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Evaluation of Accelerated Plethysmography as a Measure of Health and Fitness

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THESIS APPROVAL

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ABSTRACT

An abstract of the thesis of Angela Marie Humble for the Master of Science in Health Education presented November 6, 1997.

Title: Evaluation of Accelerated Plethysmography as a Measure of Health and Fitness.

Plethysmography is a technique used for measuring alterations in the volume of organs or limbs. Japanese researchers have developed a relatively new application of plethysmography (accelerated plethysmography) that uses information from the pulse wave measured at the fingertip to make inferences about health and fitness status. The instrument used to collect data -- the Precaregraph (accelerated plethysmograph) -- provides an accelerated pulse waveform and and APG index, a mathematical representation of the waveform. It was the purpose of this study to evaluate the validity of the Precaregraph by examining the relationship between the APG index and previously validated measures of health and fitness status.

Forty-three individuals volunteered for participation. Blood pressure, resting heart rate, weekly physical activity level, estimated

$\dot{V}O_{2max}$, cardiovascular disease risk, body composition and APG index were measured.

The APG index demonstrated acceptable reliability in the pilot study (R=.999). In the principal investigation, the only measures related to the APG index were age (r=-.780), $\dot{V}O_{2max}$ (r=.709), and weekly physical activity level (r=.328). No significant correlations were found between any other variables. Correlations with the same independent variables were found when subjects were dichotomized into older and younger groups and high-fit and low-fit groups.

It was concluded that the Precaregraph may be a useful instrument for evaluating fitness status, but its efficacy for evaluating health or disease remains to be determined. Further studies are needed to gather additional data to confirm these results.

EVALUATION OF ACCELERATED PLETHYSMOGRAPHY

AS A MEASURE OF HEALTH AND FITNESS

by

ANGELA MARIE HUMBLE

A thesis in partial fulfillment of the
requirements for the degree of

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In memory of

Dr. Milan Svoboda

Thank you for your time and
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CHAPTER I

INTRODUCTION

Cardiovascular disease is one of the leading causes of death in the United States. There are three primary risk factors that have been found to play a definite and major role in the development and progression of cardiovascular disease. These are high blood pressure, poor blood lipid profiles, and smoking behavior (Pollock and Wilmore, 1990). The good news, though, is that each of these risk factors is modifiable through changes in lifestyle, especially exercise habits. The bad news is that many people do not make modifications to their lifestyle habits until the first clinical signs and symptoms of the disease present themselves.

Part of the problem is that current assessment tools are only able to track the disease state and are unable to detect the subtle changes in cardiovascular functioning that occur prior to the appearance of symptoms. Japanese scientists have developed a new technique called "accelerated plethysmography" (APG) that may have the capacity to do just that.

Researchers from Japan have designed an instrument (Precaregraph, Misawa Corporation) that presumably provides health and fitness information by evaluating blood flow characteristics in the tip of the index finger using an infrared light beam. Results are provided as a "traditional" pulse waveform as well as an "accelerated" (second mathematical derivative) waveform. Mathematical manipulations performed using components of the accelerated waveform provide an "APG index". By calculating the APG index, it is thought that individuals can be classified according to their health and fitness status.

In the assessment of health, the Japanese researchers posit that the APG index is capable of reflecting deterioration or improvement in cardiovascular functioning and thus has the potential for clinical utility. Because the instrument is sensitive to subtle changes in blood flow dynamics -- presumably due to alterations in cardiovascular health -- it can theoretically be used to evaluate patients in the early stages of disease. Therefore, the clinical focus is on early treatment and prevention rather than treatment of the advanced disease (Knowledge Information Department, Brochure).

