A COMPARATIVE ANALYSIS OF THE HEART RATE-OXYGEN CONSUMPTION RELATIONSHIP OBSERVED DURING BRUCE PROTOCOL GRADED EXERCISE STRESS TESTS AND STEADY-STATE EXERCISE

by

V. C. Shafer-Millsap

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APPROVED:

Don R. Sebolt, Chairman

William G. Herbert

Janet L. Walberg

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(ABSTRACT)

Twenty-eight endurance trained male volunteers, 18-41 years of age, were studied to determine whether the heart rate-oxygen consumption relationships observed during Bruce protocol stress tests were similar to those observed during steady-state exercise. In addition, maximal oxygen consumption and maximal heart rate values obtained during the stress tests were compared to predicted values.

The heart rate-oxygen consumption relationship observed during the stress tests was dissimilar from the relationship observed during the steady-state exercise tests. Heart rate was found to be significantly higher during the stress tests. No significant difference was found in predicted maximal oxygen consumption and maximal heart rate and actual values obtained during the stress tests.

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Chapter I

INTRODUCTION

One of the most powerful and important men in an eighteenth century American Indian tribe was the medicine man. When someone was sick, the medicine man would perform rituals and administer secret powders. Often the patient would recover. Medicine men did not understand disease etiology or what the curative agent was they used. They only knew what was effective and what was not.

The white men had their health "professionals" also. There was the traveling doctor who hawked elixirs guaranteed to cure just about any ailment. The "real doctors" were using leaches to draw out poisons. The less wealthy people relied on "old wives" to cure them. All of these "professionals" discovered through trial and error what was effective. Their patients often survived too.

Many of today's patients survive because of the benefits of modern science. The expected life span is longer than it has ever been. Deaths due to measles, plague, and similar scourges have been virtually eliminated. The average individual now dies as a result of a civilized disease, cardiovascular disease. Approximately half of the deaths in this country in 1984 could be attributed to cardiovascular disease (Hoeger, 1986). In treating cardiovascular disease, today's health practitioner is faced with problems similar to those of his earlier counterparts. For example, the complete etiology of cardiovascular disease is unknown. It is also not well established why certain treatments are effective. The health practitioner simply prescribes treatments that past experience have proven effective.

Statement of the Problem

One treatment for cardiovascular disease that appears to be effective is exercise. "We've got more people alive because of exercise. It has slowed down the progression of disease" (Miller cited in Legwold, 1985, p. 148). The reasons for exercise's effectiveness are still not well established. One postulated mechanism is improved cardiovascular fitness induced by exercise (LaPorte et al., 1984). Exercise prescriptions are designed to improve cardiovascular fitness and should specify exercise frequency, duration, and intensity (Pollock, Wilmore, & Fox, 1984).

The results of an exercise stress test are frequently the basis for exercise prescriptions. The health practitioner observes a patient's physiological responses and prescribes accordingly. The practitioner assumes the physiological responses observed during the stress test are similar to those which would occur during exercise performed in other settings. For example, he assumes that the heart rate observed at various oxygen consumption levels during the stress test will be the same heart rate observed at similar levels during exercise performed at a steady rate of oxygen consumption.

The purpose of this study was to investigate the relationship between the results of a Bruce protocol stress test and a subsequent exercise prescription. Specifically, this investigation examined the differences in heart rate measured at 60% and 75% of maximal oxygen consumption during a Bruce protocol stress test and heart rate measured during exercise tests (steady-state walking or jogging) of similar oxygen uptake requirements. Predicted and actual maximal oxygen uptake, and maximal heart rate values were also compared.

Research Hypotheses

In this investigation, the following null hypotheses were tested:

1. There was no significant difference between the heart rate-oxygen consumption relationship observed during a Bruce protocol stress test at 60% and 75% of maximal oxygen consumption and the relationship observed at similar intensities during steady-state jogging on a treadmill.

2. There were no significant differences between the maximal oxygen consumption predicted by the equations developed by Bruce, Kusumi, and Hosmer (1973), and actual maximal oxygen consumption values obtained during a Bruce protocol stress test.

3. There was no significant difference between the maximal heart rate predicted by the equation developed by Karvonen, Kentala, and Mustala (1957) and actual maximal heart rate obtained during a Bruce protocol stress test.

Significance of the Study

Approximately one half of the people who died in 1984, died as a result of cardiovascular disease (Hoeger, 1986). Vast sums of money are being spent on research to control these diseases. Exercise has been suggested as one controlling factor, because of its beneficial effects on cardiovascular parameters (Pollock et al., 1984). Furthermore, exercise is recommended in the treatment of cardiovascular disease (Hammond, 1985). Health practitioners are increasingly being called upon to prescribe exercise programs.

The results of cardiovascular assessment procedures are used in prescribing exercise (Hellerstein, & Franklin, 1984, chap. 10). One assessment procedure frequently used is the Bruce protocol stress test. Exercise prescriptions are based on factors such as the heart rate-oxygen consumption relationship, maximal oxygen uptake, and maximal heart rate. Underlying the practice of exercise prescription is the assumption that the heart rate observed at various oxygen consumption levels during a Bruce protocol stress test is the same as that observed at similar oxygen consumption levels during steady-state exercise.

If this assumption is in error, the exercise intensities prescribed may be inappropriate. Exercise intensities may be too low for significant training effects to occur or too high to be safe for subject's unknowingly at risk. Pollock et al. (1984) contended an exercise intensity of 50% of maximal oxygen consumption represents a threshold for improving cardiovascular function.

Mead, Pyfer, Trombold, and Frederick (1976) investigated exercise performed at high intensities. These researchers reviewed 15 episodes of cardiac arrest during supervised exercise and found that 12 of the victims had previously been training at exercise intensities between 80-85% maximal heart rate. Eighty to eighty five percent maximal heart rate approximates 71-78% maximal oxygen consumption (Hellerstein & Franklin, 1984). Exercise intensities above 80% maximal oxygen consumption appear not to be safe (Mead et al., 1976). Hossack and Hartwig (1985) reported 15 male participants who had experienced cardiac arrest during a supervised exercise rehabilitation program had exceeded their target heart ranges significantly more often than a control group. For the cardiac arrest group during exercise, the average heart rate was 102.8% of the upper limit of their target heart range as compared to 93.8% for the control group (Hossack & Hartwig, 1985). High intensities are not necessary to bring about significant improvements in cardiovascular function (Hellerstein and Franklin, 1984, chap. 10). Hellerstein and Franklin (1984, chap. 10) reported improvements increase curvilinearly with exercise intensity and peak at approximately 78% of maximal oxygen consumption. Pollock et al. (1972) reported no significant difference between middle-aged men who trained at 97% and those who trained at 83% maximal oxygen consumption with respect to improvements in cardiovascular fitness. In addition, high exercise intensities (95-100% maximal oxygen consumption) usually cannot be sustained long enough for subjects to develop endurance (Hellerstein & Franklin, 1984, chap. 10). Subjects prescribed high exercise intensities have an increased rate of noncompliance (Pollock et al., 1984). They suggested high intensity exercise is somewhat unattractive to noncompetitive middle-aged and older adults. High training heart rates are more difficult to obtain and can be a source of frustration to subjects.

Errors in prescribing exercise intensity can also be made if the prescriptions are based on incorrect maximal oxygen consumption and maximal heart rate values. Many health and exercise facilities do not have the capabilities to obtain actual values; therefore, predicted values are used. If the predicted values differ significantly from actual values, the exercise intensity may differ significantly from an appropriate level. Given the increased use of exercise as preventive medicine and treatment for cardiovascular disease, it is imperative that appropriate exercise intensities be prescribed (Mann, Garrett, Farhi, Murray, & Billings, 1969).

Definitions and Symbols

1. APPARENTLY HEALTHY: Persons "who are apparently healthy and have no major coronary risk factors" (American College of Sports Medicine [ACSM], 1986, p. 2).

2. BRUCE PROTOCOL: The multistage treadmill protocol established by Bruce et al. (1973) to be used in maximal exercise stress tests.

3. GRADED EXERCISE STRESS TEST: An incremental exercise test designed to stress the cardiovascular system. The test is generally performed with a bicycle ergometer or a motorized treadmill.

4. HEART RATE-OXYGEN CONSUMPTION RELATIONSHIP: The relationship between an individual's heart rate and level of oxygen consumption.

5. MAXIMAL HEART RATE: Maximum heart rate per minute.

6. MAXIMAL MINUTE VOLUME OF OXYGEN UPTAKE (VO_2max): Maximum volume of oxygen consumed in milliliters per minute. The oxygen consumed was measured in 30 second increments and expressed in milliliters per minute.

7. MINUTE VOLUME OF OXYGEN UPTAKE: volume of oxygen consumed in milliliters per minute.

8. STEADY-STATE EXERCISE: Exercise that is performed at a steady intensity as measured by oxygen consumption.

Delimitations

The following delimitations applied to this investigation:

1. Twenty-eight apparently healthy, endurance trained males between 18 and 41 years of age participated in this study.

2. The heart rate-oxygen consumption relationship was observed at 60% VO_2max during a Bruce protocol stress test and during steady-state exercise performed on a treadmill.

3. The heart rate-oxygen consumption relationship was observed at 75% VO_2max during a Bruce protocol stress test and during steady-state exercise performed on a treadmill.

Limitations

The following limitations applied to this investigation:

1. Any differences that were found in heart rates during the Bruce protocol stress tests and the steady-state exercise tests at similar oxygen consumption levels may be due to the fitness level of the subjects.

Basic Assumptions

The following assumptions were made by the investigator:

1. It was assumed that all subjects complied with instructions in preparing for the exercise stress test and steady-state exercise tests.

2. It was assumed that subjects' health and training statuses remained the same throughout the study.

3. It was assumed that subjects gave their maximal efforts during the Bruce protocol stress test.

4. It was assumed that subjects reached a steady-state of oxygen consumption during the steady-state exercise tests used.

5. It was assumed that the recorded gas values, ventilation values, and electrocardiographic values were accurately synchronized.

6. All statistical assumptions were met.

Summary

Often throughout history, health practitioners have not fully understood the etiology of a disease and/or why their treatments are effective. One such disease is cardiovascular disease. Currently, vast sums of research money are being spent on cardiovascular disease.

Research results support the postulation of exercise induced cardiovascular fitness as a controlling factor for cardiovascular disease (Hammond, 1985; LaPorte et al., 1984). The majority of deaths in the United states are attributed to cardiovascular disease; therefore, there is a high demand for preventative prescriptions (Stromme et al., 1984). In response, health practitioners are prescribing exercise (specifying intensity in terms of heart rate). The prescription is frequently based on the results of a stress test in which the heart rate-oxygen consumption relationship has been observed. The health practitioner assumes that the same relationship exists during steady-state exercise.

The Bruce protocol stress test is the most frequently employed clinical graded exercise stress test (Stuart & Ellestad, 1980). Health practitioners are prescribing exercise based on observed or predicted oxygen consumption values and heart rate values obtained during these tests;

therefore, this study was conducted to investigate the validity of extrapolating the heart rate-oxygen consumption relationship from a Bruce protocol stress test to steady-state exercise. The heart rate-oxygen consumption relationship was observed at 60% and 75% VO_2max during the stress test and during steady-state exercise. The accuracy of predicting maximal oxygen consumption by using the equations of Bruce et al. (1973) and predicting maximal heart rate by the formula developed by Karvonen et al. (1957) was also examined.

Chapter II

LITERATURE REVIEW

This chapter focuses on literature concerning cardiovascular disease, physical activity in the prevention and treatment of cardiovascular disease, exercise prescription, the heart rate oxygen consumption relationship, the heart rate-oxygen consumption relationship in different physical activities, the heart-rate oxygen consumption relationship with respect to temperature and emotion, and prediction of VO_2max and maximal heart rate.

Cardiovascular Disease

In 1984, approximately one half of the deaths in this country could be attributed to cardiovascular disease (Hoeger, 1986). Heart attacks were the leading cause of death. The nearly one million cardiovascular disease deaths approximated all the deaths caused by cancer, accidents, pneumonia, influenza, and other causes combined. Cardiovascular disease struck young and old alike, one fifth of the deaths occurred in persons under age 65 (American Heart Association [AHA], 1984).

In an economic sense, the cost of cardiovascular disease is also high. The American Heart Association in 1984, estimated that $72.1 billion was expended in 1985 for cardiovascular disease related expenses. "Heart attacks alone cost American industry 132 million workdays annually, including $12.4 billion in lost productivity because of physical and emotional disability" (Hoeger, 1986, p. 2). It is estimated that $700 million a year is spent in replacing employees who are recovering from heart attacks. The American Heart Association alone has spent $522 million on cardiovascular disease research since 1949 (AHA, 1984).

Investigators have elucidated various risk factors for cardiovascular disease. Cigarette smoking, hypertension, hypercholesterolemia, and diabetes mellitus are major risk factors; while obesity, and a sedentary life style are contributory factors (AHA, 1985; ACSM, 1986).

