (1975) compared the predicted exercise intensities calculated by the percent of heart rate maximum and the Karvonen method to measured exercise intensities. Nine male students served as subjects for this study. Each subject performed two max $\dot{V}O_2$ tests on a treadmill on two different days. The speed remained constant while the grade was increased 2.5% every three minutes until the subject became exhausted. Following the two $\dot{V}O_{2\max}$ tests, each subject participated in a third test consisting of four, five-minute workloads representing 25, 45, 65 and 85% of his net $\dot{V}O_{2\max}$. Between each test, the subject rested until his heart rate fell below 85 bts min^{-1} . The data illustrates that the Karvonen method predictions of exercise intensity were not significantly different from the measured values. However, Davis and co-workers noted that the Karvonen method resulted in an over-

all prediction of 2.6% above the mean values recorded at the four intensities of $\dot{V}O_{2\max}$. The percent of heart rate max which was determined by calculating an assigned fraction of heart rate max significantly overestimated the exercise intensity. Davis and Convertino concluded that the Karvonen method was accurate and practical in determining the subject's exercise intensity.

In a recent investigation, Smith (1979) examined the relationship between AT and both the prescribed and achieved exercise intensities. The subjects were participants in the Wake Forest Cardiac Rehabilitation Program and had suffered previous myocardial infarctions and/or by-pass surgery. A symptom-limited maximal test was administered to the subjects utilizing a modified Bruce protocol. The criteria for discerning AT were a non-linear increase in $\dot{V}_E$, a non-linear increase in $\dot{V}CO_2$, and an abrupt increase in $F_{E}O_2$. The data from the GXT illustrated that the mean value for the subject's AT was 1.34 liters $\cdot$ min $^{-1}$ with individual values ranging from 1.79 liters $\cdot$ min $^{-1}$ to 2.13 liters $\cdot$ min $^{-1}$. Smith reported that the mean AT of the seventeen subjects was 69.4% relative to net HR max which falls in the 60-85% range determined by the Karvonen method. It was also reported by Smith that only two subjects demonstrated AT values below the 60% level and these values were reported at 59.6% and 57.8%. The researcher noted that one factor to affect AT in different populations was physical training. Smith concluded that the current methodology (Karvonen method) for prescribing exercise in cardiac patients was substantiated by this investigation of AT, however, more research is needed to continue to evaluate the use of AT as an

index of submaximal fitness. The subjects in this study had completed a three-month or six-month rehabilitation program, and the variability in AT values for AT could have been the conditioning effect. Perhaps it could be noted that if the subjects were not involved in a conditioning program, their AT may have been lower and subsequently, not within the 60-85% range determined by the Karvonen method.

Goss et al (1979) conducted an investigation to determine if AT was a more accurate parameter for prescribing exercise than the Karvonen. Twenty-one subjects (i.e., 16 males, 5 females) were administered GXTS before entering an exercise program. The workload consisted of two-minute intervals until the subject became exhausted. Heart rate and $\dot{V}_E$ were measured during the second minute of each workload. The data illustrated the AT in seventeen of the eighteen cases were reported to fall between 60-85% of the exercise heart range utilizing the Karvonen method. However, Goss and co-workers reported that much individual variability was noted, and thus AT appeared to be more sensitive to individual differences.

AT Method of Exercise Prescription

Transition of Aerobic to Anaerobic Metabolism

Many investigators have tried to determine the point in progressive exercise at which there is a sharp transition from aerobic to anaerobic metabolism. Hill and Lupton (1923) conducted an early investigation to examine the recovery time of exercise from varying duration and intensity. It was hypothesized that at higher speeds of $9.7 \text{ miles} \cdot \text{hr}^{-1}$, the O_2 requirement for the body cannot be satisfied, thus, oxygen debt increases and lactic acid would accumulate. Therefore, Hill and Lupton

concluded that there is a relationship between intensity of exercise and oxygen requirement, and at high speeds there is a rapid accumulation of lactic acid. Perhaps, this is the first evidence that AT was beginning to be examined.

An early investigation of Margaria et al (1933) examined the relationship between anaerobic metabolism and the accumulation of lactic acid. They found there was an excess accumulation of lactic acid when the intensity of the exercise exceeded two thirds of the subject's metabolic rate; and below this level, lactic acid increased at a rate of $7.0 \text{ mg} \cdot \text{liter}^{-1}$ for each liter increment of O_2 debt. Therefore, it was concluded that the accumulation of lactic acid did not occur until the intensity of the exercise was severe.

Wasserman et al (1967) also examined the effects of work intensity and duration on the metabolic, circulatory and ventilatory response to exercise. Ten male medical students exercised on two nonconsecutive days. The first day the student pedaled at $170 \text{ kgm} \cdot \text{min}^{-1}$ for four minute work increments until exhaustion. The experiment was repeated two hours later. On the second day, three work rates were selected in which the first work rate was just below the anaerobic threshold and the second and third workloads were referred to as heavy and very heavy intensities. The data indicated that the time required for attaining a steady state in O_2 consumption was related to work intensities. The investigators stated that lactate concentration in arterial blood changes very little at moderate work intensities, increases at heavy work and increases more at very heavy work intensities. It has also been reported that $\dot{V}_E$ increases in proportion to $\dot{V}\text{O}_2$ until heavy work intensities. Thereafter,

$\dot{V}_E$ increases disproportionately to $\dot{V}O_2$ and correlates with the onset of "metabolic acidosis," the increase in $\dot{V}_E$ is to maintain the pH level in the blood. According to Wasserman and co-workers, during heavy work, "metabolic acidosis" is only partially compensated by increased ventilation due to the limitation of the subject's maximal breathing capacity.

In recent years, there has been much controversy for exercise physiologist's between the transition from aerobic to anaerobic metabolism during exercise. Kinderman, Simon and Keul (1979) have attempted to define what Wasserman and others (1967) have called the anaerobic threshold. Researchers Kinderman and co-workers determined the anaerobic threshold for seven cross-country skiers. The subjects ran on the treadmill at a constant grade of 5% and a starting speed of $8 \text{ km} \cdot \text{hr}^{-1}$. The speed was increased by 2 km/hr every three minutes until exhaustion. Arterial blood samples were taken at every workload. It was determined that at four millimoles of lactate there was a sharp rise in lactate levels. The subjects were then administered two additional tests of thirty minutes duration in which the intensity levels were determined at rates that corresponded to 4 millimoles of blood lactate levels. During the first exercise test, the subject's workload was adjusted so that the heart rate at four millimoles was kept constant. In the second test, the speed of the treadmill determined for the same lactate concentration was kept constant. Kinderman and others found in all subjects that lactate levels of four millimoles represented 80% of their maximal capacity. They have indicated that the speed of the treadmill had to be continuously reduced if the heart rate determined for four millimoles of lactate was to be kept constant during the thirty minute exercise session.

Conversely, they concluded that when the exercise is performed for a constant running speed determined for four millimoles of lactate, the subjects were able to exercise for thirty minutes and a few subjects were able to exercise for forty-five minutes before a change in lactate levels occurred. The results of this study illustrated that the optimal training intensity is in the range of four millimoles of lactate and can be maintained for twenty minutes. In contrast, Kinderman and others stated that the workload intensities in the range of the anaerobic threshold as defined by Wasserman et al (1973), which was a level of two millimoles of lactate, is lower and represents a level associated with aerobic metabolism which is not sufficient stimulus to elicit adaptations in the muscle cell. The investigators have suggested that for clarity and efficiency, the concepts of threshold derived from energy metabolism be defined as follows:

1. Aerobic Threshold (formerly anaerobic threshold): This is defined as the exercise level associated with the first elevation in lactate levels, nonlinear increase in $\dot{V}_E$ and R which occurs at approximately 2 millimoles of blood lactate.
2. Aerobic-anaerobic Transition: This point is identified when exercise intensity elevates blood lactate levels from two to four millimoles.
3. Anaerobic Threshold (formerly aerobic-anaerobic threshold): This is defined as the point when blood lactate levels reach four millimoles.

In a recent article, Skinner and McLellan (1980) tried to explain the transition from aerobic to anaerobic metabolism and where this

transition occurs. Based on the data from other investigators, they have proposed three phases during progressive exercise intensities. Phase one occurs when the exercise intensity increases to approximately 40% of the subject's max $\dot{V}O_2$. During this phase, there is a linear increase in $\dot{V}O_2$, $\dot{V}_E$, and $\dot{V}CO_2$, and at which time there is very little lactic acid accumulation. The values for R have been recorded at .7-.8. This first phase is considered to be primarily aerobic metabolism. Phase two is identified as the point between 40 and 60% of the subject's $\dot{V}O_{2\max}$, and $\dot{V}O_2$ and heart rate continue to rise linearly. There is a rise in lactic acid from approximately two millimoles. This rise in lactic acid is buffered largely by the bicarbonate system. The end-product of this buffering is CO_2 which is eliminated via the lungs which stimulates the respiratory center and increases ventilation. This rise in $\dot{V}_E$ and in $\dot{V}CO_2$ is greater than the rise in $\dot{V}O_2$, therefore, producing a disproportionate increase in $\dot{V}_E \cdot \dot{V}O_2$. This can be explained by the fact that the body does not consume more oxygen than is needed to replace the ATP utilized, therefore, a lower extraction of O_2 per volume of air. Phase two is characterized by an increase in $F_E O_2$ without a corresponding decrease in $F_E CO_2$. Phase three is characterized by an increase in exercise intensity to approximately 65-90% max $\dot{V}O_2$, a sharp rise in lactic acid of about four millimoles, a further increase in ventilation and a decrease in $F_E CO_2$ while the $F_E O_2$ continues to increase. Skinner and McLellan found that phase three is indicative of the AT.

Validity of Detecting AT Via Respiratory Responses

Hill, Lupton (1923) reported that the respiratory gas exchange ratio (R) was shown to reflect changes in blood lactic acid con-

centrations. An increase in R seemed indicative of the blood lactic accumulation which was associated with a rise in $\dot{V}CO_2$, increase in end-tidal O_2 , without a corresponding decrease in end-tidal CO_2 , and an increase in R. Recent literature has suggested that this increase in R which is associated with the buffering of lactic acid by sodium bicarbonate is transient (Wasserman et al, 1973).

Issekutz and Rodahl (1961) were interested in determining if the increase in R was associated with the imbalance in the production and removal of lactic acid. The researchers stated lactate concentrations were higher in active tissue than in blood and the diffusion rate of CO_2 was more rapid than lactic acid. It was suggested that R exchange is dependent upon intensity of work. The increase of CO_2 compared to O_2 was not a result of hyperventilation which would elicit a drop in alveolar as well as arterial PCO_2 . Subsequently, the rise in RQ during exercise can be attributed to an imbalance between the formation and elimination of lactic acid and the reaction to the buffering system.

AT has previously been defined "as the level of work or O_2 consumption just below at which metabolic acidosis and the associated changes in gas exchange occur" (Wasserman et al, 1973). Investigators have reported that AT may be detected from the increase in blood lactate concentrations or a nonlinear increase in $\dot{V}_E$ and $\dot{V}CO_2$ (Wasserman et al, 1964, Wasserman et al, 1973). The first non-invasive measures used to detect lactic acidosis was utilized by Naimark and associates (1964) and Wasserman and McIlroy (1964). Using breath-by-breath gas analyzers, continuous recordings of end-tidal O_2 and CO_2 concentrations produced a reliable means of observing changes in R during exercise.

These studies confirmed the findings of Issekutz and Rodahl (1961) that R is related to the intensity of work in exercise lasting more than 3-6 minutes.

Further determination of AT by non-invasive methodology was developed by Wasserman and co-workers (1973). End-tidal concentrations and $\dot{V}_E$ were recorded on eighty-five male subjects during progressive exercise on the bicycle ergometer. The researchers reported that, when graphed versus work intensity, four criterion could be utilized to discern AT. First, the researchers observed a disproportionate increase in $\dot{V}CO_2$ at work levels above the AT. This non-linear increase was associated with the additional CO_2 being produced from the buffering of blood lactate. Secondly, there was a disproportionate increase in $\dot{V}_E$ at work intensities beyond AT. Thirdly, the researchers examined the end-tidal O_2 concentration (Pet_{O_2}) and end-tidal CO_2 concentration (Pet_{CO_2}) and observed that Pet_{O_2} began to rise at the AT while the Pet_{CO_2} remained stable. Fourthly, the slope of R was observed to increase at intensities above AT. Consequently, at those levels the R ratio of $\dot{V}CO_2/\dot{V}O_2$ reflected the additional production of CO_2 in response to lactic acidosis. Wasserman and co-workers concluded that $\dot{V}_E$ was the most sensitive indicator of AT while R proved to be the least sensitive. Davis and co-workers (1976) reported that the AT for arm-cranking, leg cycling, and treadmill walk-running occurred at mean values of 46.5%, 63.8% and 58.6% of $\dot{V}O_{2max}$, respectively. It was reported the test-retest reliability for the arm-cranking, leg cycling, and treadmill modes were 0.92, 0.94 and 0.96, respectively.

To support the validity of using respiratory gas measures as a reliable technique to determine the onset of metabolic acidosis, Weltman and Katch (1979) examined thirty-one male subjects during bicycle ergometry utilizing $\dot{V}_E$ versus work rate. Workloads were increased every three minutes ($180 \text{ kpm} \cdot \text{min}^{-1}$) until the subject was unable to turn the pedals. Metabolic acidosis occurred at higher levels than reported by Wasserman et al (1973) and Naimark et al (1964). This difference was attributed to different max $\dot{V}O_2$ levels of the subjects. The mean AT- $\dot{V}O_2$ of each subject was 59.5%.

A study conducted by Koyal et al (1976) indicated findings similar to that reviewed from other investigators (Wasserman et al, 1973, MacDougall, 1979) that $\dot{V}_E$ was a reliable indicator of AT. Twenty male subjects performed three different work rates for fifteen minutes or until fatigue on the cycle ergometer and treadmill. The $\dot{V}_E$ and gas exchange measurements were recorded during the last minute of each workload. Lactate levels were sampled during the test. According to Koyal and others (1976), $\dot{V}_E$ is greater during cycle ergometry than treadmill work at comparable levels of O_2 . Cycle ergometry produced a significantly higher arterial blood lactate as opposed to the treadmill work. This resulted in a greater decrease in plasma bicarbonate concentration which reflected a greater degree of metabolic acidosis resulting from cycle ergometry work. The nonlinear increase in $\dot{V}_E$ could be attributed to the metabolic acidosis and the associated respiratory compensation required for the metabolic rate of exercise. It was concluded that $\dot{V}_E$ is more closely related to the degree of metabolic acidosis rather than the exercise modality.

Another study by Weltman and others (1978) has revealed that gas exchange variables are valid as criterion measures to detect AT. Weltman and others (1978) examined the use of the onset of metabolic acidosis as a criterion measurement of submaximal fitness. The gas exchange variables that were recorded were $\dot{V}_E$ BTPS, $\dot{V}CO_2$, and $F_{E}O_2$. Twenty-eight subjects exercised on a bicycle ergometer wherein workloads were increased every three minutes until subjects could no longer pedal. Individuals were matched according to their aerobic capacity and subsequently grouped on the basis of $AT-\dot{V}O_2$. The data illustrated that while max $\dot{V}O_2$ values were matched with respect to $\text{liter} \cdot \text{min}^{-1}$, there were no differences in $\dot{V}O_{2\text{max}}$ when expressed in $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, but there were significant differences in $\dot{V}O_2$ -AT when expressed in $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$. Therefore, it was concluded by Weltman et al (1978), that regardless of the individual's $\dot{V}O_{2\text{max}}$, the onset of lactic acidosis may be a useful tool when evaluating submaximal fitness.

Davis and co-workers (1976) examined the validity of using non-linear changes in $\dot{V}_E$ and $\dot{V}CO_2$ and abrupt increases in $F_{E}O_2$. Thirty-nine male college students volunteered for this study. Each subject performed two tests - each of arm cranking, leg cycling and treadmill walk-running. During the arm cranking test, each subject pedaled at a frequency of 50 rpm and the workload was increased .25 kp each minute until fatigue occurred. The leg cycling test consisted of work rates of 60 rpm and the work rate increased $200 \text{ kpm} \cdot \text{min}^{-1}$ every minute. For the walk-run test, the walk phase consisted of a speed of $72 \text{ meter} \cdot \text{min}^{-1}$ and zero percent grade. At the end of four, seven, and ten, speed was increased $10 \text{ meter} \cdot \text{min}^{-1}$ with the grade increased every minute except

when speed was increased. During the thirteenth minute, the speed was then increased to $120 \text{ meter} \cdot \text{min}^{-1}$ until the subjects became exhausted. The AT was determined by using a non-linear change in $\dot{V}_E$ when plotted against work rate, $\dot{V}\text{CO}_2$ plotted against work rate, and a line at which an abrupt increase in R was observed. An additional criteria was accepted as a determinant of AT which was an abrupt increase in $F_{E\text{O}_2}$. A high correlation ($r=0.95$) was found between the gas exchange variables and increases in blood lactate. Davis and associates reported results that were similar to that of Wasserman et al (1973) in that R was found to be the least sensitive indicator. It was also noted that $\dot{V}_E$ yielded a high correlation ($r=0.88$) thus, the detection of AT can be determined without measuring blood lactate levels. Davis and associates noted that one limitation of their study was that the criterion measure of AT is only an indirect index of lactate production by the working muscles. This criterion measure for AT allowed for subjectivity and experimental error on the point where the AT occurred.

Workload Durations Related to AT

There has been much disagreement among exercise physiologists in discerning the AT relative to workload increments. Wasserman et al (1973), reported that one-minute incremental work rates are associated with changes in gas exchange variables ($\dot{V}_E$, $\dot{V}\text{CO}_2$, R, Pet_{O_2} , Pet_{CO_2}). It has been demonstrated by Wasserman and co-workers (1973) that increasing the length of the work bout can significantly alter the assessment of AT because of the delay in diffusion of lactic acid from the muscle to the blood. Stamford et al (1978) and Weltman et al (1978)

have suggested that three-minute work increments provide ample data to accurately detect the subject's AT. In contrast, Davis et al (1976) suggested that one-minute incremental tests are appropriate because an abrupt increase in $F_{E}O_2$ is noted which provides another noninvasive method.