These same researchers have also shown the APG index to be sensitive to changes brought about by exercise (Sano, Kataoka, Ikuyama, and Osanai, 1993; Sano, Kataoka, and Osanai, 1993a, 1993b, 1993c). In the past, it has been repeatedly demonstrated that exercise can increase fitness levels and alter the course of disease by modifying risk factors. The APG index presumably reflects the changes in circulation caused by exercise training. Therefore, by monitoring improvements in the APG index, the effects of exercise training on fitness and health status can be evaluated. As a result, the Precaregraph may be useful in homes and health clubs as a tool for developing individualized exercise programs and tracking the progress of participants in those programs, thereby providing baseline and follow-up data.

The growing importance being placed on prevention of disease through lifestyle changes has illuminated the need for sensitive assessment tools capable of detecting the potential for disease. Research conducted to this point using the Precaregraph has produced promising results in this area (Sano, Kataoka, Ikuyama, Wada, et al., 1986, 1988). No studies have yet been undertaken to evaluate the efficacy of using the Precaregraph with United States citizens. Therefore, this study was designed to address issues of validity and reliability of the APG index in healthy adults residing in the United States.

STATEMENT OF THE PROBLEM

The accelerated plethysmography index (APG index) was developed in Japan and is currently being used by physicians and other healthcare professionals in Japan to evaluate health and fitness status in patients. Although many studies conducted in Japan have demonstrated the usefulness of this measurement technique, it is unknown whether these results are applicable to other populations. Furthermore, Japanese research has focused primarily on gathering descriptive data (i.e., how the instrument works in certain situations) and not on whether it measures what it purports to measure.

Therefore, it was the purpose of the present study to examine the validity and, to some extent, the reliability of accelerated plethysmography in a healthy adult population living in the United States.

The research hypothesis was that the APG index would be related to commonly used and previously validated measures of health and fitness. Specifically, the APG index would be significantly positively correlated with estimated $\dot{V}O_{2max}$ and involvement in physical activity. The APG index would also be significantly inversely correlated with resting blood pressure, resting heart rate, age, and cardiovascular disease risk.

SCOPE OF THE STUDY

Due to the population and assessment tools used in this study, the reported results may have limited applicability. Subjects for this study were overtly healthy individuals 20 to 60 years of age with no known history of cardiovascular disease. The results obtained may not reflect the correlation between the APG index and other measures of health and fitness in younger or older individuals or those who have clinical signs or symptoms of cardiovascular or other diseases.

The research may also be limited by the measurement instruments used. Although the tools have undergone validation testing, it is important to remember that each provided only an estimate of health and/or fitness status. These estimations may not accurately portray an individual's actual fitness or health status, and thus may have reduced external validity.

DEFINITION OF TERMS

1. Accelerated Plethysmography - Plethysmography is a technique designed to measure blood flow characteristics. Traditional plethysmography involves an analysis of the typical pulse wave pattern. In accelerated plethysmography, the typical pulse wave is mathematically altered to provide the second derivative. This second

derivative more clearly shows changes in the dynamics of peripheral circulation (Appendix A).

2. Precaregraph - The Precaregraph is a plethysmograph designed in Japan by the Misawa Corporation. It measures and records blood flow characteristics in the tip of the index finger through the use of and infrared light beam. The device then converts these data into an accelerated plethysmogram and computes the APG index.

3. APG Index - The APG index is the score assigned to the pulse waveform by the Precaregraph. This score is calculated by measuring the distance of the "turning points" (a, b, c, d) in the accelerated waveform from the baseline and using the measurements in the following equation: $(-b + c + d)/a \times 100$ (Sano, Kataoka, and Osanai, 1993c). A higher APG index presumably indicates better peripheral circulation and therefore better fitness and health, while a lower APG index indicates poorer peripheral circulation, health, and fitness status.

RESEARCH ASSUMPTIONS

The following is a review of the underlying assumptions used during this research project:

1. The measurement tools (RISKO, activity survey, resting heart rate, blood pressure, and non-exercise $\dot{V}O_{2max}$ estimation)

used in this study were valid, reliable, and appropriate for use with this sample.

2. Measures of estimated maximum oxygen uptake and participation in physical activity and exercise reflected an individual's fitness status.