Physical Activity in the Prevention and Treatment of Cardiovascular Disease

Cigarette Smoking

Hickey, Mulkahy, Bourke, Graham, and Wilson-Davis (1975) examined the relationship between physical activity and cardiovascular disease risk factors in 15,171 males, 25 to 74 years of age. These researchers reported a negative association between leisure activity and cigarette smoking.

However, Hickey et al. (1975) reported no association between physical activity performed at work and smoking behavior. Other researchers have reported negative associations between physical activity and cigarette smoking, but failed to differentiate between physical activity performed during leisure time and work (Thomas 1979). Hickey and coworkers (1975) suggested that men who are physically active during their leisure time smoke less for personal, psychological or cultural reasons. These researchers felt that physical activity itself was not the direct cause of reduction in cigarette smoking.

In contrast, Stromme et al. (1984) concluded that physical activity itself caused a decrease in smoking behavior. Perhaps as a person becomes physically active, their self-image changes and "the individual increasingly regards himself as an 'athlete' whose body should be respected" (Stromme et al., 1984, p. 317). Taylor, a psychiatrist performed a study with 93 male post-myocardial infarction patients (48 to 60 years of age) and concluded that the decline in smoking behavior by new exercise participants was more than a change in self image (Duda, 1984). Taylor stated, "there seemed to be some sort of training effect independent of psychological factors" (Duda, 1984, p. 23).

Other researchers found no relation between physical activity and smoking behavior (Ilmarinen, & Fardy, 1977;

Paffenbarger, 1970). Blair (1985) felt that the data weakly supported "the hypothesis that physical activity and smoking are negatively associated" (p. 164). It appears that more research is needed to determine whether a relationship exists and if it does; the quantity and intensity of physical activity necessary to decrease smoking behavior.

Hypertension

Seals and Hagberg (1984) reviewed studies concerned with hypertension and exercise published in English from 1967-1983 and offered a theoretical basis for the use of exercise training in treating hypertensive individuals. They suggested the physiological responses to exercise may lower blood pressure. The acute vasodilatory effect of exercise may lead to a "chronic state of vasodilation and, therefore, a reduction in vascular resistance and blood pressure at rest" (Seals & Hagberg, 1984, p. 208). A reduction in sympathetic tone is also suggested as a possible mechanism for lowering blood pressure (Seals & Hagberg, 1984).

Seals and Hagberg (1984) also discussed numerous epidemiological studies indicating that active individuals have lower resting blood pressures than their less active, age-matched counterparts. Out of the 12 studies reviewed, 8 reported "modest reductions in systolic and/or diastolic blood pressure at rest. The average reduction in blood pressure for these studies was 9 mmHg for systolic blood pressure and 7 mmHg for diastolic pressure" (Seals & Hagberg, 1984, p. 213). However, Seals and Hagberg (1984) suggested that these results be interpreted with cautioned because of design and methodological weaknesses. Seals and Hagberg (1984) concluded that the reductions in blood pressure of the reported magnitude could be clinically important to the long range health status of the hypertensive individual; however, the available evidence is "inadequate to recommend exercise training as a substitute for pharmacological intervention in hypertension" (p. 214). These reviewers did not discuss the use of exercise training as an adjunct to pharmacological intervention or as preventative therapy for hypertension. Powell (1985) and Siscovik (1985) suggested that physical activity has a beneficial effect on hypertension, but agreed with Seals and Hagberg's (1984) position that more research is necessary.

In contrast to the above mentioned authors' conservative position Tipton (1984) in his review, concluded that the literature justifies the inclusion of "exercise training as a separate countermeasure in a program designed for either hypertensive or hypertension-prone individuals. The magnitude of pressure changes will range from 5 to 25 mmHg depending upon the age and health status of the patient and the training conditions utilized" (284). Tipton (1984) was not advocating replacement of pharmacological intervention, but consideration of exercise training as a separate treatment. Neither Tipton or any other author discussed the quantity or intensity of exercise required to lower blood pressure.

Hypercholesterolemia

Cholesterol is present in the blood stream in different plasma lipoproteins. High density lipoprotein cholesterol levels have a negative correlation and low density lipoprotein levels have a positive correlation with cardiovascular disease (Rainville & Vaccaro, 1983). Furthermore, Rainville and Vaccaro (1983) and Wood and Haskell (1979) upon reviewing the literature concluded that plasma levels of high density lipoprotein are positively correlated and plasma levels of low density lipoprotein are negatively correlated with exercise levels. Thus a high level of physical activity is associated with a high level of high density lipoprotein and a low risk for cardiovascular disease disease.

The results of work done by Thompson, Cullinane, Henderson, and Herbert (1980) indicate that the changes observed in total cholesterol plasma levels in inveterate exercise participants could be due to acute changes caused by exercise. These investigators based their conclusions on the analysis of blood samples drawn from trained individuals before and at periodic intervals after a 42 km footrace. In a similar type study, Lennon et al. (1983) analyzed blood samples from trained individuals before, during, and after bicycling at 40% VO_2max. Thompson et al. (1980) and Lennon et al. (1983) concluded that favorable changes in lipoprotein values occurred acutely. However, both groups of researchers used trained individuals; therefore, the changes they noted may have been due to the single bout of exercise or to a lipoprotein alteration mechanism already operating.

Cullinane, Lazarus, Thompson, Saritelli, and Herbert (1981) examined the acute effects of bicycling for 30 minutes at 75% of estimated VO_2max on plasma lipoprotein levels in sedentary subjects. These researchers reported no significant changes in lipoprotein levels. Perhaps the exercise bout was too short. In 1982, Cullinane, Siconolfe, Saritelli, and Thompson examined acute lipoprotein level changes in a similar study utilizing an hour long exercise bout. Again, no significant changes were observed in lipoprotein levels.

Quig et al. (1983) did report significantly lower levels of total cholesterol in sedentary subjects after a 6 week aerobic exercise program. The changes in plasma high density lipoprotein levels were nonsignificant. Myhre, Mjos, Bjorsvik, and Stromme (1981) after studying well trained competitive cross-country skiers concluded that elevated plasma levels of high density lipoprotein are associated with high levels of physical activity and are related to both the amount and intensity of training. These researchers reported that high density lipoprotein levels were high during physical endurance training of low intensity and long duration, and lower when training hours were decreased and intensity increased. Myhre et al.'s (1981) results substantiated Cullinane et al.'s (1982) conclusion that the lipoprotein pattern observed in inveterate exercise participants is due to a chronic effect of exercise. Haskell (1984) after reviewing the literature concluded exercise exerted acute and chronic effects on plasma lipoprotein concentrations. The quantity and intensity of exercise necessary to bring about lipoprotein changes has not been determined.

Diabetes Mellitus

At this time there is not a solid experimental basis for the recommendation of physical activity as a treatment for diabetic individuals (Maehlum et al.'s study cited in Stromme et al., 1984). However, "little doubt exists that physical activity improves carbohydrate tolerance" (Stromme et al., 1984, p. 368). Exercise "exerts an influence to enhance glucose uptake and subsequent oxidation by the working muscle" (Terjung, 1979, p. 160). Physical activity may improve the regulation of diabetes by contributing to lower blood sugar levels over a prolonged period (Stromme et al., 1984).

Some researchers considered physical activity an effective tool in treatment because of the strict regulation of blood sugar levels desired in prevention of diabetic complications (LaPorte et al., 1985; Siscovik, 1985; Thomas, 1979). Powell (1985) cautioned more research was required; although, physical activity probably has a beneficial effect. Further research is required to not only elucidate the possible benefits of exercise training for the diabetic individual, but also to identify the necessary quantity and intensity of exercise required to bring about any such benefits.

Obesity

Obesity has reached epidemic proportions in this country (Abraham & Johnson, 1980). Bray (1976) estimates that 40% of the population is obese. Exercise has been suggested as a possible treatment because of its positive association with weight control (Blair, 1985). Exercise expends calories and aids in caloric balance.

Exercise also appears to prevent the lowered resting metabolic rate experienced by persons on a diet. Donahoe, Lin, Kirschenbaum, and Keesey (1984) reported that when exercise was added to the treatment of obesity, an individual's resting metabolic rate increased to levels appropriate for his prevailing body weight. Thus by combining diet and exercise, more energy was expended due to the exercise itself and an increased resting metabolic rate.

The reason for the increased resting metabolic rate when exercise is combined with diet is unknown. Donahoe et al. (1984) postulated lean tissue may become chronically more metabolically active. In their study, subjects had an increased resting metabolic rate 8 to 10 hours after exercise. These researchers postulated the existing lean tissue was the cause of the higher metabolic rate because the subjects experienced the rate change before a significant change in lean tissue mass occurred (Donahoe et al., 1984).

Perhaps lean tissue is not the cause of the increased resting metabolic rate. Bosello et al. (1981) observed that by combining exercise with a low calorie diet, the thyroid hormone changes normally seen with a low calorie diet were not as significant. These researchers suggested "physical exercise can limit the shunt of peripheral thyroid hormone metabolism from active to inactive pathways" (Bosello et al., 1981, p. 651-652).

Other researchers would dispute this additional benefit of exercise. Warwick and Garrow (1981) reported no significant change in basal metabolic rate and spontaneous activity of 3 obese women when exercise was added to their treatment. Freedman-Akabas, Colt, Kissileff, & Pi-Sunyer (1985) reported similar results with subjects who underwent a more controlled exercise program. Perhaps an increased resting metabolic rate is a chronic effect of exercise.

Some researchers suggested exercise may affect the thermic effect of food. Bray (1976) reported an increased thermic effect of food when subjects exercised after eating. Gleeson, Brown, Waring & Stock (1982) observed an exercise induced dietary thermogenesis in rats.

Any conclusions regarding the effects of exercise are tentative because of the lack of extensive research in this area. However, the addition of exercise in the treatment of obesity is recommended because of the caloric cost of exercise.

Sedentary Life Style

Stromme et al. (1984) in their review article suggested a sedentary life-style is an independent risk factor for coronary vascular disease and physical activity is a protective factor in its own right. LaPorte, Dearwater, Cauley, Slemenda, and Cook (1985) concluded there is strong evidence supporting a negative association between physical activity and coronary vascular disease. LaPorte and coworkers (1985) clarified their position by distinguishing cardiovascular fitness or aerobic capacity from physical activity. These researchers contended cardiovascular fitness may not be as important as physical activity in protecting against disease" (Laporte et al., 1985, p. 146). LaPorte et al. (1984) suggested epidemiologic studies which reported significant findings did not demonstrate a relationship between cardiovascular fitness and coronary vascular disease, but between physical activity and coronary vascular disease. LaPorte and coworkers (1984) cited Goldsmith and Heile's results as an example. Goldsmith and Heile reported no significant difference in cardiovascular fitness (VO_2max) between postal carriers or policemen walking a beat who appeared to have a lower risk of coronary vascular disease and sedentary controls. LaPorte et al. (1984) suggested that the bus conductors in Morris et al.'s study did not have higher VO_2maxs than the bus drivers.

The American Heart Association echoed LaPorte et al.'s (1984, 1985) uncertainty regarding the role of exercise in coronary vascular disease. "Lack of exercise has not been clearly established as a risk factor for heart attack" (AHA, 1985, p. 20). Cardiologist Dr. Henry Solomon in his book The Exercise Myth, argued exercise does not decrease an individual's chance of developing coronary vascular disease, a greater VO_2max does not mean healthier coronary arteries, and a lower resting heart rate is not necessarily healthier.

Solomon contended that exercise increases cardiovascular performance but not cardiovascular health (cited in Haskell, 1985).

In opposition to Solomon's views, improved cardiovascular performance, a component of cardiovascular fitness, has been postulated as a primary mechanism for protection from heart attack (LaPorte et al., 1984). In a heart attack, death of myocardial tissue occurs due to anoxia. Rate-pressure product is an index of myocardial oxygen demand and indirectly myocardial performance. Hammond (1985) concluded "the rate-pressure product is lower at any absolute work load following an exercise program" (p. 531). If a rate-pressure product is low, there is less chance of anoxia.

Other researchers take exception to Solomon's argument that cardiovascular health, a component of cardiovascular fitness, is not improved with exercise. Hammond (1985) contended some individuals' cardiovascular health, as evidenced by increased myocardial perfusion, was improved with exercise. Froelicher et al. (1984) randomly assigned 146 male patients with coronary vascular disease to an exercise program and a conventional treatment program. These researchers reported improved myocardial perfusion or cardiovascular health.

Perhaps improved cardiovascular fitness is one of the primary mechanisms for protection from heart attacks. The lower mortality rates of exercising coronary vascular disease patients supports this theory. Hammond (1985) stated, "although no randomized prospective study has shown a statistically significant increase in survival after chronic dynamic exercise, most studies show a favorable trend, with an annual mortality 20% to 30% lower than control rates" (p. 531). However, intense physical activity may cause a heart attack. "Our data support the view that even though intense physical activity may be one of the factors that can precipitate primary cardiac arrest, habitual participation in such activity is associated with an overall reduction in the risk of primary cardiac arrest" (Siscovick, Weiss, Fletcher, & Lasky, 1984, p. 876).