In an attempt to predict performance capability, Whipp and co-workers (1981) developed a single, short duration work test which would help assess the individual's aerobic function. Sixteen male subjects exercised on a bicycle ergometer during four different tests on different days. The first test was a constant load for five or six minutes in which the work rate consisted of approximately eighty percent of the individual's AT. Next, a steady-state incremental work test consisted of five-minute work increments increasing the work rate 25 Watts. Third, an incremental work test was administered in which the work rate was increased by 15 Watts until the subject became exhausted. The fourth test was a ramp test which consisted of four minutes of unloaded pedaling at a mean rate of power increase of 50 Watts per minute until the subject was exhausted. Whipp and co-workers concluded that the ramp test elicits responses that facilitated the detection of $\dot{V}O_{2\max}$ and AT which can occur from a single work test of four to eight minutes in duration.

A very recent investigation by Bradley (1982) examined the effectiveness of an experimental protocol with respect to AT estimation and determination of $\dot{V}O_{2\max}$. Twenty male subjects were tested on a treadmill using a modified Balke protocol and then given two experimental GXTS on two occasions. Workloads were adjusted each minute according to the subject's cardiovascular response. AT detection was estimated

as the point at which $\dot{V}_E$ became nonlinear to the exercise level. The subject's mean AT when expressed as a percentage of the peak $\dot{V}O_2$ was 58.1, 48.2, and 53.6. It was found that a significant increase in R occurred near the predicted AT for the Balke and the second GXT. Bradley concluded that one minute intensity workloads provide more data points, thus, allowing for easier detection of AT and $\dot{V}O_{2\max}$.

Normative Values of AT for Adults

AT Levels in Healthy Subjects

In recent years, there has been much controversy among researchers over defining and identifying AT. Davis et al (1979) defined AT as the highest oxygen uptake beyond which lactate begins accumulating in the blood. Wasserman and others (1973) defined AT as "the level of work or O_2 consumption just below at which metabolic acidosis and the associated changes in gas exchange occur." Based on the physiological parameters, the AT could be identified by the point of a nonlinear increase in $\dot{V}_E$, nonlinear increase in $\dot{V}CO_2$, an increase in end-tidal O_2 without an equivalent decrease in end-tidal CO_2 and an increase in R as the work rate was increased (Wasserman et al, 1973). Hill and Lupton (1923) stated lactic acid was produced when there was inadequate supply of O_2 going to the working muscle which implied hypoxia. However, this hypothesis was questioned by several researchers. Graham (1978) stated blood lactate concentrations may not be indicative of muscle lactate concentrations due to the accumulation rate differences. Davis and co-workers (1976) reported that one limitation to their study was that the criterion measure of the AT which is indicated by an abrupt increase in venous blood lactate above resting levels, is an indirect index of lac-

tate production in the working muscle. Furthermore, it could be argued that the muscle does indeed produce lactate much earlier than what is reflected by the data and that possibly lactate is removed as rapidly as it is produced. As a result, the AT that is observed is a reflection where lactate production exceeds removal.

Researchers have stated that the AT can be most accurately detected from an abrupt increase of arterial blood lactate concentration above resting values during incremental exercise (Naimark et al, 1964, Wasserman et al, 1964, MacDougall, 1979). Astrand and Rodahl (1977) have reported that arterial blood lactate levels start to rise once the $\dot{V}O_2$ reaches 50-60% $\dot{V}O_{2max}$. However, Skinner and McLellan (1980) have reported that once the exercise intensity reaches between 40-60% $\dot{V}O_{2max}$, there is an initial rise in lactate that is twofold. It has also been reported by researchers that the AT occurs between 40-85% of an individual's $\dot{V}O_{2max}$ depending on the mode of exercise, the fitness level of the subject, and the progression of the workloads (Davis et al, 1976, Wasserman et al, 1973, Stamford et al, 1978).

Davis and others (1976) examined the comparability of AT during arm-cranking, leg cycling and treadmill walk-running with thirty-nine male subjects. It was reported that the AT for arm-cranking, leg cycling and treadmill walk-running occurred at mean values of 46.5%, 63.8% and 58.6% of $\dot{V}O_{2max}$, respectively. There were no significant differences in AT detection for cycling and walking in relation to $\dot{V}O_2$, whereas arm-cranking resulted in a lower level for relative AT $\dot{V}O_{2max}$. In contrast, Wisewell et al, (1979) reported the AT for cycling and treadmill running occurred at 69.4% and 74.5% of $\dot{V}O_{2max}$, respectively,

and concluded that AT may be exercise modality dependent.

Ekblom et al (1968), Costill (1970) and Nagle et al (1970) reported that the AT occurs approximately 50%, 75% and 85% of $\dot{V}O_2$ max in the untrained subject, the active non-endurance athlete and the highly trained athlete, respectively. MacDougall (1979) had similar finding to the above mentioned. It was found that the AT for the endurance athlete and the non-endurance group occurred at a mean value of 85% and 70% of $\dot{V}O_2$ max, respectively.

Weltman and Katch (1979) determined the onset of lactic acidosis on thirty-one male subjects using a friction-type bicycle ergometer. The level of lactic acidosis occurred at a mean value of 59.5% of $\dot{V}O_2$ max. This finding is in contrast to the findings of Naimark et al (1964) and Wasserman et al (1973) who reported a lower $\dot{V}O_2$ -AT level. It was concluded by Weltman and Katch that the difference is due to the different $\dot{V}O_2$ max and fitness level of the subjects.

Davis et al (1979) investigated AT alterations caused by endurance training in nine sedentary middle-aged men. Two incremental tests in which the work rate was increased 15 Watts each minute to the limit of the subjects' tolerance was performed to determine test-retest reliability of the AT. To discern the subject's AT, an increase in ventilatory equivalent for $\dot{V}O_2$ without an increase in the ventilatory equivalent for CO_2 and an increase in end-tidal PO_2 (Pet_{O_2}) without a decrease in Pet_{CO_2} were utilized. It was concluded that $\dot{V}_E/\dot{V}CO_2$ was easier to discern than the rise in Pet_{O_2} . Davis and others reported a correlation coefficient of 0.91 for pre- and post-training AT measurements.

AT Determination in CHD Patients

There are limiting studies pertaining to the determination of AT in CHD subjects. An early study conducted by Harrison and Pilcher (1930) illustrated that patients with heart failure developed metabolic acidosis and a higher R value at a lower work rate than normal subjects. The higher R value during exercise was attributed to the excess CO_2 from bicarbonate.

Wasserman et al (1964) examined patients with different types of heart disease and reported that the possibility of AT detection was dependent on the severity of the disease. The severity of the disease may limit the subject's exercise performance. Patients with less severe symptoms had a higher threshold as a result of increased exercise tolerance. The measurement of R during an exercise test can be used to detect abrupt measures in anaerobic metabolism because of the cardiovascular failure to supply the tissues with the needed oxygen.

Wasserman et al (1973) reported that subjects with limited cardiovascular function have higher lactate levels than normal subjects at comparable fraction of peak $\dot{V}\text{O}_2$. Therefore, it was concluded that CHD subjects are often unable to even exercise at a moderate walking intensity without developing lactic acidosis.

Smith et al (1979) studied seventeen cardiac patients and reported AT occurrence at a mean value to be equivalent to an O_2 uptake of 1.34 $\text{liters}\cdot\text{min}^{-1}$. The subject's AT levels ranged from .79 $\text{liters}\cdot\text{min}^{-1}$ to 2.13 $\text{liter}\cdot\text{min}^{-1}$. According to Smith et al (1979) and Glover (1981), these values are substantially higher than those findings reported by

Wasserman et al (1964) who reported the AT levels at $.72 \text{ liter} \cdot \text{min}^{-1}$. Smith reported that the higher values may be attributed to the following reasons. First, subjects of Wasserman and McIlroy (1964) suffered from mitral valve stenosis and congenital heart defects. The subjects in the present investigation were selected on the basis of myocardial infarction and/or coronary artery bypass surgery. Presently, there has been limited research conducted on subjects with these cardiovascular complications and its relationship to AT. Secondly, the subject's fitness level in the Wasserman and McIlroy study was unknown. However, the subjects in the Smith study had completed three months or six months participation in a rehabilitation program which may alter the subject's AT.

Glover (1981) examined twenty patients from the Wake Forest Cardiac Rehabilitation Program, and reported the mean values for the subject's AT was $1.33 \text{ liters} \cdot \text{min}^{-1}$. It was further noted that the individual ranged from $.86 \text{ liters} \cdot \text{min}^{-1}$ to $1.90 \text{ liters} \cdot \text{min}^{-1}$ which were significantly higher than the findings of Wasserman et al (1964).

Validity and Reliability of Perceived Exertion as an Indicator of Exercise Intensity

It is the objective of the researcher to substantiate the reliability that the rate of perceived exertion can be used as a primary indicator to help determine the individual's exercise prescription. Studies have indicated that perceptual cues serve as the primary information source in physical performance (Borg et al, 1974, Gamberale, 1972, Ekblom et al, 1971, Stamford, 1976). Also literature states that perceptual cues help individuals regulate work intensity which are compatible with objectives and goals for that activity (Borg et al, 1974).

Borg et al (1974) and Ekblom et al (1971) stated that individuals evaluate their perceived exertion during exercise from two sources: a local or general feeling of fatigue or strain in working muscles, and a central factor where dyspnea, palpations of the heart and specific sensations such as muscles and joint pain are present. The factors related to the differential influence of local or central ratings of perceived exertion is attributed to the muscle mass involved in the task. In work with small muscle groups, the local factors seem to be prevalent, however, work with large muscle groups appear to stress the pulmonary ventilation and circulation (Ekblom et al, 1971).

The literature has suggested that there is a causal relationship between HR and RPE. Borg et al (1974) stated that ratings of perceived exertion gave a very high correlation with absolute HR ($r=.85$) when work was varied from light to heavy. However, when the workload remained constant, the correlations ranged from .20 to .50. The RPE scale was constructed to follow HR for work on the bicycle ergometer for healthy middle-aged men (Borg et al, 1974).

Several psycho-physical studies have been investigated to explain the variation in perceived exertion with workload duration, sex differences, body weight, kinds of movement and exercise modality. Ekblom and Goldbarg (1971) studied the relationship between HR and RPE after it had been experimentally changed. They also examined the relationship between HR and RPE when comparing different types of exercise (i.e., cycling, swimming, and running). Nineteen healthy male subjects, between 21-32 years old, participated in this study. Ekblom and Goldbarg have stated several conclusions. First, there is a good correlation

when work is performed with smaller muscle groups as well as with larger muscle groups in running, swimming as well as cycling. Second, the relationship between HR and RPE can be significantly altered when the influence of the autonomic nervous system on the circulation is blocked. It was reported that the RPE for a given HR can vary from 8-15 points after atropine or propranolol has been administered. Third, the comparison of cycle ergometry and running resulted in the RPE for a given submaximal O_2 uptake or HR is higher for cycling than running. However, when RPE is related to relative O_2 uptake, RPE will be the same. One explanation for the higher RPE and HR during cycling is due to the more static work performed in cycling as opposed to running. Consequently, the RPE score for submaximal work may result because of the higher blood lactate concentration causing more local strain. Finally, in the physical training experiment, RPE for a given submaximal level was significantly lower indicating that there is a lesser strain on the cardiorespiratory system and improvement in muscular function.

Previous studies have indicated that the use of ratio scaling methods for work on a cycle ergometer increases as the intensity increases. Gamberale (197²) investigated the relationship between perceived exertion and heart rate during exercise that involved different muscle groups. Twelve male subjects participated in this study. The exercise session consisted of lifting weights, pushing a wheelbarrow and cycling on the bicycle ergometer. It was reported that there is a linear relationship between RPE and HR independent of the kind of work producing the physical strain. Exercise on the cycle ergometer corresponded very closely to one tenth of the HR as discussed by Borg et al

(1974). However, in the weight lifting and wheelbarrow pushing, rating of perceived exertion was higher than the cycling. Gamberale hypothesized that this could be attributed to the higher lactate concentration as compared to the oxygen uptake which produced higher overall levels of perception of exertion levels.

With the increase in popularity of using perceptual ratings during exercise, Skinner et al (1973) and Stamford (1976) examined the validity and reliability of the Borg scale under various conditions. Skinner et al and Stamford reported correlations of .78-.80 and .90, respectively. Skinner tested the reliability of Borg's scale using 8 lean and 8 obese male subjects. The subjects were given 2 trials using progressively increasing and randomly assigned work loads. In the progressive test, each subject started exercising at 150 kgm/min during the first 2 minutes. The work load was increased 150 kgm/min, thereafter, until the subject reached maximum. During the random test, the subject started exercising at 150 kgm/min for 2 minutes and the workload was increased randomly to 300, 450, 600, 750, or 900 kgm/min for a 4 minute duration. During the final 20 seconds of each test, HR and respiratory frequencies were recorded and the subject was instructed to rate the intensity of the exercise. Skinner and associates reported that subjects could perceive small differences on the cycle ergometer and there were no significant differences in the physiological or perceptual variables. The progressive test seemed to offer higher reliability and validity than the random test and it was also stated by Skinner and others that the progressive test takes less time.

In Stamford's study (1976), fourteen sedentary females performed

work tasks which included treadmill walking, jogging, cycling and stool-stepping. Heart rate was measured at regular work intervals and RPE responses were recorded at regular intervals (i.e., every minute or every two minutes) or during the final minute of work. During the bicycle work, the test-retest reliability was high ($r=.76$). During the treadmill running and walking, the correlations for RPE were .74 and .79, respectively. The stool-stepping exercise also demonstrated a high reliability of .76. Stamford noted that there was a higher correlation of RPE responses when the subject was asked to rate the work in the final minute of the workload ($r=.76$). Stamford, therefore, concluded that the RPE scale is a valid and reliable instrument for assessing stress during exercise.

In previous studies, it has been stated that there is a linear relationship between HR and RPE during exercise regardless of the modality (Gamberale, 1972, Ekblom et al, 1971). However, there is some concern if heat influences these two variables. Noble et al (1972³) examined the physiological parameters that would influence RPE in heated and neutral environments. Six male subjects were required to pedal a cycle ergometer for 30 minutes at 60 rpm during 3 trials at temperatures of 24 degrees centigrade and 2 trials at 44 and 54 degrees centigrade. Perceived exertion, HR, $\dot{V}_E$, respiratory rate, $\dot{V}O_2$, $\dot{V}CO_2$, RQ, rectal and skin temperatures were recorded at 5, 15, and 30 minutes during each trial. Perceived exertion continued to rise during both conditions, however, the physiological parameters resulted in a steady state at 15 minutes. The physiological parameters showed a linear increase to the workload.

Skinner and others, (1972³), examined the perception of effort during exercise on the cycle ergometer and treadmill. Eight lean and 8 obese male subjects participated in the study. The subjects were tested twice on each apparatus at temperatures of 24 degrees centigrade and 32 degrees centigrade for the cycle ergometer and treadmill, respectively. Each lean subject was paired with an obese subject and then given a lead-weight vest to match his counterpart. The subject began exercising at 150 kgm/min and the workload was increased to 150 kgm/min every 2 minutes, thereafter, until the subject reached a self-imposed maximum. During the treadmill test, the subject began walking at 3.5 mph at 0% grade and the grade was increased 2.5% every 2 minutes. During the last minute of each workload, $\dot{V}_E$ and $\dot{V}O_2$ were recorded. The subject was instructed to rate the intensity of the exercise during the final 20 seconds of the workload. Skinner and associates made the following conclusions. First, there was no significant differences in RPE and $\dot{V}O_2$ on the treadmill. On the cycle ergometer, lean subjects reported higher RPE's than the obese subjects. All subjects perceived the bicycle to be harder than that of the treadmill at the same $\dot{V}O_2$. Second, obese subjects were not influenced by the 32 degrees Centigrade environment. Conversely, the lean subjects had higher RPE values at the same $\dot{V}O_2$. Third, when RPE was related to absolute values of $\dot{V}_E$ and $\dot{V}O_2$, there were differences between the lean and obese subjects, but not when related to maximal values. In conclusion, Skinner and others reported that RPE appears to be related to the proportion of maximal capacity.

According to the literature, sex differences in RPE also occur occasionally. Henrikson et al (1972) reported that females perceived

their exertion to be greater than did males both at equal workloads and equal oxygen consumption for eccentric and concentric work. Michael et al (1972) studied 4 male and 4 female subjects to determine physiological responses when each subject rated the effort on the treadmill and bicycle ergometer which would exhaust them in 15 minutes. The men chose work levels that resulted in heart rates and respiratory quotients similar to those of the women, however, the oxygen consumption and oxygen debt was twice that of the female subjects.

There has been much research conducted during the last 15 years regarding the concept of perceived exertion among healthy individuals. However, to broaden the scope of perceived exertion, Ekblom et al (1971) and Gutman et al (1981), studied perceived exertion on heart rate relationships under different conditions. Ekblom and Goldbarg (1971) illustrated that the linear relationship between HR and RPE was altered when the influence of the autonomic nervous system on circulation was blocked. The rate of perceived exertion became unreliable when the subjects were given atropine or propranolol. Gutman and associates (1981) examined the relationship between RPE and HR during graded exercise testing and rehabilitation. Twenty male patients were selected following myocardial revascularization surgery. It was concluded by Gutman and others, that cardiac patients perceive exercise at a given HR in the GXT and training sessions, however, with training and post surgical recovery, the perception of effort shifts to allow the same RPE at higher heart rates and MET levels. It was also noted by Gutman and others that because of the wide variation of maximal heart rates and the patient population, the use of HR to terminate the GXT may be inappropriate. Perhaps a better

indication is the combination of HR and RPE for maximal working capacity.