3. Blood pressure measurement and cardiovascular disease risk assessment were reflective of an individual's health status.

4. Subjects were forthright and truthful when completing survey items.

CHAPTER II

LITERATURE REVIEW

INTRODUCTION

The ability to measure and record changes that occur inside the body with minimally invasive techniques is quickly becoming the norm in health care. Advancing technology has made it possible to peer inside the human brain and body and make observations without using potentially dangerous surgical procedures or x-rays. Likewise, many operations that once were considered major surgeries have been reduced to outpatient procedures. As technology continues to advance it will become more critical to both predict the onset of disease and to treat illness with less invasive and more effective methods.

Plethysmography is a non-invasive technique with many applications. Specifically, it is the process of "measuring and recording changes in volume in a part, organ, or whole body" (Boggs, 1993). Information collected from plethysmographs may include blood pressure and arterial pulse waveforms, or show alterations in venous blood flow. Traditionally, plethysmography has been used in a medical setting to diagnose and locate deep vein thromboses or blood clots (Verstraete, 1993). This technique is referred to as impedance plethysmography and results will show the traditional pulse wave. Depending upon the size and shape of the pulse wave, diagnosis of different types of peripheral vascular disease can be made (Bright and Georgi, 1992).

Japanese researchers at the Misawa Corporation have taken the concept of plethysmography and made some important alterations. These researchers felt that the pulse waveforms gathered from traditional plethysmography did not show in sufficient detail the many subtle changes that occur in peripheral blood flow with disease or physical activity. Therefore, they mathematically altered the traditional waveforms by taking the second derivative, thereby creating the "acceleration plethysmogram" (Sano, Kataoka, Ikuyama, Wada et al., 1986). This new type of plethysmography more clearly shows alterations in the dynamics of peripheral circulation (Appendix A).

The pioneers of accelerated plethysmography contend that the development of cardiovascular disease is usually preceded by subtle changes in blood flow dynamics, and that the functioning of the central circulatory system can be investigated by measuring parameters within the peripheral circulatory system. For example, atherosclerosis may compromise blood flow to the periphery. Careful, continual monitoring of accelerated plethysmography scores may signal the onset of cardiovascular disease in an individual. This can lead to early detection, lifestyle changes, and eventually prevention of the clinical symptoms of diseases such as angina pectoris (chest pain), myocardial infarction (heart attack), stroke (cerebral apoplexy), etc.

THE PRECAREGRAPH: MEASUREMENT AND RESULTS

The Precaregraph accelerated plethysmograph measures peripheral blood flow characteristics in the index finger. This is accomplished with an infrared light beam directed through the tip of the finger. Light is absorbed by the hemoglobin of the red blood cells flowing through the peripheral vasculature. The amount of absorption occurring is proportional to the volume of blood flowing past the light beam. The measurement of absorbance -- and subsequent mathematical manipulations -- are hypothesized to reflect characteristics and functioning of the peripheral circulatory system. Traditional pulse waveforms are collected using this procedure and then transformed through differentiation into the accelerated waveform. Measurement is painless and requires only that the individual being tested remain quiet and still.

After data collection, the accelerated waveforms are analyzed. Two types of scores are calculated and presented for each person tested. The first type of score is the classification of the accelerated plethysmograph (APG) waveform. The waveforms are distinguished according to the height and position of four separate inflection points (a, b, c, d). These points classify the waveform into one of seven major categories (A, B, C, D, E, F, G) or one of 22 minor categories (e.g. A-, B+, BX). Scores ranging from A+ to B- signify good or "healthy" blood flow dynamics. Patterns in the C range reflect slightly insufficient or compromised blood flow, and waveforms in the D through G categories show poor or "unhealthy" blood flow dynamics (Knowledge Information Department, vol. 22) (Appendix B).