Another primary mechanism postulated by LaPorte et al. (1984) for reducing the risk of heart attack is increased physical activity. These researchers proposed physical activity indirectly reduces the risk of heart attack by modifying risk factors. LaPorte and his colleagues questioned whether cardiovascular fitness is a necessary component in risk factor reduction. These researchers contended that it is possible to be physically active, have a reduced risk for coronary vascular disease, and be cardiovascularly unfit. For example, a physically active, nonathletic, working population had an average high density lipoprotein plasma level of 42 mg/dl; while people with spinal cord injuries averaged 26 mg/dl (LaPorte, Brenes, &

Dearwater, 1983). LaPorte and his fellow researchers (1984) suggested a broader spectrum of physical activity needs to be examined in order to elucidate the roles of cardiovascular fitness and physical activity in cardiovascular disease prevention.

Blair (1985) agreed with his colleagues that more research with less active (disabled) persons is needed. However, Blair disagreed that cardiovascular fitness can be separated from physical activity. He argued that LaPorte et al.'s (1984) statements regarding mail carriers, policemen, and bus workers are not tenable because only work related physical activity was considered. Hickey et al. (1975) has demonstrated that erroneous conclusions can be drawn when leisure activity is disregarded.

Blair (1985) raised the issue of whether a physical activity threshold exists for improving cardiovascular fitness. "Intuitively this is an attractive concept, but the answer is not simple" (Blair, 1985, p. 154). Many authors and organizations have suggested a physical activity intensity of approximately 75% VO_2max; however, Blair et al. (cited in Blair, 1985) reported significant changes in VO_2max in a group of relatively fit college men after an exercise program with an intensity of 50% VO_2max. In addition, these changes were not significantly different "than changes in a similar group of men who performed the same total amount of work at 80% of VO_2max" (Blair et al.

cited in Blair, 1985, p. 154). Perhaps those studies which demonstrated differences in coronary vascular disease risk factors but not cardiovascular fitness were of insufficient duration to cause VO_2max changes give the intensity used.

Blair (1985) submitted the physical activity threshold for improving cardiovascular fitness remains to be determined along with the thresholds for the various coronary vascular disease risk factors. He argued that the relationship between physical activity and each of the risk factors may be different. Certain levels of physical activity may be appropriate for lowering blood pressure but not for increasing high density lipoprotein plasma levels. Blair's model of the relationship between physical activity and coronary vascular disease allows for LaPorte et al.'s supposition that some benefits may be derived from being physically active but not cardiovascularly fit. Laporte et al.'s (1984) primary mechanisms for reducing the risk of heart attack also are in harmony with Blair's model.

Exercise Prescription

In order to obtain improvement in cardiovascular fitness, the cardiorespiratory system must be overloaded (Brooks & Fahey, 1984). Within limits, the amount of overload used is the most important factor in cardiorespiratory improvement (Pollock et al. 1984).

Pollock et al. (1984) maintained that 180-300 liters of oxygen (900-1,500 Kcal) per week or 60-100 liters of oxygen (300-500 Kcal) per exercise session is a sufficient overload for most people. This overloaded can be achieved by having the individual perform greater physical activity than customarily performed. The type, frequency, duration, and intensity of physical activity used in overloading the cardiovascular system must be specified.

Type of Physical Activity

Cardiovascular fitness is "best enhanced by dynamic aerobic activities involving sustained movement of large muscle groups" (Hellerstein & Franklin, 1984, p. 253). Walking, hiking, bicycling, basketball, jogging, cross-country skiing, racquetball, tennis, running, and swimming are examples of appropriate activities. Walking, jogging, and cycling are relatively consistent in energy expenditure; therefore, these activities lend themselves well to exercise prescription. Pollock, Dimmick, Miller, Kendrick, and Linnerud (1975) demonstrated these activities are equally effective modes of training.

Frequency of Physical Activity

Gettman et al. (1976) reported that improvements in cardiovascular fitness were in direct proportion to the frequency of training. Surprisingly, improvements were noted with a frequency as low as 1 training session per week. Perhaps the improvements occurred, in part, because the researchers used an exercise intensity between 85-90% of maximal heart rate for a 30 minute session. It may be difficult for the average individual to perform at that high of an intensity.

Hellerstein and Franklin (1984) reported an optimal training frequency of 3-4 sessions per week. This is the same frequency recommended by the American Heart Association (1972), and by the American College of Sports Medicine (1986) for individuals with a 5-8 MET capacity.

Duration of Physical Activity

Improvement in cardiovascular fitness is directly related to the duration of activity (Pollock et al., 1984). Ribisl (1980) suggested 30-45 minutes as an optimal session length. He maintained that shorter durations consistently produce less significant gains in cardiorespiratory fitness; while longer durations offer little advantages (Ribisl, 1980). The American Heart Association (1972) and the American College of Sports Medicine (1986) recommended exercise sessions be at least 15 minutes long. Hellerstein and Franklin (1984) recommended 20-30 minute sessions because sessions greater than 30 minutes have a greater risk of orthopedic complications.

Exercise duration can not be considered independent from exercise intensity. The two factors are related in an inverse, nonlinear relationship (Ribisl, 1980). Pollock et al. (1984) maintained that as long as an exercise intensity threshold is met and the total energy expenditure is the same, duration and intensity can be manipulated without detracting from improvements in cardiovascular fitness. The American College of Sports Medicine (1986) recommended that the interaction of duration and intensity be such that the individual does not experience undue fatigue 1 hour after the exercise session.

Intensity of Physical Activity

Wilmore and Haskell (1971) postulated the exercise intensity is the most important factor in prescribing exercise. Pollock et al. (1984) maintained there is an exercise intensity threshold for improving cardiovascular fitness. According to these authors, this threshold value fluctuates significantly depending on the individual's initial level of fitness. Several investigations were reviewed that supported their contentions. In these studies, exercise intensity ranged from 39-96% of VO_2max. Hellerstein, Hirsch, Ader, Greenblot, and Siegel (1973) reported significant improvements in cardiovascular fitness with an exercise intensity as low as 25% of VO_2max.

The American College of Sports Medicine in 1986, recommended an intensity of 40-60% of VO_2max for individuals with low functional capacity, and 60-70% for asymptomatic adults. Ribisl (1980) ascertained that most of the research regarding optimal training levels is supportive of a 60-80% VO_2max range.

Once the range of exercise intensity has been determined in percentages of VO_2max, it should be expressed in terms of heart rate. Oldridge (personal communication, July 31, 1985) and the American College of Sports Medicine (1986) recommended graphing the results of an individual's stress test with oxygen consumption plotted against heart rate. The heart rates corresponding to the desired oxygen consumption levels are interpolated from the graph and used in exercise prescription.

The Karvonen method and the maximal heart rate method of determining exercise intensity use heart rate directly. The maximal heart rate method involves taking a percentage of the maximal heart rate obtained during a stress test, e.g. 60-75% of maximal heart rate as recommended by the American Heart Association (1972). The Karvonen method involves taking a percentage of the heart rate reserve achieved by subtracting resting heart rate from maximal heart rate. Both methods rely on the linear relationship between heart rate and oxygen consumption. Dressendorfer and Smith (1984) reported that this relationship is not always linear (i.e. cardiac patients). These authors concluded that a graph of observed heart rates plotted against measured oxygen consumption values, or predicted values if measured values are not available, would be a better tool in exercise prescription than an indirect method.

Heart Rate-Oxygen Consumption Relationship

For each individual performing a specified mode of endurance exercise there is generally a linear relationship between heart rate and oxygen uptake (Astrand & Rodahl, 1977; McArdle, Katch, & Katch, 1981). Hellerstein and Franklin (1984) stated the linear relationship exists at "high submaximal and maximal levels of effort under standardized conditions" (p. 237). An individual's unique heart rate-oxygen consumption relationship can be observed by noting his responses to increasing levels of exercise. A desired exercise intensity can then be prescribed in terms of heart rate as previously described.

The prescription can be made with some degree of confidence because the heart rate-oxygen consumption relationship has been reported to be highly reproducible for a specified mode of activity (Bradfield, 1979). Washburn and Montoye (1985) reported the heart rate response to submaximal leg cycling to be highly reliable over work rates ranging from 0-100 watts (correlation coefficients of .91 and .95 respectively). These researchers found the heart rate response to arm cycling to be reliable only at higher power outputs (50 watts-correlation coefficient of .89).

Fox, Naughton, and Haskell (1971) reported that a universal heart rate-oxygen consumption relationship exists. This universal relationship is based on percentages of maximal heart rate and VO_2max. For example, 70% maximal heart rate corresponds to 55-60% VO_2max (Davis & Convertino, 1975). Hellerstein and Franklin (1984) expressed that this universal relationship provides a sound physiologic basis for prescribing exercise intensity.

One problem that may arise in using the heart rate-oxygen consumption relationship is that other factors, in addition to exercise intensity, can affect the relationship. These factors include the type of exercise performed, body position, temperature, and emotions (McArdle et al., 1981).

Heart Rate-Oxygen Consumption Relationship in Different Activities

Arm Versus Leg Exercise

It has been well established that arm exercise yields different cardiorespiratory and hemodynamic responses than leg exercise. For a given submaximal work load, heart rate will be significantly higher during arm work (Astrand & Rodahl, 1977; Hellerstein & Franklin, 1984). The VO_2max obtained during arm exercise is approximately 70 $\pm$ 15% of that obtained during leg exercise (Hellerstein & Franklin, 1984). "However, regression equations between percentage maximal heart rate and percentage VO_2max revealed no differences between arm exercise and leg exercise for the same relative workload" (Hellerstein & Franklin, 1984, p.210). At a given oxygen consumption level, Hellerstein & Franklin did not establish whether heart rate is similar for arm and leg exercise. Furthermore, improvements in cardiovascular fitness are achieved by overloading the system. An exercise prescription based on an arm ergometry stress test may not be of sufficient intensity to create an overload for the cardiovascular system.

Inclined Versus Horizontal Treadmill Stress Tests

Relative VO_2max characterizes the functional capacity of the individual (Mitchell & Blomqvist, 1971). Theoretically, the same muscle mass employed in similar activities should yield comparable VO_2maxs. Erickson, Simonson, Taylor, Alexander, and Keys (1945) reported higher VO_2max values in inclined as opposed to horizontal treadmill stress tests. Later investigations yielded similar results (Astrand & Saltin, 1961; Hermansen & Saltin, 1969; Ralston, 1960; Taylor, Buskirk, & Henschel, 1955). None of these researchers studied maximal heart rate or heart rate-oxygen consumption relationship during the two modes of exercise.

The results of Kasch, Wallace, Huhn, Krough, & Hurl (1976) would intuitively suggest that the relationships observed during the two exercise modes are similar because these researchers reported no significant difference in VO_2max values. These investigators suggested horizontal treadmill stress tests must be of long duration utilizing relatively fast running speeds to obtain VO_2max levels observed in inclined treadmill stress tests. Kasch and coworkers did not report on maximal heart rate or the heart rate-oxygen consumption relationship.

Weltman (1982) reported similar results as Kasch and colleagues and also observed the heart rate-oxygen consumption relationships. Weltman (1982) reported a higher slope for the heart rate-oxygen consumption relationship observed during an inclined treadmill protocol versus a horizontal treadmill protocol. A significant difference was reported in submaximal oxygen consumption values obtained at matching heart rates between 70-90% maximal heart rate. Weltman (1982) concluded an exercise prescription based on an inclined treadmill protocol would yield a lower intensity than desired. To alleviate this problem, he recommended the use of a horizontal treadmill protocol for stress tests.

Specificity of Graded Exercise Tests

Stress test protocols vary not only in elevation, but also in speed of movement, muscle groups employed, stage time, and continuity. The direct relationship between the speed of movement and oxygen consumption levels has been well established (Fellingham, Roundy, Fisher, & Bryce, 1978; Gaesser & Brooks 1975; Seabury, Adams, & Ramey 1977). In fact, researchers have proposed regression equations for determining oxygen consumption levels using speed as a variable (ACSM, 1986; Van Der Walt & Wyndham, 1973). Montoye, Ayen, Nagle and Howley's results appeared to validate the American College of Sports Medicine's linear regression equations (1985). Hagan, Strathman, Strathman and Gettman (1980) compared linear and curvilinear regression equations and concluded that curvilinear equations were more accurate. None of these researchers however, investigated the effect of speed on the heart rate-oxygen consumption relationship.

Hermansen and Saltin (1969) did observe this relationship during the use of different muscle groups in stress tests. These investigators studied 6 untrained male students and 8 male athletes. Higher heart rates were reported during bike ergometry when compared to treadmill ergometry at the same absolute oxygen consumption levels.