Summary

The exercise prescription is composed of four components in which the intensity is the most important. The most conventional technique used to determine an individual's exercise intensity is the Karvonen method which is based on heart rate responses. However, Goss et al (1979), Skinner and McLellan (1978), MacDougall (1979) reported that the AT may be more sensitive to the individual's needs. The optimal intensity suggested by Davis et al (1975), Sharkey et al (1967), and Karvonen et al (1957), for stimulating cardiovascular improvement is 60% of the individual's maximal capacity.

In recent studies, Kinderman et al (1979) and Skinner and McLellan (1980) examined the transition from aerobic to anaerobic metabolism. Kinderman and associates suggested the transition between aerobic and anaerobic metabolism occurs between 2-4 millimoles of lactate. Skinner and others identified aerobic threshold as when the blood lactate reached two millimoles and that point where the lactic acid reached four millimoles as the AT.

It has been reported that nonlinear alterations in gas exchange provide a reliable noninvasive method for AT detection. Davis et al (1976) validated this technique and found a correlation of 0.95 between AT measures using respiratory gas measure and venous lactic acid values. Of the gas exchange variables, $\dot{V}_E$ was reported to be the most reliable. However, some current literature suggested $F_{E}O_2$ was reliable to detect AT. One-minute incremental work stages are more conducive in discerning

the AT.

It appears that the AT level is dependent upon exercise modality and the fitness level of the individual. Ekblom et al (1968), the Nagle et al (1970) reported that the AT level occurs at approximately 50%, 75% and 85% in the untrained subjects, the active non-endurance athlete, and the highly trained, respectively. The AT detection in CHD patients depends on the severity of the disease and CHD patients have consistently lower AT's than the normal population. It was also concluded that CHD patients have higher R values at lower exercise intensity levels than ~~that~~ observed for healthy subjects.

Davis and Convertino (1975) validated the Karvonen method and stated that this method was an accurate and practical procedure for determining an individual's exercise intensity. However, it was noted by the researchers that the Karvonen method resulted in an overall prediction of 2.6% above the mean values recorded at various exercise intensities.

Studies have indicated that RPE is a valid and reliable instrument for rating exercise intensity (Skinner et al, 1973, Stamford, 1976). Skinner and Stamford reported a reliability of 0.90 and 0.78-0.90, respectively. There are occasional differences in RPE rating between male and female subjects during exercise. It was observed that cardiac subjects have a higher RPE rating at the same workload intensity than normal subjects.

Chapter III

METHODOLOGY

Subjects

Ten male students, 22-26 years of age enrolled at Virginia Polytechnic Institute and State University volunteered to be subjects for this study. Only those who were physically active, as defined by participation in exercise once or twice weekly but not on a systematic training schedule of regular participation of more than three times a week, became subjects. The activity level of the subjects prior to this study was characterized by their low predicted body fat and their high $\dot{V}O_{2\max}$ levels when compared to the norms of the same sex and age (Pollock et al, 1978). Table 1 summarizes the subjects' physical characteristics. Individual descriptive data can be found in Appendix A.

Prior to the participation in the study, each subject was given a written and oral explanation of this study. All subjects signed a written consent form agreeing to the procedures of the study (Appendix B). It was made clear that participation in the study was totally voluntary and that each subject was free to withdraw from the experiment at any time.

General Method

A screening procedure (ACSM, 1980) was administered to each subject to ensure that subjects might appropriately be maximally exercise tested without significant risk of cardiovascular injury. A graded exercise test (GXT) was administered on the first test day in which the data were collected to determine the exercise prescription. From the subject's GXT, an exercise prescription was calculated by two methods,

Table 1. Physical Characteristics of Subjects

Measure	$\bar{X}$	SD
Age (years)	23.3	± 1.3
Height (cm)	180.4	± 6.6
Weight (kg)	77.9	± 5.3
$\dot{V}O_{2\max}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	59.2	± 5.6
Skinfolds (mm)		
Scapula	12.1	± 3.4
Triceps	11.7	± 3.4
Abdominal (h)	16.1	± 6.2
*Predicted Body Fat (%)	14.1	± 2.5
n=10		

* Percent fat was predicted by a regression equation based on skinfold measurements (Wilmore and Behnke, 1969).

one of which was the Karvonen method (a technique based on heart-rate response). The second method utilized in determining the exercise prescription was the AT method (a technique based on pulmonary responses). After the two exercise prescriptions were determined, the subjects participated in a training simulation task of exercising on a motor driven treadmill for 60 minutes on alternate days. To avoid experimental bias, due to ordering effects, half of the subjects were tested using the Karvonen method on the first day and the remaining subjects were tested using the AT method (Appendix C).

Procedures

Preliminary

Prior to the experimental testing, each subject reported to the Human Performance Laboratory in the War Memorial Gymnasium for familiarization of the test equipment and procedures. Each subject practiced a walk/jog on a Quinton Model 27-74 motor driven treadmill. As the subject adapted to the exercise on the treadmill, speed and grade were changed to simulate conditions of the GXT and the training simulation task. In addition, subjects were introduced to the breathing valve and nose clip that were to be used in connection with the respiratory equipment for $\dot{V}O_2$ determination. All subjects completed a Self-Administered Pre-Exercise Test Medical History Form (Appendix D) and were given pre-test instructions (Appendix E).

GXT Protocol

An approximation of a "ramp" type protocol was used to determination of AT. According to the literature, when workloads are increased in small increments, AT detection may be more easily discerned.

(Davis et al, 1976; Whipp et al, 1981). Each subject started at an initial load of 4 METS and the increments were increased by 0.33 METS every 20 seconds until termination of the test. The change of the workloads every 20 seconds helped in discerning AT.

Sampling of Dependent Measures During GXT

During the GXT, expired $F_E\text{CO}_2$ and $F_E\text{O}_2$ were recorded every 20 seconds. The expired gases entered a low resistance baffled mixing chamber of which the total volume was 4.57 liters. Two pieces of flexible plastic tubing (I.D. = $1\frac{1}{4}$ ") were connected, one to the inspired and the other to the expired side of a Daniel's breathing valve. The plastic tubing on the inspired side was connected to a Parkinson-Cowan CD-4 gas meter (Instrumentation Associates, Inc., New York, New York). The $F_E\text{O}_2$ and $F_E\text{CO}_2$ were measured continuously and values in the last 5 seconds were accepted as representing the responses for that 20 second period. The expired CO_2 and O_2 were measured with a Beckman Model LB-2 CO_2 analyzer and a Beckman Model OM-11 O_2 analyzer. Ventilation was measured every 20 seconds using the Parkinson-Cowan CD-4 dry gas meter during continuous exercise.

The analyzers were calibrated with standard gases verified by Haldane analysis. During the GXT and training simulation task, the analyzers were calibrated prior to, during and at the conclusion of each test. The Parkinson-Cowan CD-4 gas meter and treadmill were calibrated prior to testing.

Electrodes were mounted on the chest of each subject (CM_5 lead) for measuring heart rate via the electrocardiogram (ECG). Electrocardiograms were recorded at rest (2 minute supine), exercise (every

20 seconds), and recovery (6 minutes) using the Hewlett-Packard one channel system. The ECG was continuously monitored by an oscilloscope. Blood pressure was measured by auscultation with a mercury manometer at every odd minute. The rate of perceived exertion (RPE) were recorded every even minute using Borg's Scale (Borg, 1969).

Karvonen Exercise Prescription Procedure

To determine the intensity for one of the two experimental training simulation sessions, the individual's cardiac reserve (cardiac reserve $HR_{\max} - HR_{\text{rest}}$) was determined. The resting heart rate value was determined by recording a ten second ECG strip after the subject rested in a supine position for two minutes. The maximum heart rate was accepted as the highest rate attained during the GXT.

As indicated in the previous literature, (Karvonen et al, 1957; Sharkey et al, 1967), a training intensity of approximately sixty percent of the individual's maximal aerobic capacity is needed for an individual to receive cardiorespiratory improvement. The training heart rate was determined by taking a predetermined percentage (65-75%) of the individual's cardiac reserve (Appendix F).

Anaerobic Threshold Exercise Prescription Procedure

From the subject's GXT, a noninvasive method ($\dot{V}_E$) was used to estimate AT. A microcomputer (Apple II Plus - 48K) was used to objectively and graphically display the estimated AT. This technique also required utilization of a Curve-Fitter Software Program developed by Paul K. Warne (1980). A polynomial least square curve fitting software routine was selected to produce regression models of $\dot{V}_E$ on exercise time. From the GXT, the bivariate distribution of $\dot{V}_E$ versus exercise time was sub-

mitted to regression analyses to determine the lowest order polynomial to "best" predict the function (i.e., maximum r and minimum $s_{y \cdot x}$). Next a series of linear regressions were computed wherein each bivariate point was deleted until the highest r and lowest $s_{y \cdot x}$ was determined. The regression models from the two previous steps were overlaid graphically to objectively reveal the point where there is a nonlinear increase in $\dot{V}_E$. This point was defined as the AT and was equated with the corresponding heart rate obtained from the GXT (Appendix G).

The training heart rate was derived from the AT exercise prescription. The upper limit of the exercise intensity was derived at the point where the AT occurred. From that point, the lower limit was determined below the AT by subtracting the same number of beats which was represented in the Karvonen exercise prescription.

Procedure to Obtain Unbiased Exercise Prescription

To avoid experimental bias, a schedule of testing for the timing simulations was developed by an individual other than the researcher to assign half of the subjects on the first day using the Karvonen method and the remaining subjects using the AT method. Subsequently, this schedule was given to an assistant who administered the prescribed training intensity (i.e., speed and grade) and had knowledge of the training heart rate for each subject during the two methods.

Training Simulation Task

There were three phases in the training simulation task: the warm-up period (5 minutes); the exercise stimulus period (60 minutes); and the cool-down period (5 minutes). Each subject warmed-up by walking at 4 METS to gradually increase his heart rate to the prescribed training

intensity. The subject was then instructed to exercise (running was encouraged) on the treadmill for 60 minutes at a constant grade (2%) and speed. This grade and speed were calculated from the subject's $\dot{V}O_2$ level in the GXT which represented the median of his training heart rate zone and were derived from tables published by the American College of Sports Medicine (1980). Termination of the exercise session resulted from the participant's own volition or the termination criteria stated in Appendix K. The cool-down period consisted of decreasing the treadmill to a slow walking speed. Following the cool-down period, the subject was asked to lie in a supine position on the cot adjacent to the treadmill. Post-exercise heart rates and blood pressures were recorded at every odd and even minute, respectively, until the subject's heart rate was below $100 \text{ bts} \cdot \text{min}^{-1}$ and blood pressure had returned to baseline measurements.

Data Analysis

In this study, AT was interpreted as the point beyond which there was a nonlinear rise in $\dot{V}_E$, as described by Skinner and McLellan (1980). A microcomputer was utilized to graphically display variables ($\dot{V}_E$ versus time) which objectively revealed the predicted AT. In order to validate the predicted AT's, an attempt was made to evaluate the physiological responses that occurred during exercise levels near the AT. As the subject reached his AT, it was expected that a disproportionate increase in $\dot{V}CO_2$ would occur when anaerobiosis was reached (Wasserman et al, 1973). Subsequently, this increase in $\dot{V}CO_2$ should be reflected by an increase in R values. Therefore, R values were analyzed two METS below the AT and two METS above the AT during the GXT. A one-way ANOVA was used to analyze the R values represented by these exercise levels.

The main objectives of this study were to determine if there were significant differences in the subject's ability to perform exercise at a prescribed level using the Karvonen and AT prescription methods or in the durations to fatigue when exercise was performed at these same two prescriptive levels in the simulation trials. Dependent t-tests were administered to determine whether responses for the following variables differed significantly in the training simulation trials ($p \leq .05$):

- (a) the duration that the prescribed training heart rate was maintained at steady-state;
- (b) the level of oxygen uptake evidenced during the exercise period in which the prescribed heart rate was maintained;
- (c) the duration that exercise was maintained before fatigue was expressed;
- (d) maximal heart rate attained at the point of fatigue;
- (e) the level of respiratory exchange that was maintained before fatigue was expressed;
- (f) the subject's rating of perceived exertion of the intensity during either the duration of steady-state exercise or the duration to fatigue.

Summary

The purposes of this study were twofold. First, it was desired to determine if there were significant differences in the subject's ability to sustain steady-state exercise at a prescribed level using the Karvonen and AT methods. Second, the researcher wanted to determine whether significant differences existed in the subjects' capacity for continuous exercise using the two exercise prescription methods. Descriptions of

the two exercise prescription procedures and training simulation tasks were presented. The subjects' AT's were determined objectively during graded exercise testing through analysis of $\dot{V}_E$ - exercise intensity response curves by the utilization of a Curve-Fitter program (Warne, 1980). The following variables were evaluated with dependent t-tests during the training simulation tasks: duration that the prescribed heart rate was maintained; $\dot{V}O_2$ during the steady-state; duration that exercise was maintained before fatigue; maximal heart rate attained at the point of fatigue; R values during exercise before fatigue was expressed; and the subjects' rating of perceived exertion during either the steady-state exercise or the duration of fatigue. A one-way ANOVA was employed to determine if there were significant increases in R values near the exercise level where anaerobic metabolism had occurred.

Chapter IV

RESULTS

The purposes of this study were to determine if differences existed between the steady-state and capacity of subjects to sustain exercise at a prescribed level using the Karvonen and AT exercise prescription methods in young healthy male adults. To perform this, the data were analyzed in several ways. First, a series of dependent t-tests were performed to determine if, during exercise at the prescribed training heart rate, the individual's exercise duration, $\dot{V}O_2$, and RPE values differed between the two exercise prescription methods. Secondly, another series of dependent t-tests were utilized to determine if there existed significant differences in the subject's capacity to perform continuous exercise in the maximal heart rate attained at the fatigue point, or in the respiratory exchange and RPE values measured during the two different training simulation trials.

To reiterate the general approach of this study, each subject was administered a GXT on the first test day in which data were collected to determine the exercise prescription. Subsequently, the subject's exercise prescription was derived from this test utilizing the Karvonen and AT methods. Next, the subjects participated, on alternate days, in an exercise training simulation task on a motor driven treadmill.

Result Presentation of Data Analysis Procedure

In an attempt to validate the two exercise prescription methods, the data were analyzed by various procedures. First, the researcher wanted to determine if the subjects' responses indicated a $\dot{V}O_{2\max}$. The importance of this procedure is related to the verification that the

subject attained a $\dot{V}O_{2\max}$. If this could not be determined, then an appropriate exercise prescription would be calculated using the Karvonen method. To verify $\dot{V}O_{2\max}$, the $\dot{V}O_2$ ($\text{ml}\cdot\text{min}^{-1}$) changes between the last two workloads were computed for each subject. The results were considered value if the $\dot{V}O_2$ ($\text{ml}\cdot\text{min}^{-1}$) change between the last two workloads were equal to or less than $150 \text{ ml}\cdot\text{min}^{-1}$. In a further attempt to verify attainment of $\dot{V}O_{2\max}$, two additional ranges were implemented. If the subject's $\dot{V}O_2$ change during the last two workloads was between $150 \text{ ml}\cdot\text{min}^{-1}$ to $300 \text{ ml}\cdot\text{min}^{-1}$ and more than $300 \text{ ml}\cdot\text{min}^{-1}$, the test result was termed borderline and indiscriminate, respectively.

To further validate the Karvonen method, some appraisal of the subject's accepted resting heart rate was needed. If the accepted resting heart rate was incorrect, an inappropriate exercise prescription could result. This procedure consisted of averaging the subject's resting heart rate during the three test days.

As it was previously explained in Chapter III, a regression technique was utilized to predict the $\dot{V}_E$ breakaway point. This procedure was an objective method to determine the subject's $\dot{V}_E$ responses to exercise. However, additional procedures were developed to further strengthen the determination of AT. First, the researcher subjectively observed the $\dot{V}_E$ response during the subject's GXT and determined if there was an apparent $\dot{V}_E$ breakaway point. Secondly, a one-way analysis of variance was utilized to determine if the R exchange values in the vicinity of the AT (i.e., 5 levels) were significantly different. This significance would suggest a level of sudden increase in anaerobic metabolism, thus, suggesting that the AT did occur. Following this procedure, a series

of dependent t-tests were utilized to determine if a significant difference existed between the duration of exercise that subjects could maintain their steady-state heart rate levels as prescribed by either the Karvonen or AT methods. The parameters that were analyzed were the subject's exercise time at the prescribed heart rate intensity, $\dot{V}O_2$ and RPE. In addition, the subject's capacity to perform continuous exercise was analyzed. A series of dependent t-tests were performed on the following variables: the subject's capacity for continuous exercise before expressed fatigue, maximal heart rate values, R exchange values, and RPE values.

Validity of GXT Measurements for Exercise Prescription

To validate the Karvonen method, determination of $\dot{V}O_{2\max}$ was computed by examining if changes occurred in absolute $\dot{V}O_2$ ($\text{ml} \cdot \text{min}^{-1}$) between the last two workloads. These values were then placed in either acceptable ($0\text{--}150 \text{ ml} \cdot \text{min}^{-1}$ change), borderline ($150\text{--}300 \text{ ml} \cdot \text{min}^{-1}$ change) or indiscriminate ($> 300 \text{ ml} \cdot \text{min}^{-1}$) categories. As can be seen in Table 2 five subjects reached valid $\dot{V}O_{2\max}$ values, two subjects were categorized as borderline, and three subjects had indiscriminate results. The subjects' $\dot{V}O_{2\max}$ ranged from 53.71 to 70.22 $\text{ml} \cdot \text{kg} \cdot \text{min}^{-1}$ with a mean value of 59.20 ($\text{SD} \pm 5.55$; Table 1). To enhance the accuracy of the Karvonen exercise prescription method, the subjects' resting heart rate values were averaged. The subjects' mean resting heart rate values were accepted as 68, 67, and 68 $\text{bts} \cdot \text{min}^{-1}$ during the three testing sessions (Table 3).