The second type of score is the APG index. This is a numerical value calculated by measuring the distance from the baseline of the waveform to the four inflection points and inserting these measurements into the following equation: $(-b + c + d)/a \times 100$ (Sano, Kataoka, and Osanai, 1993a). Presumably, a higher index indicates better peripheral blood flow dynamics, thus a better health and fitness status. While not used nearly as much in the Japanese research, the index assigns a numerical value to the waveform. This provides an opportunity for parametric statistical analysis of data collected. It has been reported that age is more strongly correlated with the APG index (r=-0.70) than the waveform classification (r=-0.58) (Sano, Kataoka, Ikuyama, Wada, et al., 1988). Unlike the waveforms, though, the indices have not been classified into "good", "average", and "poor" categories. Utilized together, however, both methods of pulse waveform evaluation may provide information about health and fitness status.

PRECAREGRAPH, HEALTH AND FITNESS

Because the Precaregraph has been purported to provide information along two fronts -- health status and fitness status-- preliminary research from Japan has been separated into health studies and fitness studies. Several different studies conducted by Sano and his colleagues focused on health-related aspects as well as disease states. These investigators made three important conclusions concerning the Precaregraph accelerated plethysmograph.

In their cross-sectional study of 738 men age 20 to 69, the incidence of "better" waveforms (A, B) decreased while D, E, F, and G waveforms increased with age. The 20 to 29 year-olds showed waveforms in the A or B categories approximately 95 to 97% of the time. On the other hand, the 60 to 69 year-old group demonstrated no A waves, about 35% B waves and approximately 52% D through G waveforms. It was concluded that as an individual ages, the APG index and waveform type tend to worsen, suggesting a trend toward poorer peripheral circulation (Sano, Kataoka, Ikuyama, Wada, et al., 1986).

Using this same sample, the researchers also examined the relationship between blood pressure and the APG index and waveform classification. The 738 men were divided into three groups on the basis of their resting blood pressure. These groups were assembled according to World Health Organization standards and were labeled "normal", "boundary range" or "borderline hypertension", and "hypertensive". Results indicated that as resting blood pressure increased, waveforms worsened. This was noticed as a trend, although was not strong enough to imply a significant relationship between blood pressure and accelerated plethysmography (Sano, Kataoka, Ikuyama, Wada, et al., 1986).

Finally, they investigated the effect of a variety diseases on APG scores. Under the premise that changes in the central circulatory system are reflected in the dynamics of the peripheral circulatory system, case studies led researchers to conclude that individuals with histories of angina pectoris and myocardial infarction did, in fact, have poorer APG scores. Interestingly, regardless of how poor the waveform was, blood pressure was sometimes normal and sometimes high. This suggested to the researchers that blood pressure was not an accurate method for diagnosing or tracking the progress of ischemic heart disease; accelerated plethysmography was concluded to be a better technique (Sano, Kataoka, Ikuyama, Wada, et al., 1986).

Not only did the researchers study cardiovascular disease, but they also examined cerebral apoplexy and various cancers including, breast cancer, ovarian cancer, and lung cancer. In each case studied, APG waveforms were in the D through G range. Their conclusion was that compromised blood flow, and hence lowered oxygen and nutrient supply, could be a contributing factor in some forms of cancer as well as cerebrovascular disease (Sano, Kataoka, Ikuyama, Wada, et al., 1986). However, these conclusions were also based on individual case studies and have not been followed up with larger cross-sectional or longitudinal studies.

Accelerated plethysmography research has also focused on physical fitness. Research has examined APG responses to both single bouts of exercise as well as to aerobic training. Sano, Kataoka, Ikuyama, Wada, et al., (1986) found that blood pressure was lowered and waveforms were improved after 15 to 20 minutes of continuous aerobic exercise. They also found that long-term aerobic training programs improved APG scores.