Bouchard, Godbout, Mondor, and Leblanc (1979) designed a study to compare stress test protocols in general. They reported significant differences in VO_2max, maximal ventilation, and maximal heart rate using supine leg cycling, seated leg cycling, standing arm cycling, bench stepping, and treadmill walking. "It was estimated that the overall common variance for Max ml oxygen $\cdot$ Kg^{-1} $\cdot$ min^{-1} reached about 50% of the total variance" (Bouchard et al., 1979, p. 85). Bouchard and his colleagues did not compare the heart rate-oxygen consumption relationships. Bruce et al. (1973) compared the Bruce protocol to Taylor's and reported no significant difference in VO_2max. Yet when Froelicher et al. (1974) compared the Taylor, Bruce and Balke treadmill protocols, they reported significant differences between the Taylor versus Bruce and Balke protocols in VO_2max values. Maximal heart rate did not differ significantly. Because VO_2max values were different and maximal heart rate values were not, the heart rate-oxygen consumption relationship could not have been the same for all 3 protocols.

Treadmill versus Overground Exercise

If oxygen consumption values are specific to treadmill protocols, can the heart rate-oxygen consumption relationship observed during a treadmill stress test be extrapolated to overground exercise? The question has no simple answer. The oxygen consumption levels obtained during the two conditions have been compared. Daniels, Vanderbie, and Winsmann in 1953 reported 10% lower oxygen consumption values in young adult males when walking on a treadmill as compared to overground at 5.63 km per hour. These researchers suggested walking surface and body mechanics may be responsible for the difference noted. Frishberg (1983) also reported significant differences in oxygen consumption values at comparable speeds for the two conditions. However Frishberg's results are controversial, because he used oxygen debt in estimating total energy expenditure rather than measuring oxygen consumption values.

Ralston (1960) reported no significant differences in oxygen consumption values obtained during treadmill and overground exercise with 2 female and 4 male subjects exercising at speeds of 2.93 and 5.86 km per hour. The results of other researchers' work supports Ralston's (Daniels, 1976; Ingen Schenau, 1980; McMiken and Daniels, 1976; Nelson, Dillman, Lagasse, and Bickett, 1972; Pugh, 1970; Pugh, 1971). In a more recent study, no significant difference between level and inclined treadmill running versus level and hill overground running was reported (Bassett et al., 1985). In summary, it appears the energy requirement of treadmill exercise is the same as overground exercise. Whether the heart rate-oxygen consumption relationship observed on a treadmill is similar to that observed during overground exercise remains to be determined.

Heart Rate-Oxygen Consumption Relationship with respect to Temperature and Emotion

The specificity of stress test protocols may be caused, in part, by differing levels of body temperature. One protocol may be of longer duration and yield higher body temperatures than another. An increased body temperature would cause increased blood shunting to the skin's surfaces which would lower the arterial-mixed venous oxygen difference and thus VO_2max (Froelicher et al., 1974). Environmental conditions similarly affect oxygen consumption values, although laboratory conditions are generally controlled. The influence of temperature and humidity make extrapolation of stress test data to outside environments difficult. "It is well established that increased environmental temperature and/or relative humidities result in an increased heart rate response but do not alter the steady-state oxygen consumption response" (Davis & Convertino, 1975, p. 298). Thus, an individual who exercises in a very warm ambient situation at their prescribed heart rate would be working at an intensity lower than desired.

Emotions can also affect the heart rate-oxygen consumption relationship. Rowell, Taylor, and Wang (1964) expressed concern that submaximal heart rate during work up to and exceeding 50% of VO_2max may vary independent of any known physiologic change. Cardus (1979) cautioned that steps must be taken to reduce the level of subject anxiety and to increase his confidence in laboratory personnel in order to minimize any personality effects on stress test results. If psychological factors inflate the heart rate at various times during a stress test, an exercise intensity prescribed in terms of heart rates observed during the stress test data may have an actual intensity lower than intended.

Prediction of VO_2max and Maximal Heart Rate

VO_2max

Given the inherent problems (physiological and psychological) and the need for expensive equipment in performing stress tests, many health practitioners have chosen to use predicted VO_2max and maximal heart rate values in prescribing exercise. This practice is justified for apparently healthy individuals under 45 years of age.

Prediction equations have been developed for VO_2max and maximal heart rate.

Bruce et al. (1973) developed equations for predicting VO_2max. In developing the equations, Bruce and his colleagues observed sex, age, physical activity levels, body weight, height, and history of cigarette smoking to be related to VO_2max. The first 4 variable accounted for 65% of the observed variation in VO_2max; therefore, these variables were incorporated into their equations. Bruce et al.'s (1973) regression equations and estimates of reliability are as follows: active females, VO_2max = 44.4 - .343(age), r = .72; sedentary females, VO_2max = 41.2 - .343(age), r = .63; active males, VO_2max = 69.7 - .612(age), r = .70; sedentary males, VO_2max = 57.8 - .445(age); r = .66.

For those health practitioners utilizing a stress test, but not gas analysis in exercise prescription, Bruce et al. (1973) developed regression equations for predicting VO_2max based on the Bruce protocol. These equations use general health status (normal or cardiovascular disease patients), sex, and treadmill time as variables. The equations and reliability coefficients are as follows: healthy persons, VO_2max = 6.70 - 2.82(1 for males, 2 for females) + .056(treadmill time in seconds), r = .92; male cardiovascular disease patients, VO_2max = 10.5 + .035(treadmill time in seconds), r = .82.

Bruce et al.'s (1973) equations used with a Bruce protocol stress test have proven to be reliable. Foster et al. (1984) used a Bruce protocol stress test for 25 male coronary artery bypass patients and 12 healthy males and reported no significant difference between actual and VO_2max values predicted by Bruce et al.'s equations. Foster and coworkers (1984), however, emphasized that the biomechanical difficulties inherent in the fourth stage of the Bruce protocol, make oxygen consumption prediction unreliable for that stage. Liang, Alexander, Stull, Servass, and Wolfe (1985) had similar difficulties with the fourth stage. These investigators concluded "that the Bruce equation is a reliable and reproducible equation that can be used effectively for estimating oxygen uptake based upon treadmill performance time up to 9 minutes or stage 3 of the BMTT {Bruce protocol stress test}. When treadmill performance exceeds stage 3 or greater than 9 minutes, however, the Liang equation is recommended for estimating oxygen uptake" (p. 38). The Liang equation is: VO_2max = 3.79(treadmill time in minutes) + 2.18. The Liang equation is designed for healthy adult males. These researchers emphasized this equation's applicability to other populations has not been established.

When prediction equations are applied to treadmill stress tests, the accuracy of the predicted values is dependent on the selection of the appropriate equation.

Error that results from the use of an inappropriate equation may be greater than the inherent error in the equation alone (Foster et al., 1984). Care must also be taken in the proper administration of the stress test. For example, individuals should not be allowed to hold onto the handrails. Holding onto a handrail during a treadmill stress test can cause overestimation of oxygen consumption levels by as much as 30% (Pollock et al., 1984). Foster et al. (1984) concluded that if the appropriate prediction equation was used and the stress test was properly administer, prediction of submaximal oxygen consumption and VO_2max values are acceptably accurate using the Bruce equations and protocol.

Maximal Heart Rate

The results of Astrand, 1952; Astrand, 1960; Hollmann, 1963, and Robinson, 1938 (cited in Astrand & Rodahl, 1977) established that maximal heart rate gradually declines with age. For this reason, prediction equations for maximal heart rate generally contain age as a variable. The most commonly used equation involves simply subtracting an individual's age from 220 to obtain predicted maximal heart rate. Health practitioners when using a predicted maximal heart rate for exercise prescription should take into consideration the standard deviation of maximal heart rate during exercise is $\pm$ 10 beats (Astrand & Rodahl, 1977). Another consideration is the wide individual variation in the decline of maximal heart rate with age (Astrand & Rodahl, 1977).

Summary

In this country, cardiovascular disease extracts a high price in terms of human lives and dollars. Almost one million people died in 1982 because of cardiovascular disease. It is estimated that $72.1 billion was spent in 1984 for cardiovascular related expenses. The American Heart association alone has expended $522 million on research since 1949 and can now identify various risk factors for cardiovascular disease. The major risk factors are cigarette smoking, hypertension, hypercholesterolemia, and diabetes mellitus. Contributory risk factors are obesity, and a sedentary life style (AHA, 1984).

Two primary mechanisms for reducing the risk of heart attack have been postulated by LaPorte and colleagues (1984). The first mechanism is physical activity's indirect effect on cardiovascular disease through risk factor modification. Research on the association between physical activity and cigarette smoking has yielded conflicting results. Results of research regarding physical activity's impact on hypertension are also not definitive; however, Tipton (1984) contended that the literature justifies the inclusion of exercise training as a separate countermeasure for hypertension. It appears physical activity also may be an effective countermeasure for hypercholesterolemia (Rainville & Vaccaro, 1983). The use of physical activity in the treatment of diabetes mellitus has a sound theoretical basis; however, the solid experimental base has not been achieved (Maehlum et al.'s study cited in Stromme et al., 1984). In contrast physical activity's effectiveness in the treatment of obesity has been demonstrated; however, the reasons for its effectiveness remain to be established (Blair, 1985).

The second mechanism postulated by LaPorte et al. (1984) for reducing the risk of heart attack is exercise induced cardiovascular fitness. Blair (1985) agreed upon the role of cardiovascular fitness, but argued Laporte et al.'s two mechanisms are one. Improved cardiovascular performance, a component of cardiovascular fitness, obtained through exercise training has been demonstrated to lower myocardial oxygen demand at a given workload (Hammond, 1985). The existing oxygen demand is better met with improved myocardial perfusion achieved through exercise training (Froelicher et al., 1984).

Health practitioners prescribe exercise training by specifying exercise type, frequency, duration, and intensity. Intensity is usually described in terms of heart rate. Specifying intensity in terms of heart rate is justified because a linear relationship between heart rate and oxygen consumption generally exists for endurance activities (Astrand & Rodahl, 1977). This relationship may be unique for a given activity and/or the manner in which the activity is performed. The validity of generalizing an observed heart rate-oxygen consumption relationship has not been established.

The training heart rate is defined by using a graph of the observed heart rate-oxygen consumption relationship, the maximal heart rate method, or the Karvonen method. Often predicted VO_2max values and maximal heart rate values are used.

Chapter III

JOURNAL MANUSCRIPT

Abstract

Twenty-eight endurance trained male volunteers, 18-41 years of age, were studied to determine whether the heart rate-oxygen consumption relationship observed during a Bruce protocol stress test was similar to that noted during steady-state exercise. In addition, maximal oxygen consumption and maximal heart rate values obtained during the stress tests were compared to predicted values (Bruce, Kusumi, & Hosmer, 1973; Karvonen, Kentala, Mustala, 1957).

Approximately 1 week after the Bruce protocol stress tests were performed, subjects performed two steady-state exercise tests. These sessions were performed on a horizontal treadmill by gradually increasing the speed until the subject achieved and sustained 60% or 75% of maximal oxygen consumption. Heart rates recorded at that time were compared to those observed at similar oxygen consumption levels during the stress tests.

The heart rates observed at 60% and 75% VO_2max were significantly higher during the stress tests than during the steady-state exercise tests. The mean differences at 60%

and 75% of maximal oxygen consumption were 4.25 and 9.25 beats per minute respectively. No significant difference was found between predicted VO_2max values derived from age and activity level, VO_2max values derived from treadmill time, and actual VO_2max values obtained during the stress test. Similarly, predicted maximal heart rate values were not significantly different from actual values obtained during the stress tests.

Based on these results, it was concluded that the heart rate-oxygen consumption relationship was specific to the activity in which it was observed. Because of the specificity in heart rate-oxygen consumption relationships with higher heart rates occurring during the stress tests, exercise prescriptions based on stress test results may produce higher exercise intensities than desired.

Introduction

In 1984, approximately one half of the deaths in this country could be attributed to cardiovascular disease (Hoeger, 1986). Vast sums of money have been spent on research in an attempt to determine the disease's etiology and why some treatments are effective. Based on these efforts, researchers have elucidated various risk factors for cardiovascular disease and have demonstrated a negative relationship between physical activity and cardiovascular disease (Stromme et al., 1984). LaPorte et al. (1984) suggested the effectiveness of physical activity in reducing the risk of heart attack is due to risk factor modification and/or improved cardiovascular fitness.

Currently health practitioners are prescribing exercise in an attempt to control cardiovascular disease. The exercise prescription is frequently based on the heart rate-oxygen consumption relationship observed during a Bruce protocol graded exercise stress test. It is assumed that this relationship is similar to the relationship that exists during steady-state exercise.

Purpose

This study was performed to determine if the heart rate-oxygen consumption relationship observed in Bruce protocol exercise stress tests was similar to the relationship observed during steady-state exercise. Specifically, the heart rates measured at 60% and 75% of VO_2max during the two conditions were compared. In addition, predicted and actual VO_2max values, and predicted and actual maximal heart rate values were also compared.