To validate the AT exercise prescription method, a subjective procedure was designed to observe the variability of the subject's $\dot{V}_E$

Table 2

Determination of $\dot{V}O_2$ max (Change between last two workloads
in milliliters of absolute O_2 consumption) during the GXT

Valid 0-150	Borderline 150-300	Indeterminate 300 and above
5	2	3

Table 3
Subjects' Resting Heart Rate During Testing

Subject	Resting HR During GXT (bts·min ⁻¹)	Resting HR During Test 1 (bts·min ⁻¹)	Resting HR During Test 2 (bts·min ⁻¹)
1	85	85	75
2	57	60	57
3	71	71	74
4	65	62	60
5	54	56	54
6	76	72	75
7	68	64	67
8	77	70	74
9	60	60	75
10	67	65	65
X	68	67	68
SD	±9.6	±8.4	±8.2

response during the GXT. As indicated in Table 4 and 5, all subjects produced homogenous $\dot{V}_E$ response curves and discernable $\dot{V}_E$ breakaway points. To further verify the AT exercise prescription method, the increase in R value between exercise levels two and one MET below and above the AT was found to be statistically nonsignificant (Table 6). The subject's individual R values can be seen in Appendix H. As can be seen in Table 7 and 8, the Karvonen and AT methods yielded very similar exercise prescription heart rates for exercise training intensities and measured $\dot{V}O_2$ ($\text{ml} \cdot \text{kg} \cdot \text{min}^{-1}$). The measured AT values for the subjects when expressed as a percentage of $\dot{V}O_2$ peak averaged 65.3% (SD, $\pm 5.8\%$) with a subject range of 59.5 to 77.2%.

Analysis of Exercise Performance and Responses During Maintenance of Steady-State

To assess the efficacy of the two prescription methods, the exercise time in the training simulation at the prescribed heart rate and intensity was analyzed. The subjects exercised significantly longer (AT method = 29 minutes, Karvonen = 16:42 minutes) at the prescribed heart rate intensity using the AT method (Table 9). To further ascertain if a difference existed between the two exercise prescription methods, the subject's $\dot{V}O_2$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) was analyzed. As can be seen in Table 10, there was no significant difference between the two methods with respect to the $\dot{V}O_2$ maintained during the steady-state exercise prescription. The $\dot{V}O_2$ values for the Karvonen and AT methods were 40.03 and 37.80 $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, respectively. Lastly, there were no significant differences in the subject's rate of perceived exertion (RPE) between the two exercise prescription methods (Table 11).

Table 4

Subjective Assessments of $\dot{V}_E$ Response Curve Patterns in GXT

Heterogenous Response Curve	Homogenous Response Curve
0	10

Table 5

Experimentor's Subjective Estimation of $\dot{V}_E$ Response
Curves and $\dot{V}_E$ Breakaway Point

Apparent	Non-Apparent
10	0

Table 6
Results of ANOVA for R Between Exercise Levels

Source	Sum of Squares	DF	Mean Squares	F Ratio
Between	.08	4	.02	4.59
Within	.20	45	4.54	6.00

$F_{.05} = 5.71$ $df = (4,45)$

Table 7
Exercise Intensities Computed for the Two
Exercise Prescription Methods

Subject	Karvonen Method	AT Method
1	166-179	157-170
2	145-159	136-150
3	155-168	153-166
4	144-156	146-158
5	134-146	130-142
6	148-159	153-164
7	154-167	164-177
8	156-168	146-158
9	151-165	153-167
10	153-167	160-174
$\bar{X}$	151-163	150-162
SD	$\pm 8.6-8.8$	$\pm 10.5-10.8$

Table 8

Mean Values for Measured $\dot{V}O_2$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)

During Training Simulations

Exercise Prescription Method	$\bar{X}$	SD	t-ratio
Karvonen	37.02	± 3.09	
AT	36.15	± 3.58	1.32

Critical t-ratio_{.05} = 2.26 df = 9

Table 9

Results of Dependent t-test for Exercise
Time at the Prescribed Heart Rate Intensity

Method	$\bar{X}$ (min)	SD (min)	t-ratio
Karvonen	16:42	± 17:30	
AT	29:00	± 22.09	
			2:50*

* a significant @ .05 (t-ratio = -2.48, df = 9)

Critical t-ratio_{.05} = 2.26

Table 10

Results of Dependent t-test for $\dot{V}O_2$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)
 During the Prescribed Heart Rate Intensity

Method	$\bar{X}$	SD	t-ratio
Karvonen	40.03	± 3.90	
AT	37.80	± 5.40	
			1.32

Critical t-ratio_{.05} = 2.26 df = 9

Table 11
Results of Dependent t-test for RPE at
the Prescribed Heart Rate Intensity

Method	$\bar{X}$	SD	t-ratio
Karvonen	10.2	± 2.1	
AT	10.7	± 1.8	
			- .512

Critical t-ratio_{.05} = 2.26 df = 9

Analysis of Performance and Responses to Fatigue Point

To further compare the Karvonen and AT methods, data were analyzed with respect to the subject's capacity to perform continuous exercise during the two training simulation tasks. As seen in Table 12, the subject's mean time for continuous exercise was 47.20 and 50.40 minutes utilizing the Karvonen and AT methods, respectively. These values were not significantly different. To further substantiate intensity levels of the two exercise prescription methods, and the subjects' capacity to perform continuous exercise, R values were analyzed. The data indicated that no significant difference for R existed between the two methods. The mean R values during the training simulation task were .96 and .98 utilizing the Karvonen and AT methods, respectively (Table 13). The highest heart rate attained near the time exhaustion in the two training simulation tasks was 179.3 and 174.0 $\text{bts} \cdot \text{min}^{-1}$. This difference was statistically significant (Table 14). RPE values were also assessed in the two training simulations. No significant difference was found between the two exercise prescription methods with respect to mean RPE values, and these values were 13.2 and 12.1 for the Karvonen and AT methods, respectively (Table 15).

Summary

It was the purpose of this study to determine if differences existed between the duration of steady-state exercise and capacity to sustain exercise at a prescribed level using two different exercise prescription methods (i.e., Karvonen and AT methods). In order to examine these two methods, subjects participated on different days, in two training simulation tasks comparing exercise duration and responses at exercise

Table 12
Results of Dependent t-test for Duration
of Continuous Exercise

Exercise Prescription Method	$\bar{X}$ (min)	SD (min)	t-ratio
Karvonen	47.20	± 13.05	
AT	50.40	± 11.07	
			-.68

critical t-ratio_{.05} = 2.26 df = 9

Table 13
Results of Dependent t-test for R During
Training Simulation Tasks

Exercise Prescription Method	$\bar{X}$	SD	t-ratio
Karvonen	.96	± 0.04	
AT	.98	± 0.06	
			-.97

Critical t-ratio_{.05} = 2.26

df = 9

Table 14
Results of Dependent t-test for Maximum
Heart Rate Attained During Training Simulation Task

Method	$\bar{X}$ (bts·min ⁻¹)	SD (bts·min ⁻¹)	t-ratio
Karvonen	179.3	± 17.3	
AT	174.0	± 17.0	
			-2.32*

*a significant @ .05 (t-ratio = -2.32, df = 9)

Critical t-ratio_{.05} = 2.26

Table 15
Results of Dependent t-test for RPE During
the Training Simulation Tasks

Method	$\bar{X}$	SD	t-ratio
Karvonen	13.2	± 1.7	
AT	12.1	± 1.8	
			0.83

Critical t-ratio_{.05} = 2.26 df = 9

intensities derived from the Karvonen and AT prescription methods. A series of dependent t-tests were used to test the hypotheses. The data indicated that a significant difference did exist between the two exercise prescription methods with respect to the duration of exercise at a prescribed heart rate intensity.

The subjects' duration of maintaining a steady-state was substantially longer utilizing the AT method. There were no significant differences found in oxygen uptakes or RPE values in the steady-state periods during the training simulations. In terms of the subjects' capacity to perform continuous exercise during the training simulation tasks based on intensities derived from the two exercise prescription methods, a significant difference was found in the maximal heart rates attained with a higher value observed at the conclusion of the Karvonen based training simulation task. No significant differences were found in the time to expressed fatigue, or in R values and RPE responses in the two trials.

Chapter 5

DISCUSSION

This chapter contains a discussion of the results, interpretation, implications, conclusions, and recommendations. In addition, the researcher specifically addressed the following areas: validity of data base for Karvonen and AT exercise prescription methods, performance validation of exercise prescriptions with respect to exercise performance within prescribed level and subjects' capacity to perform continuous exercise.

Subjects

In an attempt to test the research hypotheses, subjects were selected on the basis of their physical activity level. For comparison of the two exercise prescription methods, it was important to select subjects who were physically active to increase the probability that they would be able to exercise longer than sedentary subjects. However, it was equally important that the subjects were not participating in systematic endurance training more than three times a week. This would limit the generalizability only to that particular population level. Therefore, during the screening process, subjects were interviewed to determine their activity level and to determine their health status to reduce the amount of risk that could be incurred (See Appendix D). All subjects participating in this study were classified as physically active subjects. The various activities that the subjects participated in were officiating, jogging, soccer, tennis, cycling and swimming. Subsequently, the subjects that were selected for this investigation were physically active as evidenced by their relatively

high mean $\dot{V}O_{2\max}$ level and their low predicted body fat. The subjects' mean $\dot{V}O_{2\max}$ was $59.2 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ which is extremely above average for their age (Pollock et al, 1978). The subjects' predicted body fat was 14.1% which is below the average for the same sex and age category (Pollock et al, 1978). Since the subjects appeared to represent a physically fit level in terms of $\dot{V}O_{2\max}$ and predicted body fat, it was appropriate that generalizations be addressed to young, healthy, physically active male individuals.

Validity of Graded Exercise Data Base for Exercise Prescription

In an attempt to validate the two exercise prescription methods, the data (i.e., $HR_{\max}$, HR_{rest} , and AT) derived from the GXT were examined. The purpose of validating the measurements recorded during the GXT was to assess the accuracy of the exercise prescription. The first parameter that was examined was attainment of $\dot{V}O_{2\max}$. If this parameter could verify that the subject attained a maximal effort during the GXT, then it would be safe to accept the subjects' highest heart rate as his true maximal heart rate. As previously mentioned, if the subjects' $\dot{V}O_2$ change between the last two workloads were equal to or less than $150 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, then the highest $\dot{V}O_2$ was accepted as the $\dot{V}O_{2\max}$. If the subject's $\dot{V}O_2$ change between the last two workloads was between $150 \text{ ml}\cdot\text{min}^{-1}$ to $300 \text{ ml}\cdot\text{min}^{-1}$ or more than $300 \text{ ml}\cdot\text{min}^{-1}$, the test result was termed borderline and indiscriminate, respectively. According to this validation criteria, five subjects reached a valid $\dot{V}O_{2\max}$, two were classified as borderline and three were termed indiscriminate. There may be a possible explanation for this finding; Although this is speculative, it could be measurement error in the gas

analyzers and the subjects did reach a plateau and attained their maximal heart rate. However, the gas analyzers were calibrated before and between the testing sessions using standard gases and were assumed correct. Therefore, it may be concluded that only five subjects attained a maximal heart rate according to the above mentioned criteria. To further assess if the subjects reached a $\dot{V}O_{2\max}$, the subjects' heart rate was observed during the last three minutes of the GXT to determine if the heart rate reached a plateau. It has been suggested in the literature that the heart rate will plateau although the workload continues to increase (Astrand & Rodahl, 1977). The data indicated that subjects' heart rate did plateau, thus, indicating that the highest heart rate during the GXT was the subjects' maximal heart rate.

It has also been stated that age-predicted HR values will allow for estimating an individual's maximal heart rate ($SD \pm 10 \text{ bts} \cdot \text{min}^{-1}$) (Pollock et al, 1978). The procedure is determined by subtracting the subject's age from 220. This value gives an approximation of the individual's maximal heart rate. Eight subjects attained their max HR according to the criteria mentioned. Of the remaining two subjects, both subjects recorded peak exercise heart rates which were 10 and 20 beats under the age predicted values.

Finally, when observing the subjects' performance and the rate of perceived exertion during the GXT, it appeared that the subjects' experienced fatigue and termination of the test was of the subjects' own volition. Eight subjects perceived the intensity as very hard (18 on Borg's scale) while the remaining two described the intensity above hard (16 on Borg's scale). Therefore, according to the following criteria:

$\dot{V}O_2$ validation; age-predicted heart rate values; subject observation of subjects' performance; and rate of perceived exertion during the GXT, it may be accepted that eight subjects obtained a true maximal heart rate.

To accurately assess the Karvonen exercise prescription, the resting heart rate was examined during the three testing sessions to verify that the resting heart rate prior to the GXT was valid. The data indicated that there was a one beat difference during the testing sessions. Therefore, it was concluded that the subjects' resting heart rate used in the Karvonen exercise prescription method was accurate.

It appears that the regression technique utilized in the determination of AT in this study is an objective method. The variable used ($\dot{V}_E$) to determine the AT has been utilized by other researchers and was found to be a reliable indicator of the onset of metabolic acidosis (Davis et al, 1976, Wasserman et al, 1973). As previously mentioned, Davis and associates (1976) found a very high correlation ($r = .95$) between the gas exchange AT measurements when compared to blood lactic acid measurements. Also, it was stated by Davis and co-workers that $\dot{V}_E$ alone yielded a high correlation of .88 when compared to work-rates and $\dot{V}O_2$, therefore, $\dot{V}_E$ as used in this study was accepted to be a valid AT measurement. However, in contrast, Davis and co-workers indicated that one limitation to their study of gas exchange measurement as a criterion measure of AT was that venous blood lactate above resting levels is only an indirect index of lactate production by the working muscle. Perhaps, the muscle begins to produce lactate much earlier and that the lactate is removed as readily as it is produced. Thus,

this would allow for overestimation of the individual's AT. In a very recent study, Green et al (1982) investigated the interrelationship between the anaerobic threshold as determined by gas exchange and by blood lactate and the alteration of muscle metabolism. It was concluded that the gas exchange AT as determined by the blood lactic acid accumulation are not consistent. Therefore, it may be hypothesized that $\dot{V}_E$ may be an invalid indicator of AT. However, in view of the previous studies and their apparent validity and reliability of $\dot{V}_E$ as a reliable indicator of AT, the AT in this study was accepted as the point where $\dot{V}_E$ becomes nonlinear and was considered a valid indicator of AT.

To further substantiate the AT procedure, the researcher subjectively observed the $\dot{V}_E$ response curve during the GXT. It was concluded that all subjects exhibited a homogeneous $\dot{V}_E$ response curve and apparent $\dot{V}_E$ breakaway points (Appendix I). Therefore, the data indicated the subjects' AT was not a result of hyperventilation which would have elicited a heterogeneous $\dot{V}_E$ response curve.

To further verify the predicted AT's, changes in R at exercise levels in proximity to the predicted AT (i.e., 5 levels) were examined. An increase in R would suggest a sudden increase in anaerobic metabolism. Several early researchers used sudden changes in R as the primary non-invasive indicator of AT (Issekutz & Rodahl, 1961, Naimark et al, 1964). Other investigators stated that R can be utilized to determine AT, but was not as sensitive as other measures (Wasserman et al, 1973, Davis et al, 1976). However, since no invasive procedures were utilized to validate the AT predictions, it was important to examine

the R value changes. The results of a one-way analysis of variance indicated that no significant differences existed in the increase in R values between exercise levels two and one MET below and above the AT. The mean R values as illustrated in Figure 1, indicated that there was an increase in R, thus, suggesting that anaerobic metabolism was occurring. One possible explanation for this result in this study, is that R was not sensitive to reveal sudden changes to reflect anaerobic metabolism. Secondly, another possible explanation could be the duration of the workloads.

In recent years, many researchers have disagreed as to the duration of the workloads (Wasserman et al, 1973, Davis et al, 1976, Stamford et al, 1978, Weltman et al, 1978). Davis et al (1976) and Wasserman et al (1978) were in agreement regarding the duration of workload and stated that one minute workloads are sufficient in accurately assessing the AT. Wasserman and associates (1973) also reported that increasing the length of the workload may sufficiently alter the assessment of AT as a result of the delay in diffusion of lactic acid from the muscle to the blood. It was also concluded by Wasserman and others that workload durations shorter than thirty seconds may overestimate the subject's AT since it does not allow for diffusion of lactic acid from the muscle to the blood. Conversely, Stamford et al (1978) and Weltman et al (1978) have suggested that three minute workloads are appropriate as it allows for adequate diffusion of lactic acid from the muscle to the blood to occur. Stamford also concluded that short workloads may overestimate the AT because the diffusion time necessary for lactic acid to accumulate in the blood is reduced. Subsequently, this delay

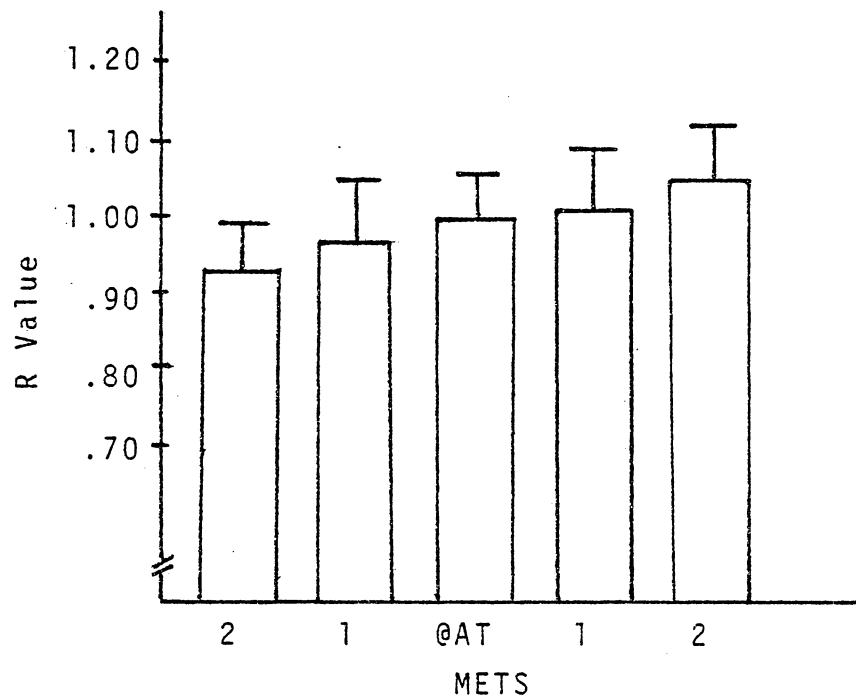


Figure 1. R values between exercise levels two and one MET below and above the AT.

in lactic acid accumulation results in a delay in $\dot{V}CO_2$ which may not cause a significant increase in R at the predicted point of AT. In fact, the delay may be reflected in higher R values later. However, as shown in Figure 1, this was not evident. Therefore, it may be concluded that there were no abrupt changes in R several minutes later and that the utilization of R in this study was an insensitive indicator of the subjects' AT. Consequently, the utilization of R in this study to substantiate the subjects' AT was not a valid procedure.

In this study, AT's were recorded as a percentage of peak $\dot{V}O_2$ to allow for comparisons with earlier researchers. The mean group AT when expressed as a percentage of peak $\dot{V}O_2$ was 65.3%. This finding was in contrast to Davis et al (1976) and Weltman et al (1979) who reported mean AT values of 58.6 and 59.5%, respectively. MacDougall reported AT values for the endurance and non-endurance group at 85% and 70% of $\dot{V}O_{2max}$, respectively. Skinner and McLellan (1980) stated that the AT could occur between 35 to 65% of the subjects' $\dot{V}O_2$. One possible explanation for a higher group mean AT than cited in the previous literature was the fitness level of the subject. Davis and co-workers did not state the fitness level of the subjects, however, did state that none of the subjects had undergone systematic endurance training for four months prior to the study. Therefore, upon speculation, it may be assumed that the fitness level of the subjects in the Davis et al study were less physically fit than in this study. In that case, it would be expected that the mean AT would be higher than of a less fit group (MacDougall, 1977). Another possible explanation is the difference in the mean AT as evidenced in this study as the

duration of workloads. Wasserman (1973) and Davis et al (1976) stated that workloads shorter than one minute may alter the assessment of the subjects' AT, thus, overestimating the AT. This overestimation of the AT would be reflected in later workloads by a sudden increase in the R values. However, as previously mentioned, this did not occur (Figure 1).

Therefore, it was concluded that eight subjects did attain a maximal $\dot{V}O_2$ on the basis of the $\dot{V}O_2$ validation criterion, the age-predicted maximal heart rate, plateauing effect of the heart rate during the final minutes of the GXT, and by observation of the subjects' performance during the GXT. The subjects' resting heart rates were accepted to be accurate which was indicated by the data that a one beat difference existed in the resting heart rate during all three testing sessions. It was evident in this study that all subjects exhibited homogeneous $\dot{V}_E$ response curves and apparent $\dot{V}_E$ breakaway points. Therefore, it appeared that the regression technique utilized in the determination of AT in this study was an objective method. Lastly, the results of the one-way analysis of R to validate the estimation of AT was insignificant and reported to be an insensitive indicator of AT. It can be assumed that the majority of the variables (AT, HR_{max} , HR_{rest}) from which the exercise prescription was obtained were considered valid.

Performance Validation of Exercise Prescriptions

Duration and Responses in Steady-State

To examine the effectiveness of the exercise prescription during the training simulation, the subjects' exercise time, $\dot{V}O_2$ and RPE values were analyzed. The data indicated that there was a significant difference

($p \leq .05$) in the subjects' duration to exercise within his prescribed training heart rate. When comparing the Karvonen versus the AT methods, the data indicated that the subjects' mean exercise time during the prescribed duration was 16:42 and 29:00 minutes using the Karvonen and AT methods, respectively. The subjects exercised substantially longer utilizing the AT method versus the Karvonen method. When converting these values to percentages, it was found that the subjects exercised within their prescribed heart rate 48.4% and 27.4% of the sixty minutes available utilizing the two exercise prescription methods. Several explanations may be responsible for this finding.

First the $\dot{V}O_2$ values exhibited by the Karvonen and AT methods during the prescribed level were $40.03 \text{ ml} \cdot \text{kg} \cdot \text{min}^{-1}$ and $37.80 \text{ ml} \cdot \text{kg} \cdot \text{min}^{-1}$, respectively. Although this difference was not found to be statistically significant, the small difference of approximately 0.65 MET between the two prescription procedures may have been a limiting factor in the subjects' duration to exercise within their training heart rate zone. Also, it was observed that the intensities derived by the Karvonen method were above the mean group AT which limited the subjects' duration within their prescribed level. Secondly if there was an error in the computation of the subjects' exercise prescription, then an inappropriate exercise prescription could have resulted. However, computations were repeated to prevent this from occurring. Thirdly, it may be that the Karvonen exercise prescription method may overestimate the prescribed intensity at which a subject should exercise. It was indicated by Davis and Convertino (1975), that the Karvonen method was proven to be a valid and accurate procedure for determining exercise

intensity. However, Davis et al (1975) noted that the Karvonen method resulted in an overall prediction that was 2.6% above the mean values recorded at 25, 45, 65 and 85% of $\dot{V}O_{2\max}$. To support this finding, in a very recent study conducted by Smith et al (1982), it was concluded that the Karvonen method overestimated the actual mean heart rate by ten beats in coronary artery diseased patients. The training heart rate predicted by the Karvonen method was significantly higher ($p \leq .005$). In this study, the Karvonen method yielded an overall prediction of 7.5% above the measured $\dot{V}O_2$ training intensity value. Conversely, the data indicated that the AT method yielded an overall prediction of 4.0% above the measured $\dot{V}O_2$. Consequently, this increased difference between the actual and predicted $\dot{V}O_2$ could be a limiting factor in the subjects' duration when working at a relatively high percent of $\dot{V}O_{2\max}$.

To further evaluate the difference between the Karvonen and AT exercise prescription methods, the subjects' mean $\dot{V}O_2$ values in each training simulation were analyzed. The $\dot{V}O_2$ values for the Karvonen and AT methods were found to be $40.03 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and $37.80 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$, respectively. These differences were not statistically significant when expressed as percentages of the subjects' $\dot{V}O_{2\max}$. The Karvonen exercise prescription method elicited a higher $\dot{V}O_2$ response of 68% versus 64% yielded by the AT exercise prescription method during the training simulation tasks. Although this 4% difference is small, it appears that in terms of the percentage of $\dot{V}O_2$, the Karvonen exercise prescription was apparently higher than the mean group AT of 65.3%. This difference when expressed in METS was 0.65 higher in the Karvonen

exercise prescription methods than was the AT method. Perhaps a small increase in the work level in the intensity range of the AT can be associated with a rapid increase in anaerobiosis. Subsequently, this difference could be an explanation as to the subjects' duration during a physiological steady-state which was substantially longer utilizing the AT method.

As indicated in Figure 2, the mean values for the measured $\dot{V}O_2$ during the GXT and the two exercise prescriptions during the training simulation tasks, a difference of $1.51 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ was noted for the AT exercise prescription method. Conversely, the difference of $3.02 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ was observed for the mean values for the measured $\dot{V}O_2$ and during the training simulation tasks utilizing the Karvonen method. When expressed in percentages, the Karvonen and AT exercise prescription methods overestimated the $\dot{V}O_2$ values by 7.5 and 4% during the training simulations, respectively. This difference may be attributed to the assigned intensity derived from the formulas in the ACSM Guidelines (1980). It may be speculated that measurement error could have occurred in the gas analyzer. However, since the gas analyzers were calibrated before, during and between tests, it can be assumed that the measurements recorded were correct.

In another attempt to compare the two exercise prescription methods, the subjects' caloric expenditure was examined. As previously stated, duration and intensity are closely related and both of these components should be considered simultaneously rather than separately (Ribisl, 1980). It is extremely important for an individual to be able to maintain the appropriate intensity for a length of time that will promote cardiovascular

fitness. In addition, another factor closely related to the duration component of the exercise prescription is the individual's caloric expenditure. It is recommended by several researchers (Ribisl, 1980; Wilmore, 1972) that the individual should expend approximately 300 to 500 calories per workout. In view of this, the researcher examined the subjects' caloric expenditure when implementing the two exercise prescription methods. The subjects' caloric expenditure during the physiological steady-state was 260 and 435 kilocalories per session utilizing the Karvonen and AT methods, respectively. A possible explanation for this finding is that the prescribed intensity derived by the Karvonen method was over the mean group AT. Consequently, this was a limiting factor in the subjects' ability to exercise within his prescription level for the proper duration which would enable the subjects to expend more calories per workout. Therefore, it appears that the AT exercise prescription method was superior based on the above-stated criterion regarding the individual's appropriate caloric expenditure per workout.

The final analysis was performed to verify if differences existed in the subjects' rate of perceived exertion (RPE) between the two exercise prescription methods. No significant differences existed and the subjects' perception of the intensity during the prescribed duration was extremely similar during the two training simulation tasks. Although the subjects' were given instruction on using the Borg scale, it is apparent that all subjects did not adequately understand its use. It has been indicated in the literature (Borg, 1974), that there is a very high correlation ($r = .85$) of perceived exertion and absolute heart rate when the work is varied from light to hard. According to the RPE

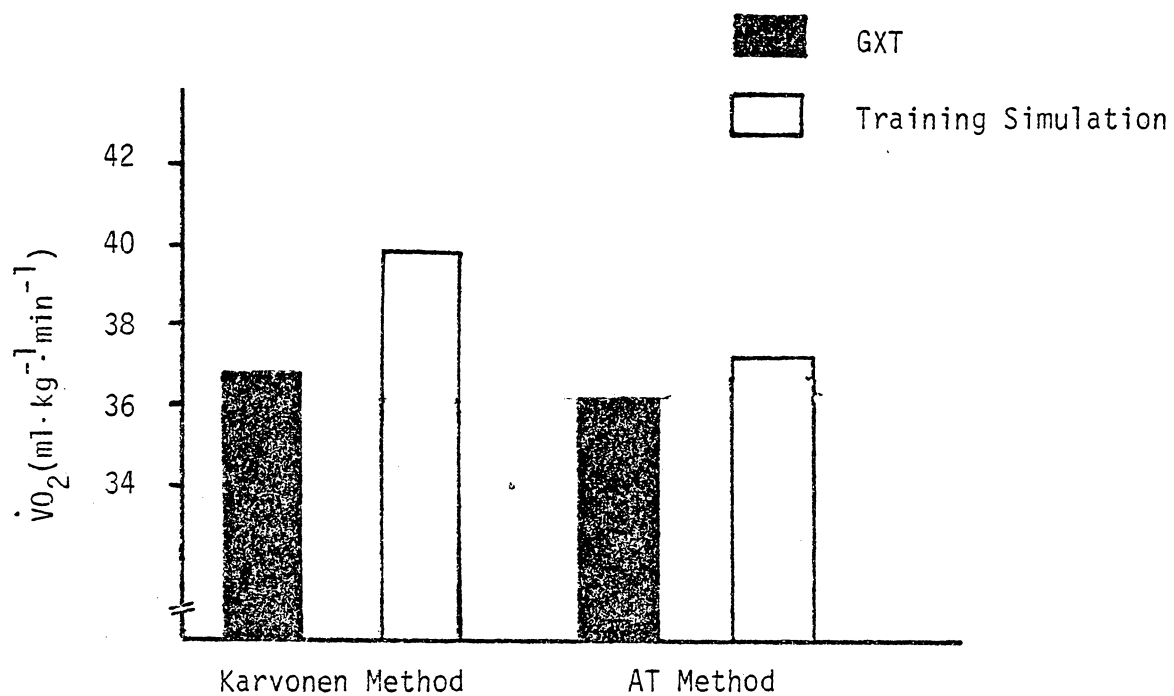


Figure 2. Mean values for subjects' $\dot{V}O_2$ at the prescribed intensity during the GXT and during the training simulation tasks utilizing the two exercise prescription methods.

values exhibited by the subjects, their heart rates should have been approximately 100 to 110 $\text{bts}\cdot\text{min}^{-1}$. However, during the two training simulation tasks, the subjects' heart rates were recorded at 156 and 157 $\text{bts}\cdot\text{min}^{-1}$ utilizing the Karvonen and AT methods, respectively. Thus, the subjects' accuracy for rating the two exercise prescription methods may be questioned.

Duration and Responses to Fatigue Point

In an attempt to further compare the performance validity of the Karvonen versus AT exercise prescription methods, examination of the subjects' capacity to perform continuous exercise during the two training simulations was performed. During the two training simulations tasks, the subjects' mean time for continuous exercise was found to be 47.20 and 50.40 minutes utilizing the Karvonen and AT methods. These differences were not statistically significant. This may be a reflection of the similarities in the two exercise prescriptions which apparently did not limit the capacities for performing continuous exercise. It was noted, however, that during the second test, four subjects complained of leg fatigue and muscle soreness. Perhaps this could have biased this study by the fact that the muscle soreness and expressed leg fatigue may have limited their performance during the second training simulation tasks. When the data were analyzed with regard to the time, the subject's were able to maintain their prescribed training heart rate during continuous exercise and a significant difference was noted. Utilizing the Karvonen method, subjects exercised for 16:42 minutes at their prescribed heart rate during the 47.20 minutes of continuous exercise. The subjects exercised within their prescribed heart rate range for 29 minutes during the 50.4

minutes using the AT method. When expressed as percentages, the subjects' mean exercise duration during continuous exercise was 27.4% and 48.4% of the time within their prescribed intensities utilizing the Karvonen and AT exercise prescription methods. This is almost a twofold difference in favor of the AT. When viewed within the context of this criterion of sustaining exercise at a prescribed level, it appears that perhaps the Karvonen method may be a less accurate method. As stated previously, the Karvonen exercise prescription method yielded a higher $\dot{V}O_2$ during the steady-state than the AT method. During the training simulation task, the VO_2 in the Karvonen method was above the group mean AT. This finding may have been an important factor in limiting the subjects' duration at his prescriptive intensity during the training simulation tasks.

Another important consideration when prescribing exercise for healthy individuals is the highest heart rate attained during exercise. For the cardiac population, this is a more critical concern. Previous researchers have stated that overestimating the intensity level for cardiac subjects could be potentially hazardous (Pyfer and Doane, 1969; Fletcher and Cantwell, 1977). There was a significant difference in the highest heart rate obtained during the training simulation tasks. Application of the Karvonen method resulted in a mean prescribed heart rate of $179.3 \text{ bts} \cdot \text{min}^{-1}$. The mean heart rate exhibited by the AT method was recorded at 174.0. This finding was statistically significant. According to the literature, it has been reported that there is a linear relationship between HR and oxygen uptake (Astrand et al, 1977, ACSM, 1980. If this premise is accepted, then the higher intensity as demonstrated by the Karvonen method would elicit a higher heart

rate response as evidenced in this study. Another possible explanation for this result could be measurement error in determining the maximal heart rate during the two training simulation tasks. Finally, one remaining explanation could be a possible error in assigning the predicted intensities that were derived from the formulas stated in the ACSM Guidelines (1980). An over-prediction in energy expenditure would result in a higher heart rate to meet the energy requirement. However, this error would have occurred in both exercise prescriptions. Therefore, it seems improbable that the higher heart rate attained in the Karvonen prescription method is attributable to error in determination of intensity.

Previous studies have indicated that during exercise there is an increase in R values (Hill and Lupton, 1923; Issekutz and Rodahl, 1961), and this increase in R has been related to an increase in blood lactate concentration. It has been hypothesized that increases in blood lactate may be a limiting factor in a subjects' capacity to perform endurance activities because it may inhibit mobilization of free fatty acids (Astrand & Rodahl, 1977). The increase in R may also be indicative of the fuel substrate being utilized by the muscle cell. When the oxygen supply is reduced, there is an increase in carbohydrate oxidation. The increase in lactic acid inhibits the mobilization of free fatty acids. Therefore, the fuel substrate for the muscle is dependent upon the oxygen availability during the workload. If this premise is accepted, it would be expected that the Karvonen exercise method yielded a higher R value since the intensity of the workload was greater than the AT method (Astrand et al, 1977). However, when the data were analyzed,

the AT exercise prescription elicited a higher mean R value than the Karvonen exercise prescription method. The mean R values were recorded at .96 and .98 for the Karvonen and AT exercise prescription methods, respectively. This value was found not to be significantly different. Perhaps there is an explanation for this finding. It has been stated by previous researchers that lactic acid accumulation occurs when the oxygen is not sufficient to meet the demands of the working muscle (Hill and Lupton, 1923, Margaria, 1933). In a step further, Nagle and associates (1970), stated that blood lactic acid accumulates in the blood with intensities ranging from 65 to 100% of $\dot{V}O_{2\max}$, and reported that lactic acid accumulates in subjects during exercise at a physiological steady-state. Nagle et al (1970) concluded that blood lactate is elevated during exercise over the duration of thirty minutes to sixty minutes in proportion to the aerobic demands of 65 to 90% of $\dot{V}O_{2\max}$ during a steady-state. If this is accepted, then it can be hypothesized that the higher R values yielded by the AT exercise prescription method was reflected by higher levels of lactate. These higher R values as evidenced in this study, could be attributed to the subjects' capacity to perform continuous exercise longer (3 minutes) using the AT exercise prescription method; thus, indicating higher lactate levels.