Methods

Twenty-eight endurance trained male volunteers, 18-41 years of age, participated in this study. Subjects attended an orientation session in which the risks and benefits of participation were explained. During the orientation session, subjects signed an informed consent form and were screened for contraindications to maximal exercise stress testing. Approximately 1 week later, subjects performed a Bruce protocol maximal exercise stress test. This stress test procedure has been demonstrated to be a reliable measure (Bruce et al., 1973).

Testing was performed on a Quinton treadmill model Q-55 with a Q-2000 stress test monitor or a Quinton model 24-72 with a model 643 program control. Heart rate was monitored and recorded electrocardiographically approximately every 30 seconds with a Hewlett Packard single channel recorder, model 1500B, and a CM_5 lead. Both treadmills and the recorder were calibrated before the study. During the study, Beckman gas analysis systems were calibrated before and after each testing session using standard gas mixtures, previously verified using a Haldane chemical apparatus. The systems consisted of an OM 11 or LB-2 display/control with an OM 11 or LB-2 sensor respectively. Inspired gas volumes were measured using a Parkinson-Cowan P-4 dry gas meter. Gas concentrations and volume were recorded approximately every 30 seconds into an Apple IIE computer which was used to perform metabolic calculations. The recording interval for the gas values was offset by 15 seconds from the heart rate recording interval to allow for gas transit time.

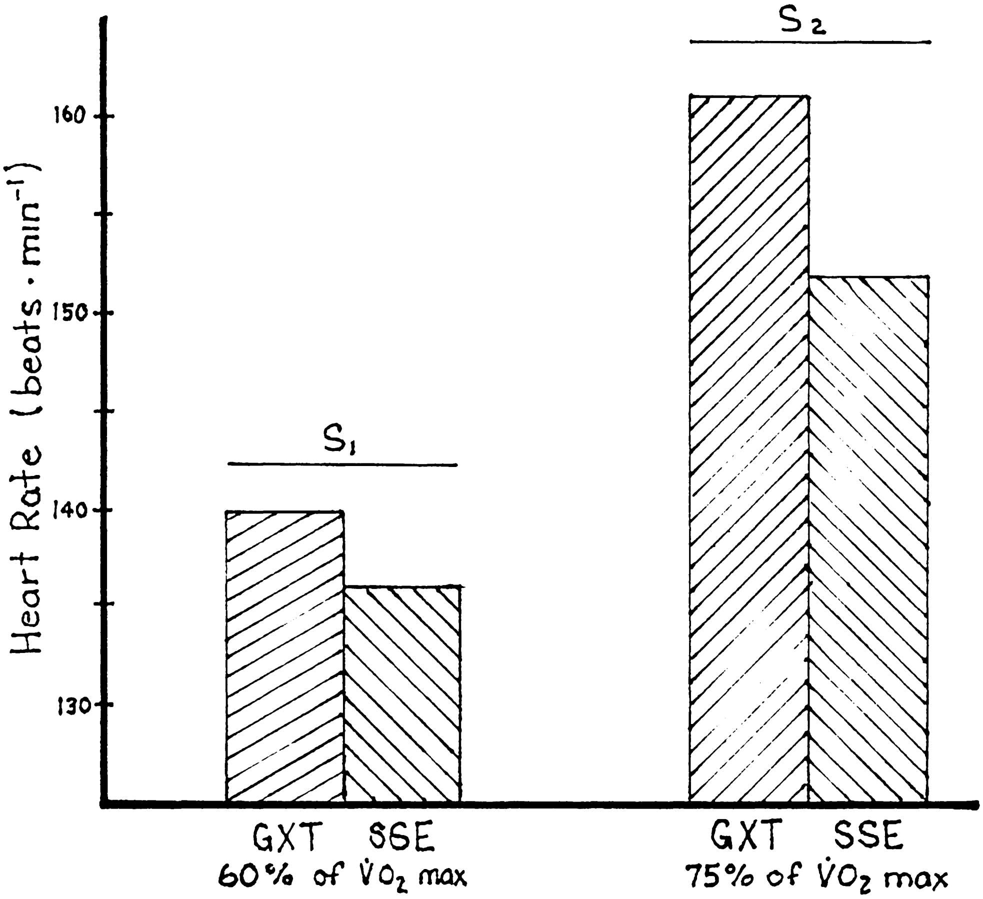
The Apple IIE computer was used not only to record gas values, but also to predict the horizontal treadmill speeds necessary for each subject to achieve 60% and 75% of VO_2max using the equations of the ACSM (1986), Bassett et al. (1985), and Hagan, Strathman, Strathman, and Gettman (1980). Approximately 4 mph was used as a warm up for the steady-state exercise tests. After the warm up, speed was gradually increased to the predicted value and then adjusted until subjects achieved and sustained the desired percentage of VO_2max. The mean differences between the achieved and desired oxygen consumption values was 0.5 ml·kg·min for the 60% VO_2max steady-state test and 0.7 ml·kg·min for the 75% VO_2max test (standard deviations of .28 and .64 respectively). On the average, the last speed adjustment was .40 mph for the lower intensity test, and .59 mph for the higher intensity test. The final speed was maintained for approximately 4 minutes. During the later stage of the steady-state tests, mean VO_2max percentages of 59.8% and 74.7% were achieved (standard deviations of 0.9 and 1.6 respectively). The lower and higher intensity steady-state tests lasted an average of 10.64 and 11.89 minutes respectively, not including active cool down. After cool down, the subject rested for 30 minutes before beginning his remaining steady-state exercise test. The sequence of the steady-state exercise tests was randomized.

Data Analysis and Results

No oxygen consumption or heart rate values recorded during the minute following a speed and/or grade change were used in data analysis. Therefore during the stress test, only some of the subjects had recorded oxygen consumption values which closely approximated 60 and 75% of VO_2max (16 and 13 subjects respectively). The mean VO_2max percentages achieved by those subjects were 59.68% and 74.87% respectively. For those subjects who did not attain the desired percentages ($\pm$ 1%), their heart rates at the desired percentages were estimated by regression equations. The individuals' regression equations were developed with oxygen consumption and heart rate values recorded during the stage in which the desired VO_2max percentage should have occurred and the adjoining stages.

During the steady-state exercise tests, the heart rates corresponding to the oxygen consumption levels which most closely approximated the desired percentages of VO_2max were used in data analysis. On the average, these heart rates were recorded at 2.38 and 2.45 minutes of the last stage of the lower and higher intensity steady-state tests respectively. The recorded heart rates were compared to heart rates obtained during the stress tests at similar oxygen consumption levels or to heart rates estimated from stress test data as previously described. The heart rate differences are illustrated in figure 1. The differences were analyzed by dependent t-tests. The differences at 60% of VO_2max and 75% of VO_2max yielded t-ratios of 2.10 ($p<.05$) and 4.75 ($p<.01$) respectively. Heart rates were higher during the stress tests by mean differences of 4.25 and 9.25 respectively.

The reliability of measured heart rates and oxygen consumption values during the steady-state exercise tests was estimated using Pearson's product-moment correlation. The oxygen consumption value most closely approximating 60% of VO_2max and the adjoining value yielded a coefficient of $r = .90$. Heart rate recorded at these points yielded a coefficient of $r = .98$. Similar recorded values for the steady-state exercise test performed at 75% of VO_2max resulted in coefficients of $r = .86$ and $r = .98$



LEGEND: GXT = Average heart rate obtained during Bruce protocol stress test at specified intensity

SSE = Average heart rate obtained during steady-state exercise at specified intensity

S_1 = Significant difference ($P < .05$)

S_2 = Significant difference ($P < .05$)

FIGURE 1. AVERAGE HEART RATE VALES OBTAINED AT SPECIFIED INTENSITIES DURING BRUCE PROTOCOL STRESS TEST AND STEADY-STATE EXERCISE

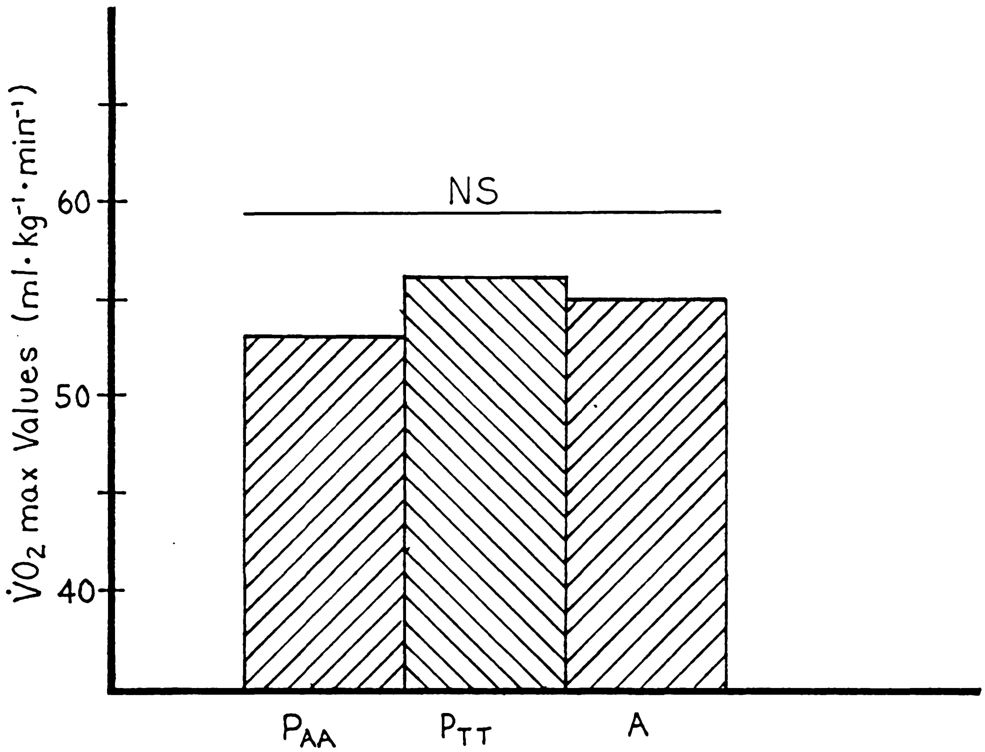
respectively.

VO_2max values predicted by Bruce et al.'s (1973) equations for prediction of VO_2max based on age and activity level, and for prediction of VO_2max based on treadmill time were compared using analysis of variance to actual VO_2max values. The differences between the VO_2max values was not found to be statistically significant. A dependent t-test was used to compare maximal heart rate values predicted by subtracting the subject's age from 220 and those obtained during the stress tests. The maximal heart rates were found not to be significantly different. The comparisons of VO_2max values and of maximal heart values are illustrated in figures 2 and 3.

Figure 3 illustrates the similarity of predicted and actual maximal heart rates. Because the subjects maximal heart rates were not significantly different from their predicted maximal heart rates and because subjects had an average respiratory exchange ratio of 1.09, the average stress test was deemed to be a true maximal exercise stress test (Bruce, 1984).

Discussion

The heart rate-oxygen consumption relationship observed during the Bruce protocol stress tests was dissimilar from the relationship recorded during steady-state exercise.