The final analysis in this section was the subjects' perception of the intensity of the two exercise prescription methods. It was found that no significant difference occurred between the two exercise prescription methods with respect to mean RPE values. The RPE values were 13.2 and 12.1 for the Karvonen and AT methods, respectively. How-

ever, it is apparent that the subjects' ability to accurately rate the intensity of the two exercise prescription methods during the training simulations was distorted. This is reflected during the training simulations when the heart rates were observed above 160, and according to the Borg scale, the heart rates should have been recorded at 120 and 130. It could be concluded that the subjects' ability to accurately rate the intensity of the training simulations has limited validity. Also, it may be concluded that because the intensities were similar, the subjects noted very little difference between the two exercise prescription methods.

Conclusions

From the results of this study, several conclusions were made:

1. The duration of continuous exercise that the subject could perform maintaining his training heart rate was significantly longer utilizing the AT exercise prescription method.
2. The rate of oxygen uptake did not differ significantly utilizing the Karvonen and AT exercise prescription methods.
3. When utilizing the two exercise prescription methods, a significant difference was not found in the subjects' rate of perceived exertion (RPE) while maintaining a physiological steady-state. Furthermore, the subjects were unable to accurately rate the intensity of the two exercise prescription methods.
4. A significant difference did not exist in the subjects' capacity to perform continuous exercise before fatigue was expressed using

the two exercise prescription methods.

5. During continuous exercise, the Karvonen exercise prescription method yielded a significantly higher peak heart rate.
6. A significant difference was not found in the respiratory exchange values during continuous exercise utilizing the different exercise prescription methods.
7. No significant differences were found in the subjects' RPE values using the Karvonen and AT exercise prescription methods. The subjects' ability in rating the intensity during the training simulation tasks was questionable.

Implications for the Exercise Specialist

There are two main forms of physical training in which lactic acid concentration is of utmost importance: continuous prolonged exercise (endurance training) and interval training. However, from a clinical standpoint, improving the individual's aerobic capacity through endurance training is recommended. The best training for this seems to come from prolonged muscular work involving the oxidative process of the cellular metabolism. This can best be achieved by the individual exercising at or below the individual's AT (Katch et al, 1978, Weltman et al, 1978). The results of this study indicated that anaerobic threshold was a viable method for prescribing exercise. As previously mentioned, several researchers (Goss et al, 1979, McLelland et al, 1978) believe that the AT used as a method for prescribing exercise intensity is more sensitive and allows for more individual variability.

The present study may have implications for the use of AT as an exercise prescription method for symptomatic and asymptomatic individuals.

First, the data derived from the GXT may be helpful in determining the individual's exercise prescription. By determining the heart rate and RPE values occurring at the individual's AT, there is adequate information for calculating an accurate exercise prescription. One advantage of utilizing the AT as the exercise prescription is that it allows the exercise intensity to be determined without attainment of the individual's maximal heart rate. As stated earlier, this is extremely important to symptomatic individuals who are unable to attain their maximal heart rate during the GXT. Therefore, determining an intensity level utilizing a conventional method (Karvonen method) may result in cardiovascular complications (Powles et al, 1979). Thus, the use of the AT may be used as a safeguard measure to prevent symptomatic individuals from over-exertion that could be potentially hazardous. Secondly, of less importance, the AT method would reduce the time required by the client and staff in the laboratory.

In various populations (sedentary and active), the AT may be sensitive to differing levels of aerobic capacity. Since duration and intensity are interrelated, it is important that the individual sustain exercise for approximately thirty minutes at an intensity to promote cardiovascular fitness. This study has implicated AT as a valid procedure in accurately prescribing exercise at an intensity that will promote cardiorespiratory fitness and that can be sustained for approximately thirty minutes.

Recommendations

The following recommendations are made for future investigators:-

1. That a similar study be done to determine the test-retest reliability

of the AT and Karvonen method as viable methods for prescribing exercise. First, two graded exercise tests should be administered to test the reliability of the computer method used to predict the AT in this study. The subjects should be administered repeated training simulation trials on different days to test the reliability of the AT exercise prescription method.

2. That once the reliability has been determined for AT as an accurate procedure for prescribing exercise, further evaluation of the AT exercise prescription method in cardiac populations should be undertaken.
3. That additional research of the AT exercise prescription method include subjects of differing cardiovascular fitness levels.
4. That a similar study be done to determine the validity of AT exercise prescription methods by use of arterial blood samples.
5. That a similar training study be done with different populations using these two exercise prescription procedures to determine if both methods promote comparable cardiovascular improvement.

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Appendix A

Summary of Individual Descriptive Measures

Subject	Measures			Skinfolds (mm)			Predicted Body Fat (%)	$\dot{V}O_{2\max}$ (ml·kg ⁻¹ ·min ⁻¹)	AT (% $\dot{V}O_{2\max}$)
	Age (yrs)	Ht (cm)	Wt (kg)	1	2	3			
1	26	180.4	79.5	16.6	16.3	28.5	19.0	57.87	64.11
2	22	178.5	79.2	12.8	12.9	15.2	12.8	60.49	64.08
3	23	180.0	77.0	16.2	17.9	18.8	16.2	54.93	66.67
4	22	185.0	79.5	8.2	9.4	7.2	10.6	67.42	60.63
5	23	175.0	67.5	9.5	11.0	10.9	12.0	70.22	58.23
6	25	174.0	78.1	13.6	11.4	19.4	14.8	56.85	77.26
7	22	187.0	72.5	9.6	8.6	11.5	11.7	54.34	72.34
8	24	180.8	80.0	11.8	11.7	20.8	15.8	59.75	64.02
9	23	170.5	88.2	15.7	6.6	16.9	12.2	56.46	66.67
10	23	193.0	78.0	7.2	11.1	11.4	13.7	53.71	59.43

Skinfold Notation:

1 = scapula

2 = triceps

3 = abdominal (ll)

Appendix B

Virginia Polytechnic Institute and State University

Informed Consent for Research Subjects

1. Brief Explanation of Study

This study has been designed to evaluate the effectiveness of prescribing cardiorespiratory endurance by utilizing the Karvonen (a technique based on heart rate responses) and the anaerobic threshold methods (a technique based on pulmonary responses). A graded exercise test (GXT) will be administered to determine the participant's oxygen consumption and anaerobic threshold. The performance of the two training simulation tasks that involve exercise at a prescribed intensity will be determined by the researcher. The participant will be exercising for 60 minutes on alternate days. The physiological measurements that will be recorded in all three tests include blood pressure, heart rate monitored electrocardiographically, rate of perceived exertion, and oxygen consumption. You may terminate the test if you do not wish to continue.

2. Risks and Discomforts

The risks involved in the graded exercise test and the training simulation tasks are possible leg fatigue, sore leg muscles and a very slight chance of cardiac arrest.

The literature has suggested that there are minimal risks involved in graded exercise testing. Zohman (1975) stated that there is a mortality rate of 1 in 10,000 due to stress testing.

3. Benefits to be Expected

The results obtained from this study should assist in evaluation of your present physical fitness status compared to your determination of norms of individuals in your age group and anaerobic threshold.

4. Inquiries

If you have any questions or concerns during this study, please feel free to inquire. Since individualized treatment is one of the main components of this research, subject-researcher interaction is necessary.

5. Freedom of Consent

Permission for you to participate in this study is voluntary. Your data will be anonymously coded before use in research publications. You are free to deny consent if you so desire.

I have read this form and I understand the research procedures that I will be asked to perform and I consent to participate in this study.

Signature of Subject

Date

Witness

Dr. Don Sebolt, Human Subjects Committee
Phone - 961-5104

Dr. William Herbert, Human Subjects Committee
Phone - 961-6565

Dr. M. P. Stomblor, Associate Dean and
Chairman of the Institutional Review
Board

Appendix C
Experimental Testing Series

Subjects	Tests	
	1	2
1	A	B
2	A	B
3	B	A
4	A	B
5	B	A
6	B	A
7	A	B
8	B	A
9	A	B
10	B	A

Test notation:

A = Karvonen Method

B = Anaerobic Threshold Method

Appendix D
LABORATORY FOR EXERCISE AND WORK PHYSIOLOGY
Division of Health Physical Education and Recreation

PART I. SELF-ADMINISTERED PRE-EXERCISE TEST AND
HISTORY FORM

Name _____
Date _____
Age _____
Sex _____
Weight _____
Height _____
Address _____

Phone _____

1. History of Cardiovascular Disease

Indicate nature of condition* for male members of immediate family.

Personal _____
Grandfather _____
 Maternal _____
 Paternal _____
Father _____
Brother(s) _____
Uncles(s) _____
No Known History _____

*Coronary artery disease, angina pectoris, coronary thrombosis, rheumatic fever, cardiac enlargement, valvular heart disease, arrhythmia, other (please specify).

2. Have you ever been diagnosed as having hyperlipidemia?

No _____ Yes _____

3. If yes, specify which type. _____

4. Do you have any of the following risk factors for heart disease (please check):

☐ sedentary life style ☐ diabetes mellitus ☐ stroke
☐ stressful life style ☐ high blood pressure ☐ obesity
☐ smoke cigarettes
☐ packs/day

5. Have you ever experienced any of the following (please check the circumstances in which they occur):

☐ chest pain ☐ at rest ☐ exertion ☐ cold weather ☐ emotion
☐ chest pressure ☐ at rest ☐ exertion ☐ cold weather ☐ emotion
☐ discomfort/pain in jaw ☐ at rest ☐ exertion ☐ cold weather ☐ emotion
☐ discomfort/pain in teeth ☐ at rest ☐ exertion ☐ cold weather ☐ emotion
☐ discomfort/pain in throat ☐ at rest ☐ exertion ☐ cold weather ☐ emotion
☐ discomfort/pain in elbow ☐ at rest ☐ exertion ☐ cold weather ☐ emotion
☐ discomfort/pain in wrist ☐ at rest ☐ exertion ☐ cold weather ☐ emotion
☐ palpitations/skipped beats ☐ at rest ☐ exertion ☐ cold weather ☐ emotion

6. Do you have or have you ever had any of the following (please check):

☐ heart murmur ☐ emphysema ☐ chronic bronchitis ☐ arthritis
☐ asthma ☐ allergies ☐ other _____

7. Have you ever undergone surgery? Please check any that apply to you and indicate the date(s). If known:

☐ coronary bypass ☐ varicose veins ☐ leg surgery
☐ valvular surgery ☐ abdominal surgery
☐ other (describe) _____

8. Have you ever had an exercise fitness evaluation? Explain _____

9. Are you taking any medications on a regular basis? ☐ No ☐ Yes
10. If yes, please list any and all medications you are taking (both prescription & non prescription drugs).

<u>Name of Medication</u>	<u>Dosage</u>	<u>Doses per day</u>
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____
_____	_____	_____

PART 2. SELF ADMINISTERED PRE-EXERCISE TEST EXERCISE/ACTIVITY FORM

1. Are you currently involved in a regular exercise program?
2. Do you regularly walk or run one or more miles continuously?
- If yes, average no. of miles you cover per workout or day: _____ miles
- What is your average time per mile? _____ minutes:seconds
3. Please check the following sports/activities in which you have participated over the past 6 months.

<u>Activity</u>	<u>Days/Wk</u>	<u>Min/Day</u>	<u>Intensity</u>
	___ 1 ___ 4	Minutes	___ Light (no sweating)
Baseball	___ 2 ___ 5	_____	___ Mild (limited sweating)
(or softball)	___ 3 ___ 6	_____	___ Moderate sweating
	Daily _____		___ Vigorous (profuse sweating)
	___ 1 ___ 4	Minutes	___ Light (no sweating)
Basketball	___ 2 ___ 5	_____	___ Mild (limited seating)
	___ 3 ___ 6	_____	___ Moderate sweating
	Daily _____		___ Vigorous (profuse sweating)

	_____1_____4	Minutes	_____Light (no sweating)
Bicycling _____	_____2_____5	_____	_____Mild (limited sweating)
	_____6_____6		_____Moderate sweating
	Daily _____		_____Vigorous (profuse sweating)
	_____1_____4	Minutes	_____Light (no sweating)
Calisthenics _____	_____2_____5	_____	_____Mild (limited sweating)
	_____3_____6		_____Moderate sweating
	Daily _____		_____Vigorous (profuse sweating)
	_____1_____4	Minutes	_____Light (no sweating)
Canoeing _____	_____2_____5	_____	_____Mild (limited sweating)
	_____3_____6		_____Moderate sweating
	Daily _____		_____Vigorous (profuse sweating)
	_____1_____4	Minutes	_____Light (no sweating)
Carpentry _____	_____2_____5	_____	_____Mild (limited sweating)
	_____3_____6		_____Moderate sweating
	Daily _____		_____Vigorous (profuse sweating)
	_____1_____4	Minutes	_____Light (no sweating)
Dancing _____	_____2_____5	_____	_____Mild (limited sweating)
	_____3_____6		_____Moderate sweating
	Daily _____		_____Vigorous (profuse sweating)
	_____1_____4	Minutes	_____Light (no sweating)
Chopping Wood _____	_____2_____5	_____	_____Mild (limited sweating)
	_____3_____6		_____Moderate sweating
	Daily _____		_____Vigorous (profuse sweating)

Farming _____	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 6 _____ 6	_____	_____ Moderate sweating
	Daily _____	_____	_____ Vigorous (profuse sweating)
Gardening _____	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6	_____	_____ Moderate sweating
	Daily _____	_____	_____ Vigorous (profuse sweating)
Golfing _____ (without golf cart)	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6	_____	_____ Moderate sweating
	Daily _____	_____	_____ Vigorous (profuse sweating)
Handball _____	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6	_____	_____ Moderate sweating
	Daily _____	_____	_____ Vigorous (profuse sweating)
Mountain Climbing _____	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6	_____	_____ Moderate sweating
	Daily _____	_____	_____ Vigorous (profuse sweating)
Racquetball _____	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6	_____	_____ Moderate sweating
	Daily _____	_____	_____ Vigorous (profuse sweating)

	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
Soccer _____	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 6 _____ 6		_____ Moderate sweating
	Daily _____		_____ Vigorous (profuse sweating)
	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
Swimming _____	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6		_____ Moderate sweating
	Daily _____		_____ Vigorous (profuse sweating)
	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
Tennis _____	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6		_____ Moderate sweating
	Daily _____		_____ Vigorous (profuse sweating)
	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
Volleyball _____	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6		_____ Moderate sweating
	Daily _____		_____ Vigorous (profuse sweating)
	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
Weight Training _____	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6		_____ Moderate sweating
	Daily _____		_____ Vigorous (profuse sweating)
	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
Other _____	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6		_____ Moderate sweating
	Daily _____		_____ Vigorous (profuse sweating)

Other _____	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6	_____	_____ Moderate sweating
	Daily _____	_____	_____ Vigorous (profuse sweating)
	_____ 1 _____ 4	Minutes	_____ Light (no sweating)
	_____ 2 _____ 5	_____	_____ Mild (limited sweating)
	_____ 3 _____ 6	_____	_____ Moderate sweating
	Daily _____	_____	_____ Vigorous (profuse sweating)

PART 3. SCREENING MEASUREMENT

Name _____

Date _____

Height _____

Weight _____

AGE _____

Sex _____

A. Body Composition

Skinfolds (Male) _____	(Female) _____
Triceps _____	Triceps _____
Abdomen _____	Abdomen _____
Thigh _____	Thigh _____
Total _____	Total _____
Obese/Non obese _____	_____

B. Family History CHD _____

C. CHD Related Symptoms

Smoking _____

Physical Activity _____

Resting BP _____

Resting HR _____

Resting ECG _____

Blood Cholesterol _____

HDL - Cholesterol _____

$\frac{\text{Total Cholesterol}}{\text{HDL Cholesterol}}$ Ratio _____

D. Relative Risk Level (circle one)

Very Low

Low

Moderate

High

Very High

Appendix E

Pre-Test Instructions

The following instructions should be followed prior to test dates:

1. subject should come dressed in running attire
2. subject should get a good night's rest (7 hours of sleep if possible)
3. subject should abstain from eating 2-3 hours prior to test
4. subject should abstain from any medications that could alter heart rate or pulmonary responses
5. subject should abstain from drinking any beverage that contains caffeine in the eight hours prior to testing
6. subject should abstain from becoming intoxicated the night prior to test

Appendix F

Determination of Training Heart Rate

Step 1:

This was accepted from a GXT in which the subject attained his HR_{max}
(Example: $HR_{max} = 193 \text{ bt} \cdot \text{min}^{-1}$).

Step 2:

Determine HR_{rest} . This resting HR was obtained prior to the GXT. The subject rested in a supine position for 2 minutes before his HR was recorded electrocardiographically (i.e., $HR_{rest} = 57$).

Step 3:

Compute HR range. Subtract the subject's resting HR from his max HR (i.e., $193 - 57 = 136$).

Step 4:

Determine the HR for the lower and upper limits of the prescribed training intensity ($HR\% = 65 - 75\%$).

$$\text{I.e., } 136 \times .65 = 88.4 + 57 (HR_{rest}) = 145.4$$

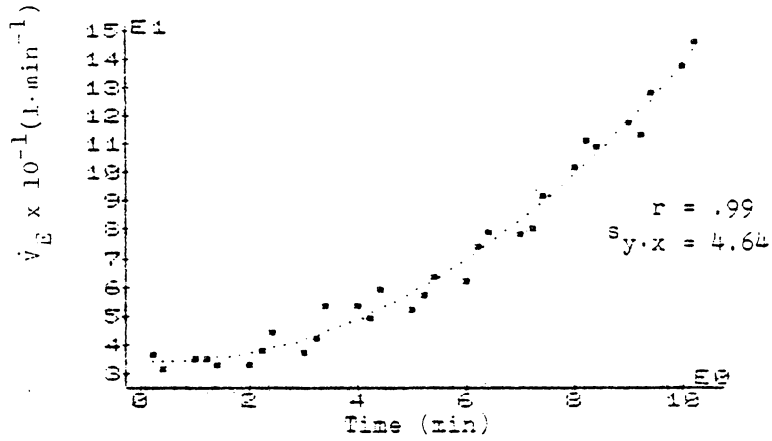
$$136 \times .75 = 102 + 57 (HR_{rest}) = 159.0$$

Training HR = 145 - 159.

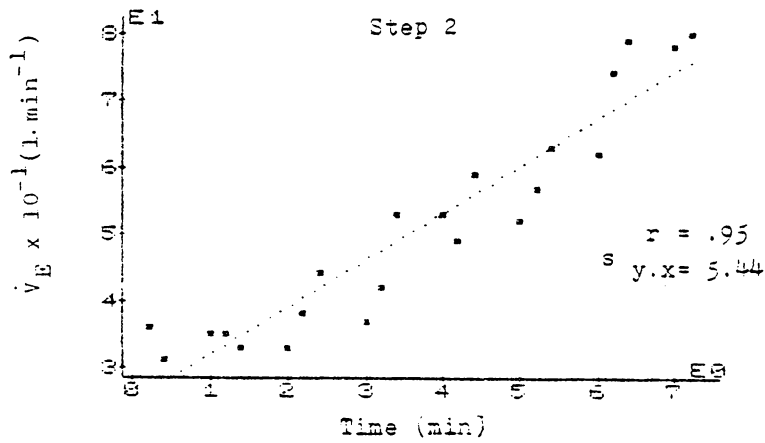
Appendix G

Procedure For Anaerobic Threshold Performance

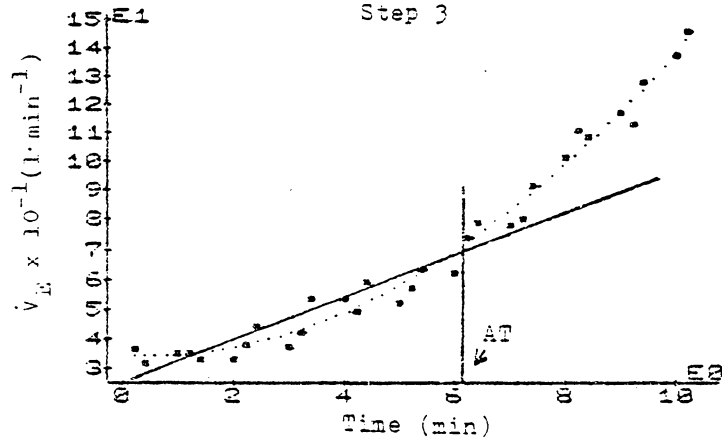
Step 1



Step 2



Step 3



Appendix G. (continued)

Step 1:

Bivariate distribution of $\dot{V}_E$ vs. exercise time was submitted in which a second degree polynomial was plotted with the highest r and the lowest $s_{y \cdot x}$.

Step 2:

A series of linear regressions were computed wherein each bivariate point was deleted until the highest r and the lowest $s_{y \cdot x}$ was determined.

Step 3:

The x and y coordinates from step two were plotted on the second degree polynomial curve and a line was drawn between those points. The point where $\dot{V}_E$ breaks away from the linear regression line was identified as the AT.

Appendix H

R Values for Subjects at the AT and Two and One MET

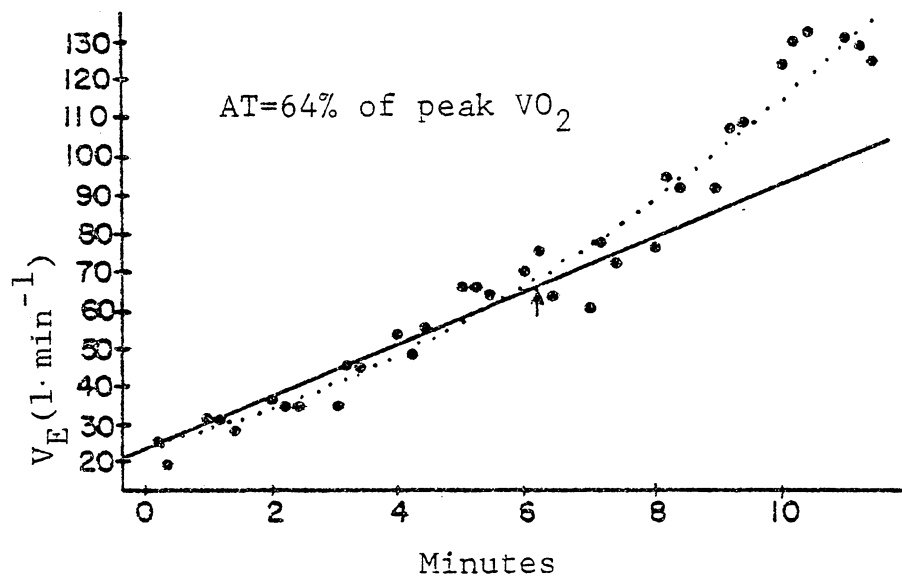
Exercise Level Below (+) and Above (+) the AT

Subject	2 MET +	1 MET +	R at AT	1 MET +	2 MET +
1	.85	1.08	1.02	1.14	1.16
2	1.01	.95	.96	.98	1.08
3	.89	.95	.94	.97	1.15
4	.89	.90	.98	.97	.97
5	1.03	1.00	1.13	1.09	1.02
6	1.00	.94	.99	1.13	1.15
7	.93	.96	.94	1.01	1.05
8	.94	.97	1.02	.92	.98
9	.91	.98	1.03	.95	.99
10	.85	.96	.96	.91	.98
$\bar{X}$	.93	.97	1.00	1.01	1.05
$\pm$ SD	.06	.08	.06	.08	.07