LEGEND:

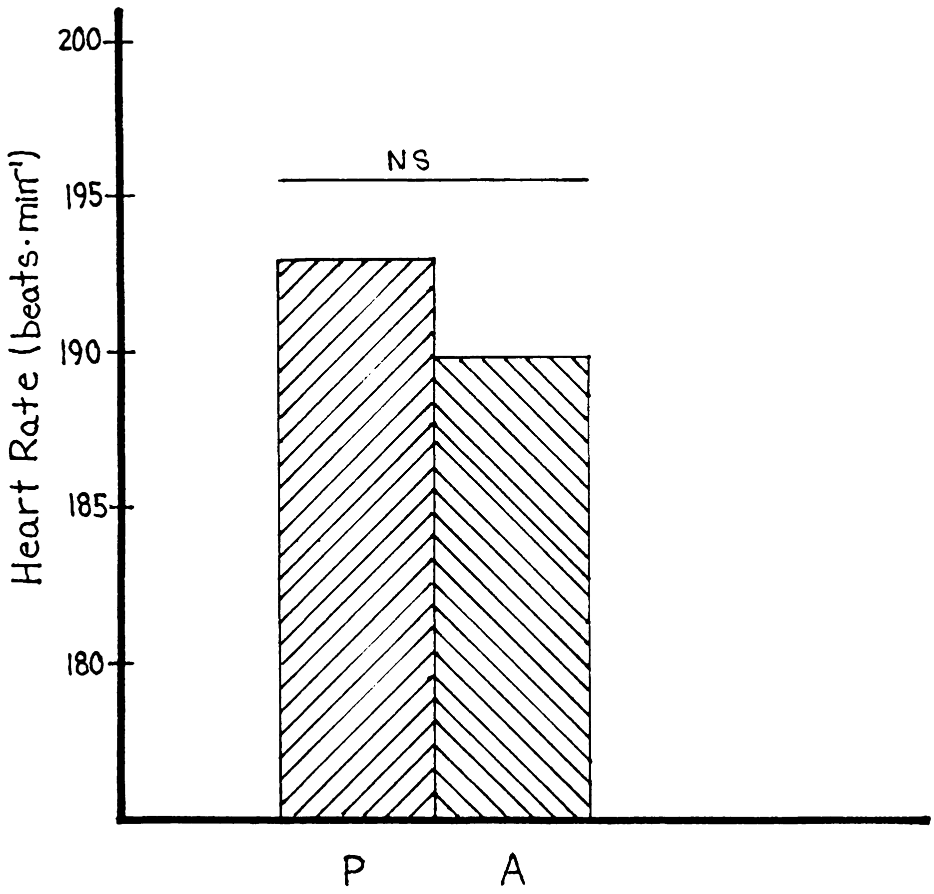
P_{AA} = Average predicted $\dot{V}O_2$ max based on age and activity level

P_{TT} = Average predicted $\dot{V}O_2$ max based on treadmill time

A = Average actual $\dot{V}O_2$ max

NS = Nonsignificant difference ($P > .05$)

FIGURE 2. AVERAGE PREDICTED AND ACTUAL $\dot{V}O_2$ max



LEGEND: P = Predicted maximal heart rate
A = Actual maximal heart rate
NS = Nonsignificant difference ($p > .05$)

FIGURE 3. AVERAGE PREDICTED AND ACTUAL MAXIMAL HEART RATES

Significant differences in the heart rate-oxygen consumption relationship under different conditions was also reported by Weltman (1982). However, Weltman used an incremental, discontinuous, horizontal treadmill protocol instead of steady-state exercise. McArdle, Katch, and Pechar (1973) reported that VO_2max values are stress test protocol specific. Treadmill protocol specificity may be caused by incline, employed muscle groups, duration, generation of body heat, and psychological factors (Astrand & Rodahl, 1977; Froelicher et al., 1974; Hermansen & Saltin, 1969: Kasch et al., 1976; Rowell, Taylor, & Wang, 1964). In conclusion, stress test protocol specificity may have caused the dissimilarity in heart rate-oxygen consumption relationships observed during the Bruce protocol stress tests and steady-state exercise tests.

Another possible cause for the dissimilarity was the inability of the subjects to attain steady-state cardiovascular levels during the stress tests after stage 2 (Bruce et al., 1973). Whipp and Wasserman (1972) contended the time to cardiovascular steady-state increases beyond 3 minutes once exercise reaches higher intensities (approximately 60% VO_2max). These researchers suggested that the proportion of energy supplied anaerobically increases with exercise intensity. The increasing proportion of energy supplied anaerobically may explain why the difference in the heart rate-oxygen consumption relationship at 60% VO_2max was half of that observed at 75% VO_2max. Perhaps oxygen consumption did not level off in 3 minutes while heart rate did. Cardus (1979) suggested that oxygen consumption and heart rate reach steady-state at different points. In conclusion, the dissimilarity of the heart rate-oxygen consumption relationship during the two conditions may have resulted from the instability in the relationship during the Bruce protocol stress test.

Exercise prescriptions based on the relationship observed during Bruce protocol stress tests may yield exercise intensities higher than desired. The actual intensity prescribed may be unsafe for individuals unknowingly at risk because of the association between exercise intensity and cardiac episodes. Mead, Pyfer, Trombold, and Frederick (1976) reported a positive relationship between exercise intensity and cardiac arrest. Hossack and Hartwig's (1985) results supported Mead et al.'s contentions. If an individual can safely attain the actual intensity prescribed, the exercise may be too intense for the individual to sustain long enough for cardiovascular fitness to be improved (Hellerstein & Franklin, 1984). In addition individuals prescribed a high exercise intensity have an increased rate of noncomplaince (Pollock, Wilmore, & Fox, 1984). In summary, individuals erroneously prescribed high exercise intensities may be exercising at unsafe intensities, may not be improving cardiovascular fitness, and may be noncompliant.

The ACSM (1986) recommended graphing the heart rate-relationship and using the graph in exercise prescription. As discussed, this procedure may introduce inaccuracy into the prescription. A second and third method of prescription recommended by the ACSM is the Karvonen and maximal heart rate method. In this investigation, no significant difference was found in actual VO_2max and maximal heart rate values and predicted values. Therefore if a health practitioner were unable to measure oxygen consumption and/or was performing submaximal stress tests, he would be justified in using predicted VO_2max and maximal heart rate in prescribing exercise intensity.

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Chapter IV

SUMMARY OF THE STUDY

Summary

The purpose of this investigation was to determine if the heart rate-oxygen consumption relationship observed during a Bruce protocol stress test was the same relationship observed during steady-state exercise. This relationship was examined at both 60% and 75% of VO_2max. In addition, predicted VO_2max and maximal heart rates values were compared to actual values obtained during the stress tests.

Twenty eight endurance trained males between 18-41 years of age volunteered to participate in this study. During a laboratory orientation session, subjects were screened for training status and contraindications to stress test performance. Bruce protocol exercise stress tests were performed on a Quinton treadmill model Q-55 with a Q-2000 stress test monitor or a Quinton model 24-72 with a model 643 program control. Expired gases sampled during testing were analyzed with Beckman gas analysis systems. A Hewlett Packard recorder and a chest modified lead five were used to record heart rate.

Approximately 1 week after their stress tests, subjects returned to the laboratory for the steady-state exercise tests. A treadmill speed of approximately 4 mph was used as a warm up, after which the speed was gradually increased until the subject achieved and sustained 60% or 75% VO_2max. Heart rates during the sustained oxygen consumption period were recorded and the subject was then allowed to cool down. After resting for 30 minutes, subjects performed the remaining steady-state exercise test (60% or 75% VO_2max). The sequence of the steady-state exercise tests was randomized.

The differences between heart rates observed at 60% and 75% VO_2max during the stress test and during steady-state exercise were statistically significant. Data analysis of the differences yielded dependent t-ratios of 2.10 ($p<.05$) and 4.75 ($p<.01$) respectively. During the stress tests at 60% and 75% VO_2max, heart rates were higher by mean differences of 4.25 and 9.25 beats per minute respectively. No significant difference was found between predicted VO_2max values derived from age and activity level, VO_2max values derived from treadmill time, and actual VO_2max values obtained during the stress test (Bruce et al., 1973). Similarly, predicted maximal heart rate values derived from Karvonen et al.'s (1957) equation were not significantly different from actual values obtained during the stress tests.

Research Implications

Specificity of the Heart Rate-Oxygen Consumption Relationship

The heart rate-oxygen consumption relationship observed during the Bruce protocol stress tests was dissimilar from the relationship noted during steady-state exercise. Higher heart rates were found during the stress tests. Significant differences in the heart rate-oxygen consumption relationship using different treadmill protocols was also noted by Weltman (1982). Weltman reported significant differences between 15 pairs of oxygen consumption values matched for submaximal heart rate obtained on an inclined and horizontal treadmill protocol. In contrast to this investigation, Weltman used an incremental, discontinuous, horizontal protocol instead of steady-state exercise. Perhaps the differences in the heart rate-oxygen consumption relationships noted by Weltman, were a function of Weltman's protocol.

However, treadmill protocols are very specific and yield significantly different VO_2maxs (McArdle et al. 1973). The specificity may be due to the usage of different muscle groups (Astrand & Rodahl, 1977; Bouchard et al. 1979). However inclined and horizontal treadmill protocols which employ similar muscle groups, also yield different VO_2maxs (Hermansen & Saltin, 1969). Kasch et al. (1976) argued the difference in VO_2max values observed between inclined and horizontal treadmill stress tests is due to the insufficient duration of the horizontal tests.

The variation in protocol duration contributes to protocol specificity. Other influential factors are body temperature and psyche (Froelicher et al., 1974; Rowell et al. 1964). Perhaps protocol duration and/or other factors also contribute to dissimilarity in heart rate-oxygen consumption relationships. Given the specificity of protocols in yielding VO_2max, it is likely the heart rate-oxygen consumption relationships observed during different stress tests also are specific. Hermansen & Saltin (1969) reported VO_2max values and heart rate-oxygen consumption relationships were specific to treadmill and bicycle ergometry. It is improbable the heart rate-oxygen consumption relationship observed during an inclined treadmill protocol is similar to the relationship observed during horizontal steady-state exercise.

The specificity of the heart rate-oxygen consumption relationship may be caused by differences in movement speed. It has been suggested that higher speeds increase oxygen consumption (Fellingham et al., 1978; Gaesser & Brooks, 1975; Seabury et al., 1977). Higher speeds were used in the steady-state exercise tests during this investigation.

Average speeds of 5.9 mph and 7.2 mph were used in the 60% and 75% VO_2max steady-state exercise tests respectively; while only one subject reached 6 mph during the stress test. However, none of the literature reviewed addressed the effect of speed on the heart rate-oxygen consumption relationship.

Differences in the heart rate-oxygen consumption relationships may be caused by the inability of subjects to attain steady-state levels during Bruce protocol tests after stage 2 (Bruce et al., 1973). Whipp and Wasserman (1972) reported the time to steady-state increases beyond 3 minutes at anaerobic threshold. Anaerobic threshold occurs at about 60% VO_2max during treadmill exercise (Davis, Vodak, & Wilmore, 1976). If these researchers contentions are correct and the subjects in this study had anaerobic thresholds at 60% VO_2max, the subjects may not have reached steady-state when 60% VO_2max was observed and should not have reached it when 75% VO_2max was observed. The increasing time to steady-state may explain why the difference in the heart rate-oxygen consumption relationship at 60% VO_2max was half of that observed at 75% VO_2max. However, oxygen consumption may level off sooner than Whipp and Wasserman suggested. Davis & Convertino (1975) reported oxygen consumption leveled off at approximately 3 minutes, but heart rate continued to rise during stages of an incremental, horizontal treadmill protocol. Cardus (1979) emphasized that it is unknown whether heart rate and oxygen consumption change at the same rate. In conclusion, any heart rate-oxygen consumption relationship observed during the later stages of a stress test is probably not a stable relationship.

Exercise Prescription

Bruce protocol exercise stress tests are frequently used in assessment. However, this investigator found the heart rate oxygen consumption relationships observed during Bruce protocol stress tests were dissimilar from those recorded in steady-state exercise. Heart rates at equivalent levels of oxygen consumption were significantly higher during the stress tests. Therefore, exercise prescriptions based on heart rate-oxygen consumption relationships observed during Bruce protocol stress tests may yield exercise intensities higher than desired. Thus, cardiac patients and individuals unknowingly at risk may be prescribed an unsafe exercise intensity. Mead et al. (1976) reported episodes of cardiac arrest in patients who frequently exercised in a 80-85% maximal heart rate range which is equivalent to a 71-78% VO_2max range (Hellerstein & Franklin, 1984).

Individuals exercising at high intensities may not be able to sustain the exercise long enough for cardiovascular fitness to be improved (Hellerstein & Franklin, 1984). In addition, individuals prescribed a high exercise intensity have an increased rate of noncompliance (Pollock et al., 1984). In summary, individuals with a high intensity exercise prescription may be exercising at unsafe levels, may not be improving cardiovascular fitness, and may be exercising sporadically. LaPorte et al. (1984) hypothesized reduced risk of heart attack may be achieved by improving cardiovascular fitness and/or increasing levels of physical activity. An exercise prescription based on a Bruce protocol stress test may be counterproductive depending on what the actual intensity is when the individual exercises at the prescribed heart rates.

The ACSM (1986) recommended graphing the heart rate-oxygen consumption relationship observed during a stress test and using the graph in exercise prescription. As discussed this method may introduce inaccuracy into the prescription. A second and third method of prescription recommended by the ACSM is the Karvonen and maximal heart rate method. In this investigation, no significant difference was found in actual VO_2max and maximal heart rate values and predicted values. Therefore if a health practitioner were unable to measure oxygen consumption and/or was performing submaximal stress tests, he would be justified in using predicted VO_2max and maximal heart rate values in prescribing exercise intensity.

Recommendations for Future Research

The following recommendations were made for future investigations.

1. A similar study should be performed with the exercise intensity during the steady-state phase increased until the subject attains a heart rate equivalent to the heart rate observed at 60% and 75% VO_2max during the Bruce protocol stress test. When an equivalent heart rate is attained, oxygen consumption should be measured.

2. Other popular stress test protocols such as the Balke, Ellestad, and Naughton should be examined to ascertain whether the error in extrapolating stress test data is unique to the Bruce protocol.

3. Studies should be performed designed to determine if the heart rate-oxygen consumption relationship is stable under different environmental conditions using the same treadmill protocol. For example, the use of different background music, annoying noise, and different lighting could be investigated.

4. Further work should be performed to ascertain whether the results of this study are unique to trained males between the ages of 18-41 years of age.

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APPENDIX A

METHODOLOGY

APPENDIX A

METHODOLOGY

Subject Selection

Twenty-eight males volunteers between 18 and 41 years of age participated in this study. In order to participate, subjects had to meet the American College of Sports Medicine's criteria for apparently healthy persons, and be free of any relative or absolute contraindications to graded exercise stress test performance (ACSM, 1986). In addition, subjects had to be endurance trained. An individual who regularly participated in an aerobic activity (minimum duration 20 minutes), 3 times a week, for the previous 3 months was considered endurance trained. A subject's health and training status was determined by the use of a questionnaire (appendix B). Subject selection procedures were approved by the Human Subjects Committee of Virginia Polytechnic and State University. Subjects' characteristics and habitual physical activities are given in Table 1.

Table 1

Subjects' Weights, Ages, and Habitual Physical Activities

Subject	Weight	Age	Activities[a]			
			Primary		Secondary	
1	60.3	25	cycling	600		
2	54.7	32	running	490	weights	330
3	66.3	32	running	100	cycling	60
4	74.0	23	cycling	480	aerobic dance	180
					basketball	180
5	67.9	23	cycling	540	weights	150
6	63.8	35	running	490	cycling	540
7	65.5	25	running	270	swimming	120
					cycling	120
8	64.6	18	running	450	cycling	244
9	86.5	24	cycling	420	running	158
10	84.9	32	cycling	210	running	167
11	75.1	22	cycling	300	swimming	150
12	90.0	25	running	360	weights	225
13	67.0	27	swimming	90	running	60
14	67.6	32	running	360	cycling	300
15	74.5	20	running	158	cycling	113
16	69.8	24	running	240		
17	70.9	28	rock climbing	360	aerobic dance	180
18	70.3	27	weights	450	cycling	300
19	64.6	25	running	30	weights	40
20	75.0	22	running	90	cycling	135
21	76.4	33	running	203	golf	360
22	84.4	28	running	248	cycling	37
23	65.4	32	cycling	120	swimming	160
24	89.7	41	running	180	cycling	60
25	73.0	33	running	225	swimming	175
26	80.4	19	cycling	46	walking	46
27	86.5	31	aerobic dance	150	cycling	60
28	76.8	25	running	200	basketball	240

[a]Activities are listed with the average time expended per week (in minutes) in that activity.

General Method

Orientation Session

Subjects attended an interview in which the nature of the study was briefly described, and subject risks and benefits explained. An informed consent form (appendix C), previously approved by the Human Subjects Committee of Virginia Polytechnic and State University, was signed by all subjects. After giving consent, the subjects were oriented to the laboratory and equipment. Subjects were shown the hand signals to be employed, the proper way to mount a treadmill, and allowed to experience various belt speeds. Appendix D contains the protocol used in the practice sessions. Written instructions for the exercise stress test and exercise test sessions (appendix E) were given to the subjects during the interview.

Exercise Stress Test

A symptom limited maximal Bruce protocol exercise stress test was performed between 6:15 and 11:00 am by each subject during July 1986. The average temperature and percent humidity in the laboratory during the stress tests were 22.3 degrees Celsius and 86.8%. To minimize distractions during the stress tests, James Galway's Nocturne was played as background music. Subjects' VO_2maxs and maximal heart rate values are listed in Table 2. These results and an introductory letter, a description of oxygen consumption, normative data, and an equation for predicting VO_2max was mailed to the subjects approximately 3 weeks after completion of data collection (appendix F).

Subjects' stress tests were performed an average of 6.1 days after their orientation session. Before their stress tests, subjects were weighed on a Detecto-Medic scale and completed a brief questionnaire to ensure their health status had not changed (appendix G). Stress test procedures were reviewed before the test.

Two different treadmill systems were used during this study. A Quinton treadmill model Q-55 was used with a Quinton Q-2000 stress test monitor providing operational control. The Bruce protocol was preprogrammed into the Q-2000 stress test monitor. The Bruce protocol had to be manually programmed into the Quinton Model 643 Treadmill Program Control which was used with a Quinton Model 24-72 treadmill. Heart rate was monitored and recorded electrocardiographically using a Hewlett Packard single channel recorder, model 1500B, and a chest modified lead five. Both treadmills and the recorder were calibrated before the study.

Table 2

Subjects' VO_2maxs and Maximal Heart Rate Values Obtained during the Bruce Protocol Exercise Stress Tests

Subject	Actual VO_2max (kg)	Maximal Heart Rate
1	68.6	196
2	68.0	200
3	66.4	177
4	64.3	190
5	64.0	187
6	62.3	187
7	60.7	188
8	60.0	214
9	59.3	207
10	58.9	190
11	58.6	194
12	58.3	177
13	56.8	187
14	56.2	182
15	55.7	200
16	53.5	187
17	53.4	177
18	52.3	190
19	51.4	194
20	51.0	182
21	50.1	187
22	49.7	187
23	48.8	197
24	48.1	184
25	48.1	187
26	46.5	201
27	45.1	187
28	36.1	177

Gas analysis was performed during the stress tests and steady-state exercise tests. Subjects used Daniel's low-resistance - low-deadspace flutter valves. The use of noseclips prevented air leakage. Inspired air was measured using a dry gas meter (Parkinson-Cowan P-4). A visual display was electronically integrated with the gas meter which allowed for measurement of .1 liter. The meter was checked for accuracy using a 3 liter volumetric syringe. If necessary, a correction factor was used in metabolic calculations. Mechanical problems with the meter necessitated the recording of gas values in .2 liter for 3 stress tests and 8 steady-state exercise tests. Every 30 seconds the ventilation value and the gas concentrations were manually entered into an Apple IIE computer.

Gas concentrations were determined using Beckman analysis systems after the expired air passed through Aquasorb absorbent. The oxygen analysis system contained an OM 11 display/control with an internal pump and an OM 11 sensor. A Beckman Medical Gas Analyzer LB-2 display/control with an internal pump, and a LB-2 model sensor were used for carbon dioxide analysis. All gas analyzers were calibrated before and after each stress test and steady-state exercise test using standard gas mixtures, previously verified using a Haldane chemical apparatus.

Any differences in pretest and posttest standard gas values were recorded and utilized when completing metabolic calculations. One half of the recorded difference was added or subtracted, as necessary, from the appropriate gas concentration values for the second half of the stress tests or steady-state exercise tests.

Blood pressure was monitored during stress tests and steady-state exercise tests to ensure subject safety. As an added safety precaution, an American College of Sports Medicine certified Exercise Test Technician was present at all times.

Exercise Stress Test Reliability

Repeat stress tests were not performed because the maximal heart rate and oxygen consumption data obtained during a Bruce protocol stress test can be considered reliable based on the work of Bruce et al. (1973). These researchers reported an estimate of reliability of 0.99 and a standard error of estimate of 1.9 ml of oxygen per kilogram of body weight per minute.

Steady-state Exercise Tests

The investigator conducted the steady-state exercise tests an average of 8.3 days after the Bruce protocol stress tests. At that time, the average temperature and relative humidity for the steady-state exercise test performed at 60% VO_2max were 23.0 degrees Celsius and 82.5% respectively. Similar values for the steady-state exercise test performed at 75% VO_2max were 22.9 degrees Celsius and 81.7%.

The laboratory technician began the morning (6:15-11:00) steady-state exercise tests by having the subject warm up on the treadmill by walking at approximately 4 mph for 2 minutes. After the warm up, the treadmill speed was gradually increased until the subject reached approximately the desired oxygen consumption level. The required speed was estimated using the equations of the ACSM (1986), Bassett et al. (1985), and Hagan et al. (1980). Once oxygen consumption levels stabilized, heart rate was measured. Oxygen consumption was determined to be stable when no significant fluctuations occurred. After the oxygen consumption stabilized the subject was allowed to cool down by walking at approximately 3 mph until his heart rate dropped below 125. The subject then rested for approximately 30 minutes before performing his second steady-state exercise test (either 60% or 75% VO_2max). The sequence of the steady-state exercise tests was randomized.

Steady-state Exercise Test Reliability

Repeat steady-state exercise tests were not deemed necessary because the oxygen consumption and heart rate measurements were stable. The oxygen consumption value most closely approximating 60% VO_2max and the adjoining value yielded a Pearson product-moment correlation coefficient of r = .90. Heart rate recorded at these points yielded a coefficient of r = .98. Similar recorded values for the steady-state exercise test performed at 75% VO_2max resulted in coefficients of r = .86 and r = .98 respectively.

Statistical Procedures

As previously discussed, Pearson product-moment correlation was used in estimating the reliability of measurements taken during the steady-state exercise tests. Other statistical procedures utilized were: descriptive statistics, analysis of variance, multiple regression, and dependent t-tests. The Statistical Analysis System (SAS, 1986) computer program was used for all statistical computations.

Data Analysis

No oxygen consumption or heart rate values recorded during the minute following a speed and/or grade change were used in the data analysis. Therefore during the stress test, only some of the subjects had recorded oxygen consumption values which closely approximated 60 and 75% of

VO_2max (16 and 13 subjects respectively). The mean VO_2max percentage achieved by those subjects approximating 60% VO_2max was 59.68%. A mean VO_2max percentage of 74.87% was achieved by those subjects approximating 75% VO_2max. For those subjects who did not attain the desired percentages ($\pm$ 1%), their heart rates at the desired percentages were predicted through the use of regression equations. The individuals' equations were developed using oxygen consumption and heart rate values recorded during the stage in which the desired VO_2max percentage should have occurred and the adjoining stages.

Dependent t-tests were used to determine if the oxygen consumption values used to approximate the desired percentages during the stress tests were significantly different from those utilized during the steady-state exercise tests. The oxygen consumption levels were not significantly different; therefore, the investigator was justified in comparing heart rate values observed at those levels. A dependent T-test was used to determine if a significant difference existed in heart rate achieved at 60% VO_2max during the stress test and during the steady-state exercise test. Similarly the heart rates at 75% VO_2max were also compared. The results of these heart rate comparisons are presented in Table 3. From the table, it can be seen that the observed heart rates at 60% VO_2max were significantly different ($T=2.10$, $p<.05$) as were the heart

Table 3

Comparison of Heart Rates Observed at 60% and 75% of VO_2max during Bruce Protocol Stress Tests and Steady-state Exercise

Intensity	Mean Difference	SEM	T-ratio	PR > |T|
60% VO_2max	4.25	2.02	2.10	0.04*
75% VO_2max	9.25	1.95	4.75	0.0001**

*$p < .05$. **$p < .01$.

rates noted at 75% VO_2max (T=4.75, $p<.01$).

VO_2max values predicted by Bruce et al.'s (1973) equations for prediction of VO_2max based on age and activity level, and for prediction of VO_2max based on treadmill time were compared using analysis of variance to actual VO_2max values (Table 4). The difference between the two predicted VO_2max values and the actual VO_2max value (F=2.05, $p>.05$) was not significant.

Maximal heart rate values, predicted by subtracting subjects' ages from 220 (Karvonen et al. 1957), and those obtained during the stress tests were also compared by using a dependent T-test. The differences between the predicted and actual values was not significant (T=1.00, $p>.05$).

Conclusions

Analysis of the data yielded significant results. A significant difference was found between heart rates measured at 60% VO_2max during the stress test and steady-state exercise. The heart rates measured at 75% VO_2max during the stress test and steady-state exercise were also significantly different. For a given oxygen consumption level, heart rate was significantly higher during the Bruce protocol stress test than during steady-state exercise. Heart rate comparisons are reasonable because the oxygen consumption values during the stress test and steady-state

Table 4

Analysis of Variance for Predicted VO_2max Values based on Age and Activity Level, Predicted VO_2max Values based on Treadmill Time, and Actual VO_2max Values

Source of Variation	DF	SS	F	PR > F
VO_2max Values	2	129.60	2.05	0.13
Error	81	2559.63		
Total	83	2689.23		

exercise tests at corresponding points were not significantly different. The difference between predicted and actual VO_2max values was not significantly different. The predicted maximal heart rate values also were not significantly different from the actual values obtained during the Bruce protocol exercise stress test.

Based on these findings the following conclusions were drawn:

1) The heart rate-oxygen consumption relationship observed during the Bruce protocol stress tests at 60% and 75% of VO_2max was not the same relationship observed at similar intensities during steady-state exercise on a treadmill.

2) Predicted VO_2max values derived from age and activity level or from treadmill time were not significantly different from actual values obtained during Bruce protocol stress tests.

3) Predicted maximal heart rate values derived from age were not significantly different from actual values obtained during Bruce protocol stress tests.

APPENDIX B

SCREENING QUESTIONNAIRE

APPENDIX B

SCREENING QUESTIONNAIRE

____
name

Your answers on this questionnaire will aid the Human Performance Laboratory personnel in assessing your health and training status. This assessment is performed for your safety and comfort. Please circle the word yes when appropriate. Thank you for your cooperation.

MEDICAL HISTORY

Yes I have not had my blood pressure checked within the past year.