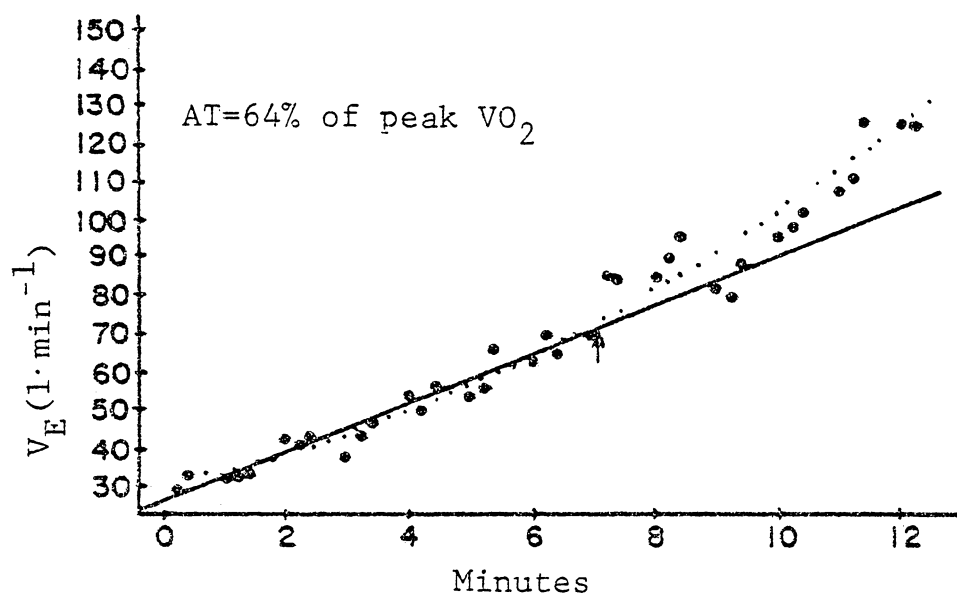
Appendix I

Subjects' Ventilatory Response Curves

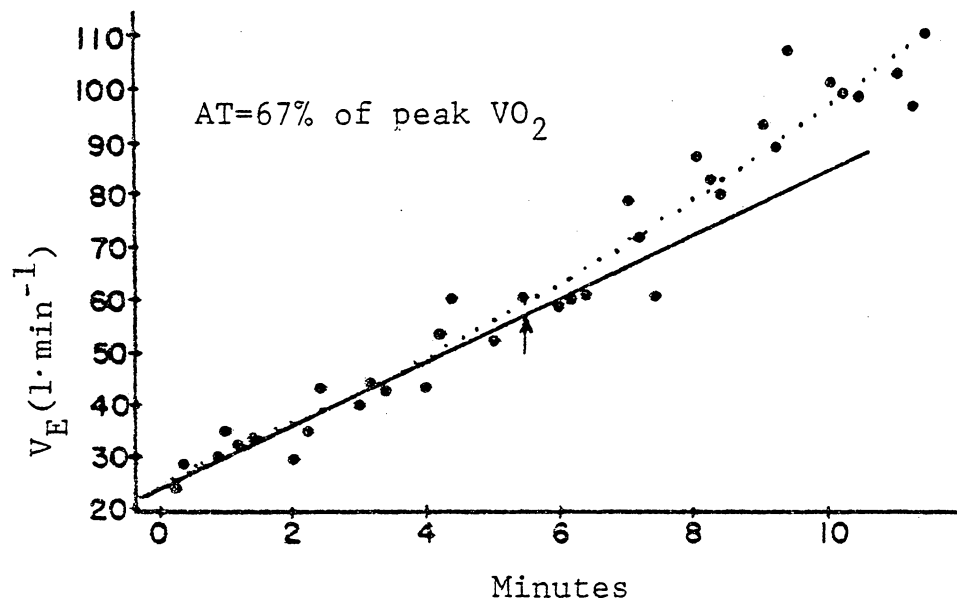
Subject 1



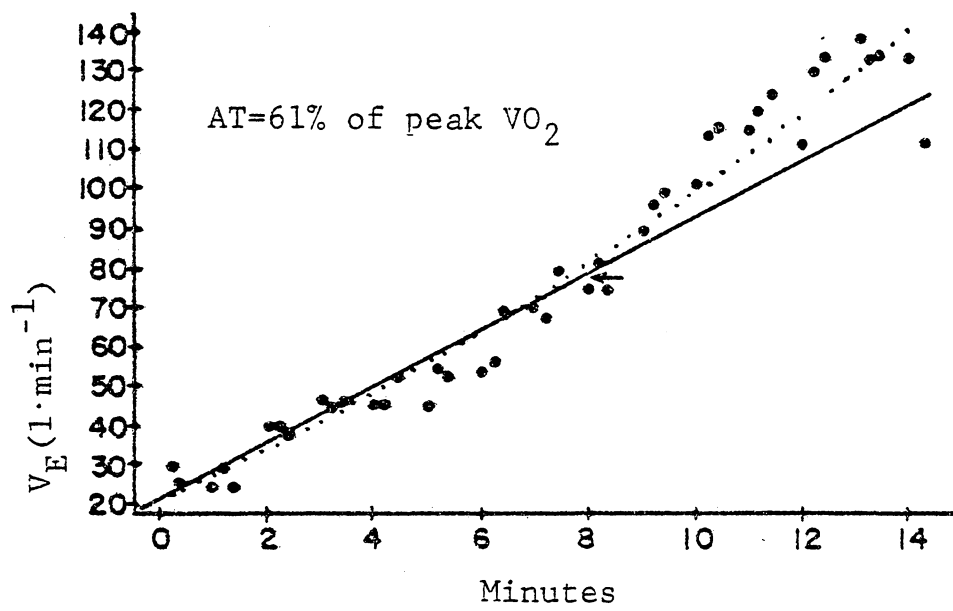
Subject 2



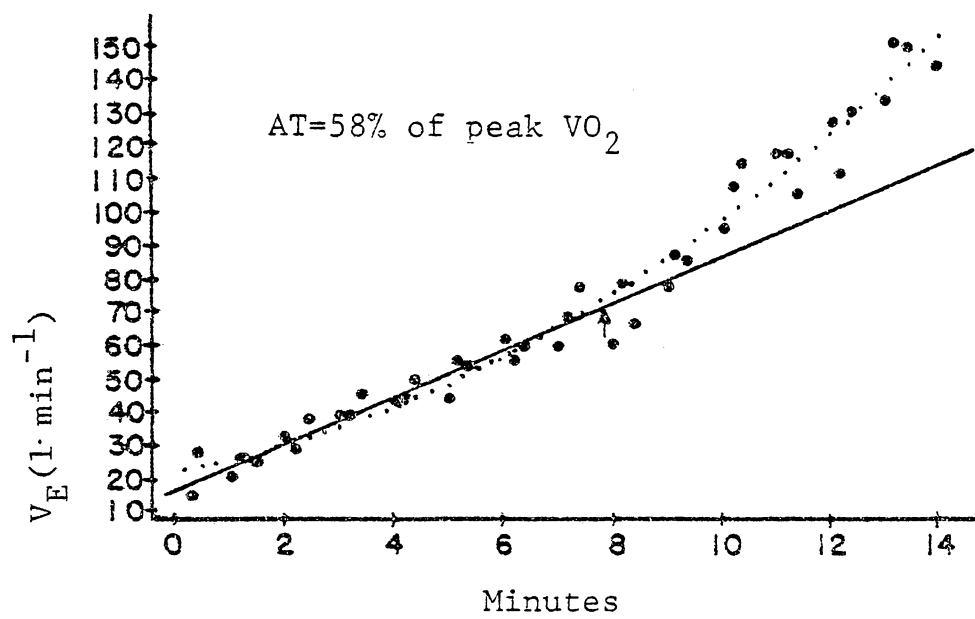
Subject 3



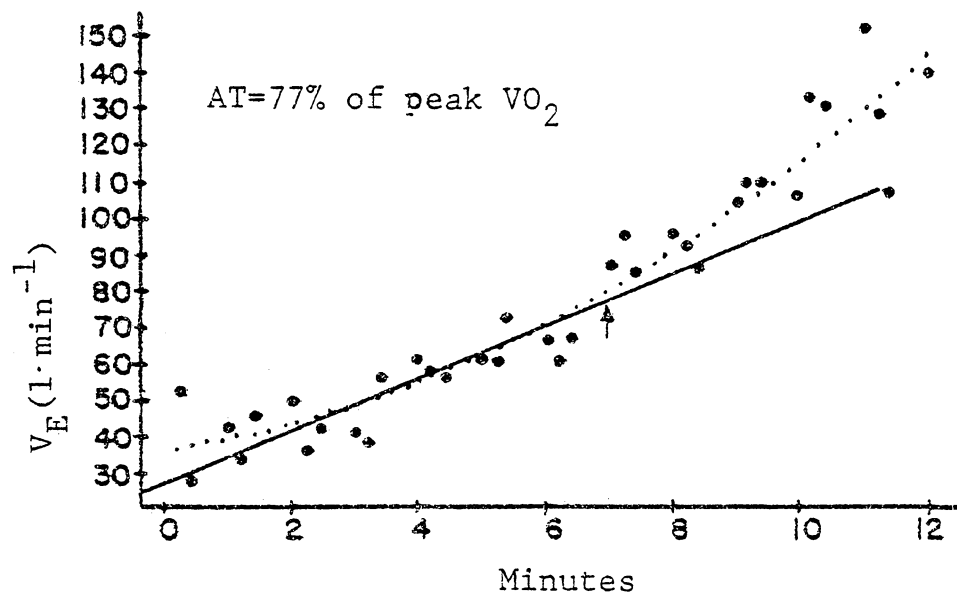
Subject 4



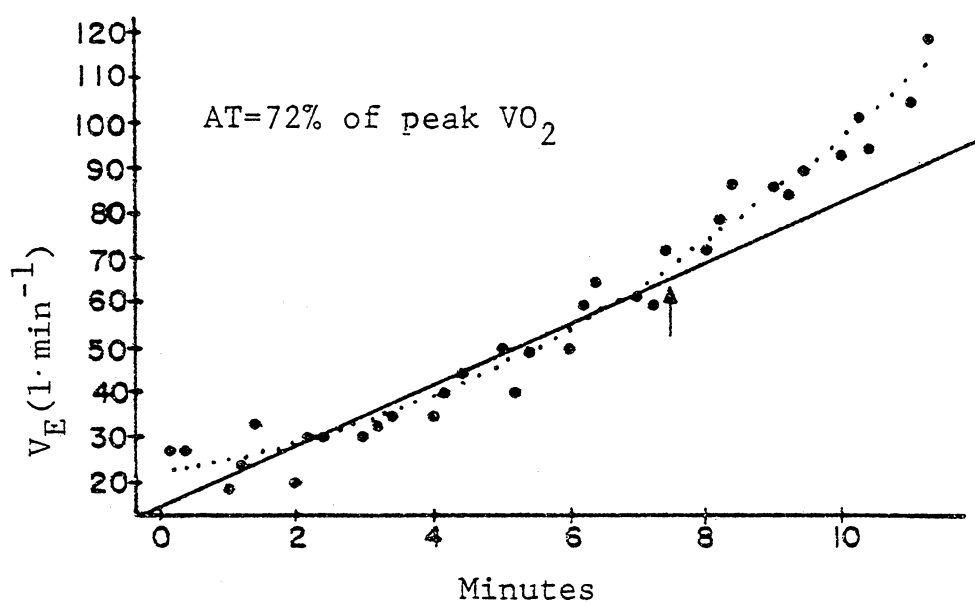
Subject 5



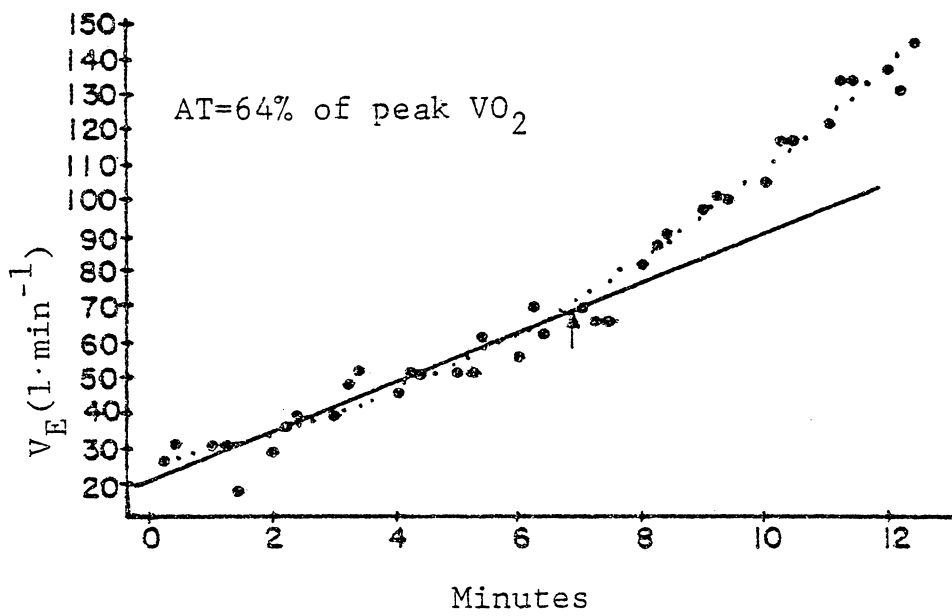
Subject 6



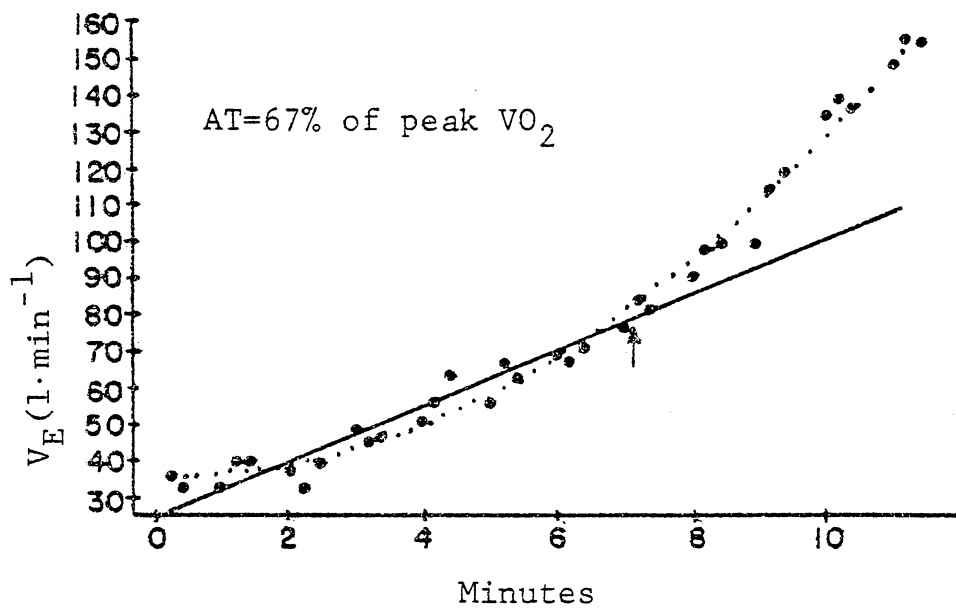
Subject 7



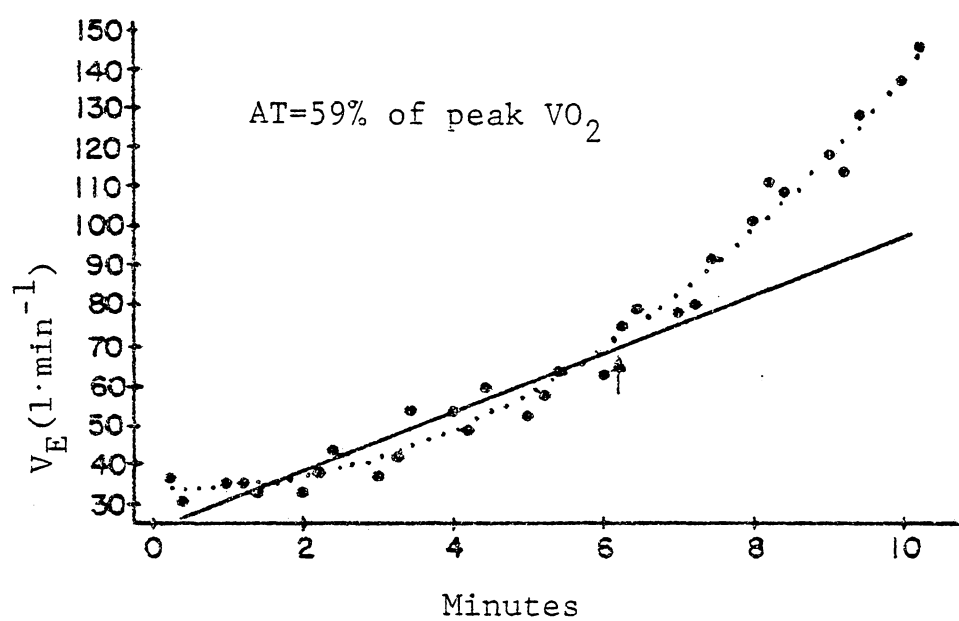
Subject 8



Subject 9



Subject 10



Appendix J

Subjects' GXT Data Sheets

Subject 1					
Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	125	31.8	1.92	1.47	.76
2	136	36.6	2.23	1.80	.80
3	136	34.8	1.94	1.75	.90
4	150	54.0	3.18	2.70	.85
5	162	66.0	2.92	3.16	1.08
5.2	167	66.0	3.08	3.08	1.00
5.4	167	63.6	2.70	2.93	1.09
*6	167	70.0	3.13	3.19	1.02
6.2	167	74.8	3.11	3.36	1.07
6.4	175	63.0	2.74	2.91	1.06
7	185	60.0	2.36	2.71	1.14
8	187	76.5	3.08	3.57	1.16
9	187	91.9	3.39	4.27	1.26
10	193	123.6	4.55	5.11	1.12
11	204	131.6	4.45	5.22	1.17
11.4	210	125.6	4.11	4.99	1.21

*denotes AT

Subject 2					
Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	100	32.0	1.48	1.29	.87
2	100	42.0	1.93	1.78	.92
3	103	37.0	1.73	1.62	.93
4	115	53.0	2.38	2.21	.92
5	125	54.0	2.27	2.16	.95
6	148	63.0	2.88	2.76	.95
6.2	136	69.0	3.00	3.05	1.01
6.4	143	65.0	3.03	2.91	.95
*7	150	70.0	3.07	2.95	.96
7.2	165	85.0	3.29	3.45	1.04
7.4	158	84.0	3.42	3.49	1.02
8	167	85.0	3.48	3.42	.98
9	167	82.0	3.00	3.25	1.08
10	187	96.0	3.61	3.89	1.07
11	187	108.0	3.86	4.17	1.07
12	193	126.0	4.24	4.78	1.12
12	193	124.0	4.27	4.88	1.14

*denotes AT

Subject 3					
Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	136	35	1.73	1.43	.82
2	143	29	1.52	1.38	.90
3	136	40	2.08	2.00	.96
4	150	43	2.54	2.23	.87
4.2	150	53	2.76	2.64	.95
4.4	158	60	2.88	2.87	.99
5	165	52	2.57	2.40	.93
*5.2	167	55	2.82	2.67	.94
5.4	167	60	3.03	2.75	.90
6	167	59	2.78	2.77	.99
6.2	177	60	2.84	2.77	.97
7	187	79	3.50	3.99	1.14
8	187	87	3.30	4.11	1.23
9	187	93	3.85	4.48	1.16
10	190	101	4.17	4.95	1.18
11	200	103	4.17	4.88	1.17
11.4	200	111	4.18	4.98	

*denotes AT

Subject 4

Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	105	24	1.29	.97	.75
2	107	40	2.10	1.62	.77
3	115	46	2.46	1.89	.77
4	125	45	2.38	2.00	.84
5	130	45	2.46	2.09	.85
6	143	54	2.79	2.47	.89
7	150	70	3.34	3.02	.90
7.2	150	67	3.13	2.85	.91
7.4	158	79	3.60	3.38	.94
*8	158	75	3.25	3.20	.98
8.2	160	81	3.92	3.64	.93
8.4	167	75	3.52	3.54	1.01
9	167	90	4.16	4.03	.97
10	177	102	4.71	4.55	.97
11	177	116	4.49	5.04	1.12
12	187	112	4.52	4.52	1.00
13	187	139	5.36	5.31	.99
14	187	134	5.03	5.05	1.00
14.2	187	113	4.00	4.22	1.05

*denotes AT

Subject 5

Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	100	15	.65	.55	.77
2	100	32	1.49	1.20	.80
3	107	38	1.73	1.43	.83
4	120	43	2.08	1.70	.82
5	130	44	1.96	1.86	.95
6	131	62	2.56	2.58	1.00
6.4	136	60	2.42	2.44	1.00
7	136	60	2.34	2.49	1.06
7.2	143	69	2.72	2.75	1.01
*7.4	143	77	2.76	3.13	1.13
8	150	60	2.43	2.37	.97
8.2	150	79	3.03	3.11	1.03
8.4	150	67	2.48	2.72	1.09
9	150	79	3.12	3.08	.99
10	167	96	3.71	3.62	.97
11	167	118	3.84	4.08	1.06
12	167	127	3.96	4.57	1.15
13	177	134	4.21	4.64	1.09
14	177	144	4.50	5.11	1.13

* denotes AT

Subject 6

Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	125	42	1.58	1.51	.95
2	126	50	2.45	1.99	.81
3	130	41	1.99	1.76	.88
4	136	61	2.78	2.53	.90
5	143	62	2.55	2.55	1.00
6	155	67	2.79	2.63	.94
6.2	158	61	2.40	2.41	1.00
6.4	165	67	2.68	2.79	1.03
*7	165	87	3.43	3.39	.99
7.2	167	95	3.54	3.65	1.03
7.4	167	85	3.16	3.32	1.05
8	167	95	3.14	3.53	1.13
9	180	104	3.33	3.83	1.15
10	187	106	3.51	3.92	1.12
11	187	152	4.44	5.13	1.15
12	187	139	4.10	4.54	1.11

*denotes AT

Subject 7					
Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	120	18	.79	.689	.86
2	120	21	1.18	.87	.73
3	125	31	1.74	1.40	.81
4	143	35	1.91	1.66	.87
5	145	50	2.57	2.29	.89
6	160	51	2.57	2.33	.90
6.2	167	60	2.84	2.73	.96
6.4	167	65.4	3.11	3.12	1.00
7	170	62	2.87	2.82	.99
*7.2	177	60	2.85	2.67	.94
7.4	177	71	3.20	3.27	1.02
8	177	72	3.09	3.27	1.06
8.2	187	79	3.35	3.39	1.01
9	180	86	3.71	3.79	1.02
10	190	93	3.81	4.10	1.07
11	200	105	3.50	4.04	1.15

* denotes AT

Subject 8

Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	97	31	1.59	1.08	.67
2	100	29	1.67	1.19	.71
3	107	41	2.16	1.83	.84
4	136	46	2.34	2.02	.87
5	136	52	2.42	2.26	.94
6	150	57	2.48	2.41	.97
6.2	158	70	3.12	2.97	.95
6.4	158	63	2.81	2.71	.96
*7	158	71	3.06	3.13	1.02
7.2	160	67	2.83	2.92	1.03
7.4	158	67	2.84	2.89	1.02
8	167	83	3.95	3.63	.92
9	177	98	4.08	3.99	.98
10	180	105	4.15	4.27	1.03
11	187	122	4.49	4.58	1.02
12	192	138	4.70	4.83	1.02
12.4	198	145	4.76	5.11	1.07

*denotes AT

Subject 9					
Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	120	33	1.33	1.41	1.25
2	125	38	1.84	1.70	.92
3	136	48	2.54	2.16	.85
4	136	51	2.42	2.28	.94
5	150	56	2.82	2.58	.91
6	160	69	3.00	2.97	.98
6.2	160	67	3.00	3.16	1.05
6.4	167	71	3.16	3.07	.97
*7	167	77	3.32	3.42	1.03
7.2	167	84	3.67	3.74	1.03
7.4	177	81	3.42	3.52	1.03
8	170	90	3.76	3.59	1.95
9	177	98	3.90	3.85	.99
10	187	134	4.64	5.05	1.08
11	197	148	4.84	5.33	1.10
11.4	200	154	4.74	5.31	1.11

*denotes AT

Subject 10					
Min.	HR	$\dot{V}_E$	$\dot{V}O_2$	$\dot{V}CO_2$	R
1	125	35	1.47	1.17	.79
2	130	33	1.43	1.26	.88
3	125	37	1.74	1.39	.80
4	150	53	2.31	1.97	.85
5	167	52	2.22	2.15	.96
5.2	167	57	2.37	2.08	.89
5.4	177	63	2.55	2.31	.90
*6	177	62	2.49	2.39	.96
6.2	177	74	3.22	2.81	.87
6.4	187	79	3.21	2.80	.87
7	187	78	3.15	2.86	.91
8	187	102	3.70	3.62	.98
9	190	117	3.89	4.02	1.04
10	198	146	4.19	4.26	1.01

*denotes AT

Appendix K

Subjects' GXT Determination Criterion

The subject continued to exercise until the following termination criteria was observed:

- A. abnormal blood pressure responses determined by baseline measurements from the first 2 measurements (If systolic blood pressure fails to rise during the first 10 minutes of the exercise session or exceeds 250 mmHg, or there is a 10 mmHg drop in systolic pressure. A diastolic pressure rise of more than 20 mmHg or greater than 110 to 120 mmHg (ACSM, 1980).
- B. signs of intolerance such as pallor, shortness of breath, staggering or persistent unsteadiness, mental confusion.
- C. the subject was unable to exercise for the 60 minute duration.

Appendix L
Individual Data During Training Simulation Tasks

Subject	Mean Heart Rates in Steady-State Period (bts·min)		Duration in Steady- State Period (min.)		Duration to Fatigue (min.)		Max Heart Rate During Continuous Exercise (bts·min)	
	KM	AT	KM	AT	KM	AT	KM	AT
1	172	167	8	31	30	40	198	187
2	153	147	8	6	40	34	187	177
3	167	168	9	7	55	60	187	187
4	153	152	7	33	31	45	167	167
5	135	130	60	60	60	60	136	136
6	155	154	12	51	55	60	180	167
7	162	175	26	28	60	35	187	187
8	157	159	5	5	60	50	187	187
9	159	162	3	9	51	60	187	187
10	152	154	29	60	30	60	177	158
$\bar{x}$	156	157	16.42	29.00	47.2	50.4	179.3	174
SD	9.9	12.7	17.3	22.09	13.05	11.07	17.3	17.2

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VALIDITY OF KARVONEN AND ANAEROBIC THRESHOLD METHODS FOR
PRESCRIBING EXERCISE IN HEALTHY ADULT MALES

by

Franki L. Robbins

(ABSTRACT)

The purpose of this study was to compare the Karvonen and anaerobic threshold methods for prescribing the intensity component of physical activity exercise prescription in healthy adult males. A performance criterion was utilized to determine both the duration at which the subjects could maintain a physiological steady-state as well as their capacity for sustained exercise at the levels prescribed by the two methods. Subjects were males, ages 22-26 years with a mean $\text{VO}_{2\text{max}} \pm \text{SD}$ of $59.2 \pm 5.6 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ and a predicted body fat of $14.1\% \pm 2.5\%$ (the latter estimated from regression formulas using skinfold measurements). Initially, subjects ($N=10$) performed graded exercise tests (GXT) to determine the exercise prescription. Each subject started at an initial load of 4 METS and thereafter increments were increased 0.33 METS every 20 seconds until volitional endpoints were reached. The variables measured during the GXT were oxygen uptake, ventilation, heart rate, blood pressure, respiratory exchange values and rating of perceived exertion (RPE). From the subjects' GXT, an exercise prescription was calculated by the Karvonen and anaerobic threshold prescription methods. Afterwards, a micro-computer was utilized to objectively and graphically display a predicted anaerobic threshold. Anaerobic threshold was accepted as the

point at which minute ventilation became non-linear with respect to time. From the graded exercise test, anaerobic thresholds were determined in all subjects from the ventilatory responses. Mean anaerobic thresholds ($\pm$ SD), when expressed as a percentage of the $VO_{2\max}$ were $65.3\% \pm 5.8\%$. The Karvonen method was also determined from the GXT data by multiplying a predetermined percentage (65-75% of the individual's cardiac reserve (cardiac reserve = $HR_{\max} - HR_{\text{rest}}$)). After the development of the exercise prescriptions, subjects were assigned to perform continuous exercise in two different training simulation trials. The order of assignment was randomized and administered in a double-blind fashion so that neither the researcher nor the subjects knew of the exercise prescription method being utilized. The subjects performed these trials on alternate days on a motor-driven treadmill for 60 min. To determine if a difference existed between the two exercise prescription methods, a series of dependent t-tests were performed on the following variables: duration of exercise at a prescribed level; the capacity to perform continuous exercise; oxygen uptake during the steady-state level; the rating of perceived exertion (RPE); and respiratory exchange values averaged for the entire simulation trials.

The duration that the subjects performed at a prescribed level was significantly longer utilizing the AT method versus the Karvonen method (AT vs. KM, 29.0 vs. 16.4 min, respectively). However, there were no significant differences found in the subjects' oxygen consumption or rating of perceived exertion. When assessing the subjects' maximal capacity to perform continuous exercise during these two training simulation tasks, no significant differences ($p \geq .05$) were found between

the two training simulations. A statistical significant difference but small mean increase ($p \leq .05$) was found in the peak heart rate ($KM=179$ and $AT=174 \text{ bts} \cdot \text{min}^{-1}$) attained during the training simulation tasks utilizing the two exercise prescription methods. Furthermore, a significant difference ($p \leq .05$) occurred in the subjects' duration to exercise during continuous exercise. The subjects' exercised significantly longer utilizing the AT method. These findings reflected that the AT method was a more sensitive technique for allowing individual variability. In conclusion, the results of this study suggest that the anaerobic threshold method is a valid procedure to determine the exercise intensity for young, healthy adult males.