YES I have been diagnosed as having high blood pressure.

YES I have been told by a medical professional that I have high blood cholesterol levels.

YES I use tobacco products.

- Yes I infrequently use tobacco products.
- Yes I smoke 1 package or less of cigarettes daily.
- Yes I smoke more than a package of cigarettes daily.
- Yes I use snuff or chewing tobacco daily.

Yes I have experienced unusual chest discomfort.

Yes I have varicose veins.

Yes I frequently feel my heart "skip or race".

Yes I have been diagnosed as having a heart murmur.

Yes I have congenital heart abnormalities.

Yes I have had rheumatic fever.

YES I have a family history of coronary or other atherosclerotic diseases prior to age 50.

Yes I have had an electrocardiogram before.

YES The electrocardiogram was abnormal.

Yes I have episodes of lightheadedness or fainting.

Yes I have episodes of unusual shortness of breath.

Yes I have asthma, emphysema, or bronchitis.

YES I have diabetes.

Yes I have a family history of diabetes.

Yes I have orthopedic problems.

Yes I have recently been hospitalized.

Yes I have recently had surgical procedures performed.

Yes I have recently been ill.

Yes I am currently on medications.

Yes I am allergic to ______________________________.

YES I HAVE MEDICAL AND OR PHYSICAL PROBLEMS THAT MAY INFLUENCE MY ABILITY TO PERFORM EXERCISE AT A MAXIMAL EFFORT DURING THIS STUDY.

EXERCISE HABITS

Please answer as accurately as possible. It is important to have an accurate exercise profile of participants in this study. In judging the intensity of an activity use the following guidelines:

light: no sweating or not tiring
moderate: sweating or somewhat tiring
hard: profuse sweating or tiring to exhaustion

Activity	Frequency (x/week)	Duration (min.)	Intensity (light-mod.-hard)
Running			
Swimming			
Aerobic Dance			
Racquet Sports			
Bicycling			
Hiking			
Weight Lifting			
Soccer			
Basketball			
Other:			
Other:			

Yes I have had a recent break (5 days or more) in my exercise routine.

Yes I have been exercising regularly less than 3 months.

____

signature

APPENDIX C

INFORMED CONSENT

APPENDIX C

INFORMED CONSENT

HUMAN PERFORMANCE LABORATORY

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

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

Title of Study: "A Comparative Analysis of the Heart Rate-Oxygen Consumption Relationship Observed during Bruce Protocol Graded Exercise Stress Tests and Steady-state Exercise Tests"

The purposes of this experiment include: To investigate the differences between heart rate at specified exercise intensities during a Bruce protocol stress test and during steady-state exercise. The differences between predicted and actual VO_2max values will also be examined.

I voluntarily agree to participate in this testing program. It is my understanding that my participation will include: a maximal Bruce protocol graded exercise test and two steady-state exercise tests. A Bruce protocol stress test will involve walking or jogging at levels of increasing difficulty until exhaustion is reached. The steady-state exercise tests will involve exercising at two different intensities for approximately ten minutes each. I may discontinue my participation in an exercise session or the entire study at any time.

I understand that participation in this experiment may produce certain discomforts and risks. Abnormal changes may occur during the stress test or during the steady-state exercise tests. These changes include: abnormal heart beats, abnormal blood pressure responses, fainting, and in rare instances heart attacks or death. Zohman (1973) indicated that the mortality rate for stress testing is 1 in 10,000 for cardiac participants. Risks will be minimized by preliminary screening, and by observation during testing. Trained technicians will monitor my electrocardiograph continuously and my blood pressure periodically. The exercise stress test and steady-state exercise tests will be terminated if I exhibit signs of exercise intolerance such as lightheadedness, confusion, pallor, cyanosis, nausea, shortness of breath, staggering or persistent unsteadiness, abnormal electrocardiograph changes, abnormal blood pressure responses, and at my request. I will receive proper instructions on warming up and cooling down. Trained personnel will be available if any unusual situations occur. A telephone is available which would be used to call the local hospital for emergency service. If an unusual situation does occur, the Human Performance Laboratory's standard emergency procedures will be followed.

I understand that I may abstain from participation in any part of the experiment or withdraw from the experiment should I feel the activities might be injurious to my health. The experimenter may also terminate my participation should he feel the activities might be injurious to my health.

I understand that it is my personal responsibility to advise the researchers of any preexisting medical problem that may affect my participation or of any medical problems that might arise in the course of this experiment and that no medical treatment or compensation is available if an injury is suffered as a result of this research.

Certain personal benefits may be expected from participation in this experiment. I should develop an increased awareness of the condition of my cardiorespiratory system with respect to population norms. I may then be motivated to increase my level of physical activity and reduce my risk for cardiovascular disease.

I understand that any data of a personal nature will be held confidential and will be used for research purposes only. I also understand that these data will only be used when not identifiable with me.

I have read the above statements and have had the opportunity to ask questions. I understand that the researchers will, at any time, answer my inquiries concerning the procedures used in this experiment.

Scientific inquiry is indispensable to the advancement of knowledge. Your participation in this experiment provides the investigator with the opportunity to conduct meaningful scientific observations designed to make a significant contribution to the field of exercise physiology.

Questions and answers:

If you would like to receive the results of this investigation, please indicate this choice in the appropriate space below. A copy will then be distributed to you as soon as the results are made available by the investigator. Thank you for making this important contribution.

______ I request a copy of the results of this study.

Date____________________ Time___________a.m./p.m.

Participant Signature______________________________

Witness____
HPL Personnel

Participant Address________________________________

Project Director Dr. Don Sebolt Telephone 961-5104

HPER Human Subjects Chairman Dr. D. Cockrell

Dr. Charles Waring, Chairman, Institutional Review Board for Research Involving Human Subjects. Telephone 961-5283

APPENDIX D

TREADMILL PRACTICE PROTOCOL

APPENDIX D

TREADMILL PRACTICE PROTOCOL: PREPARATION FOR THE BRUCE TREADMILL PROTOCOL

Stage	Speed	Grade	Duration[a]	Activity
1.	2 mph	0%	2 min.	walking with handrail support
2.	3 mph	0%	2 min.	walking
3.	3 mph	10%	2 min.	walking
4.	6 mph	0%	3 min.	running
5.	3 mph	0%	2 min.	walking

[a]All times are approximate.

APPENDIX E

INFORMATION SHEET

APPENDIX E

INFORMATION SHEET

Max. Test: ____________________
Exer. Tests: ________________

Cardiovascular disease accounts for approximately one half the deaths in this country. In an attempt to lessen the impact of cardiovascular disease, health practitioners have begun to prescribe exercise programs. Exercise prescriptions are frequently based on the results of a maximal exercise stress test.

An exercise stress test may utilize a bicycle, arm, or treadmill ergometer (device used to measure work). Treadmills are commonly used with the speed and grade manipulated according to the Bruce protocol. This protocol increases speed and grade every three minutes until exhaustion is reached.

This study is designed to investigate the validity of prescribing exercise based on a Bruce protocol stress test. Therefore, subjects will be required to perform a maximal stress test and 2 steady-state exercise tests. To enhance the accuracy of the tests, please follow the instructions listed below.

STRESS TEST INSTRUCTIONS

1. A stress test is hard work; therefore, rest or have easy workouts the two days previous to your test.
2. Rest the day of your test. You may workout afterwards.
3. Get a good night's sleep before your test.
4. Do not eat or drink anything, except water, before your test.
5. Call 951-0061 to reschedule your stress test if you ate breakfast, are sick, or are suffering from an injury on the day of your test.
6. Wear exercise clothing and be prepared to work!

STEADY-STATE EXERCISE TESTS

1. Please follow all of the same instructions given for the stress test.
2. If you wish, bring something to read during the 30 minute rest period between exercise tests.

Anytime you have a question or problem, please call me at my home 951-0061 or at the lab 961-5006. You may also leave messages for me in my mailbox located in the foyer of the gym. I appreciate your participation in this study.

V. C. Shafer-Millsap

APPENDIX F

POSTTEST INFORMATION

APPENDIX F

POSTTEST INFORMATION

401A Marlington St.
Blacksburg, Virginia
01 SEP 1986

Dear ________________

Let me thank you again for being a subject in my study. You have made an important contribution to the advancement of science (and to my education). I have enclosed some information regarding oxygen consumption values and a data sheet. If I can provide any further information or answer any questions, please call me. The lab's phone number is 961-5006; my home phone number is 951-0061.

V. C. Shafer-Millsap

your VO_2max: ______

your maximal heart rate: _______________

With these values, you can enter the accompanying table and make comparisons.

"VO_2"

VO_2 stands for oxygen consumption. It is commonly expressed in milliliters of oxygen per kilogram of body weight per minute. Your body, like an engine, requires fuel and oxygen to produce energy. You have the necessary fuel in the form of carbohydrates and fats, and you inspire the oxygen you need to burn this fuel. When you are completely at rest you use approximately 3.6 ml/kg/min of oxygen. This amount is required to simply maintain life. As you expend more energy, you use more oxygen to burn more fuel. Therefore, VO_2 is closely related to the amount of work performed.

During the first test on the treadmill, the workload was increased every three minutes. Your VO_2 also increased until it began to level off. Perhaps you can recall the feeling of running out of energy at the end of the test. The highest VO_2 obtained is termed VO_2max. It is at this point that the body has reached its peak ability to use oxygen to burn fuel. It can be compared to the top rpm of an engine. For these reasons, VO_2max is regarded as the best criterion of cardiorespiratory fitness. An individual who is quite fit has a very productive energy generating system and can utilize more oxygen.

In this study VO_2 was measured by the use of the headgear and gas analyzers. To determine the amount of oxygen consumed, we measured the volume of air inhaled and analyzed the exhaled air for oxygen content. The difference in oxygen concentration (inhaled - exhaled) was calculated by the Apple IIe computer. The computer was also used to perform the other calculations required to produce VO_2max. In a sense, you and the computer did all the work!

SUBJECT PROFILES

Subject	Actual VO_2max	Normal VO_2max	Maximal Heart Rate	Age	Activities Minutes per Week			
1	68.6	54.4	196	25	cycling	600		
2	68.0	50.1	200	32	running	490	weights	330
3	66.4	50.1	177	32	running	100	cycling	60
4	64.3	55.6	190	23	cycling	480	basketball	180
5	64.0	55.6	187	23	cycling	540	weights	150
6	62.3	48.3	187	35	running	490	cycling	540
							swimming	158
7	60.7	54.4	188	25	running	270	swimming	120
							cycling	120
8	60.0	58.7	214	18	running	450	cycling	244
9	59.3	55.0	207	24	cycling	420	running	158
10	58.9	50.1	190	32	cycling	210	running	167
11	58.6	56.2	194	22	cycling	300	swimming	150
12	58.3	54.4	177	25	running	360	weights	225
13	56.8	53.2	187	27	swimming	90	running	60
14	56.2	50.1	182	32	running	360	cycling	300
							swimming	150
15	55.7	57.5	200	20	running	158	cycling	113
16	53.5	55.0	187	24	running	240		
17	53.4	52.6	177	28	rock climbing	360	aerobic dance	180
18	52.3	53.2	190	27	weights	450	cycling	300
19	51.4	54.4	194	25	running	30	weights	40
20	51.0	56.2	182	22	running	90	cycling	135
21	50.1	49.5	187	33	running	203	golf	360
22	49.7	52.6	187	28	running	248	cycling	37
23	48.8	50.1	197	32	cycling	120	swimming	160
24	48.1	44.6	184	41	running	180	cycling	60
							swimming	40
25	48.1	49.5	187	33	running	225	swimming	175
26	46.5	58.1	201	19	cycling	46	walking	46
27	45.1	50.7	187	31	aerobic dance	150	cycling	60
28	36.1	54.4	177	25	running	200	basketball	240

Normal VO_2max values are based on a regression equation developed by R. A. Bruce and coworkers (1973). The equation is for active males and uses age as a factor. Below are VO_2max values from a similar Bruce equation for sedentary males.

Normal VO_2max Values for Sedentary Males

Age	VO2max	Age	VO2max
18	49.8	27	45.8
19	49.3	28	45.3
20	48.9	31	44.0
22	48.0	32	43.6
23	47.6	33	43.1
24	47.1	35	42.2
25	46.7	41	39.6

The equation for male cardiac patients who are tested with a Bruce protocol exercise stress test, as you were, is:

$$VO_2max = 10.5 + .035(\text{test duration in seconds})$$

APPENDIX G

PRE-EXERCISE SESSION QUESTIONNAIRE

APPENDIX G

PRE-EXERCISE SESSION QUESTIONNAIRE

Please circle the word 'yes' when appropriate.

Yes I have eaten since I awoke.

Yes I have drunk something besides water since I awoke.

Yes I have been ill recently.

Yes There is a reason I should not participate in an exercise session today.

____

The last time I exercised was:

______	______	______	______	______
exercise type	date	time	duration	intensity light,mod., hard

______________________ signature

______________________ witness

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