Other studies done have shown similar results. In their report, Sano, Kataoka, and Osanai, (1993a) concluded that short-term bouts of exercise were effective in temporarily improving both the APG index and the APG waveform classification from baseline resting levels. Another study also revealed that single bouts of aerobic exercise improved waveforms and APG indices; exercise performed on successive days showed a cumulative effect (Sano, Kataoka, Ikuyama, and Osanai, 1993). In other words, improvements continued to be realized over the course of three days of exercise and testing.

When studying the long-term effects of exercise on APG scores, Sano, Kataoka, and Osanai (1993b) reported improvements in peripheral circulation as measured by the APG index after three months participation in an aerobic training program. In a different type of training study, Sano, Kataoka, and Osanai (1993c) looked at the APG index and waveforms of two groups of elderly participants. The first group was self-sufficient and able to walk on their own. Subjects in the second group were unable to walk unassisted. The researchers found that the scores of the walkers were significantly better than the non-walkers. They concluded that walking, even in small amounts, is sufficient exercise to maintain good peripheral circulation.

The developers of the Precaregraph have made several claims concerning the function and use of their machine. Before these claims can be accepted, it is important to establish the validity of the technique. This involves determining the relationship between the APG index and previously validated measures of health and fitness.

VALIDATION TOOLS

$\dot{V}O_{2max}$

In the assessment of health and fitness status, several validated tools play an integral role. Perhaps the most important well-established of these for determining fitness status is $\dot{V}O_{2max}$. This is a measurement of the amount of oxygen an individual is able to take in, transport throughout the body, and use during maximal exercise. It is usually reported in either in liters per minute (L/min) or in milliliters per kilogram body weight per minute (ml/kg/min).

This measurement is an indicator of how the cardiovascular system is able to provide sufficient oxygen for the demands of the working muscles. Regular aerobic exercise or training improves an individual's ability to transport and extract oxygen, which is reflected in a higher oxygen uptake or $\dot{V}O_{2max}$.

Because of its accuracy and importance in determining fitness status, $\dot{V}O_{2max}$ has become a crucial dependent variable in exercise research. However, in studies where high risk populations are being observed or in studies using a large number of subjects, it may not be safe or economically feasible to directly measure $\dot{V}O_{2max}$. For this reason other techniques have been developed to estimate $\dot{V}O_{2max}$.

The most common technique for the estimation of $\dot{V}O_{2max}$ involves submaximal exercise testing. This involves testing the subject at a level well below his or her maximum capacity. Many different modes of exercise can be used in submaximal testing, including walking, stepping, and cycling. Measuring the heart rate at submaximal power outputs will provide values that can be extrapolated to estimate $\dot{V}O_2$ at the individual's presumed maximum. This technique works because increases in heart rate and $\dot{V}O_2$ are linearly related at lower power outputs (i.e., those resulting in heart rates between 120 and 150 beats per minute).

Until recently, submaximal testing was the best and only way to estimate $\dot{V}O_{2max}$ in very large or at-risk populations. Within the past few years, several researchers have developed regression equations to estimate $\dot{V}O_{2max}$ with non-exercise models. Each of these equations require the participant to provide information about age, body composition (either percent fat or body mass index), and approximate weekly energy expenditure levels; exercise testing is unnecessary.

Jackson et al. (1990) developed two non-exercise regression equations for the prediction of $\dot{V}O_{2max}$. One equation used percent fat (% fat) as an independent variable, while the other used body mass index (BMI). They reported multiple correlations for the models at R=0.81 for the percent fat model and R=0.78 for the BMI equation. The equations were cross-validated with a sample of 466 men and women. This sample confirmed the accuracy of both equations ($R_{\%fat}$=0.82, R_{BMI}=0.79). The non-exercise models provided a more accurate estimation of $\dot{V}O_{2max}$ (SEE= 5.3 to 5.6 ml/kg/min) than estimates obtained from submaximal testing using the Astrand-Rhyming single-stage cycle test (SEE= 5.5 to 9.7 ml/kg/min).

Heil, Freedson, Ahlquist, Price, and Rippe (1995) also developed non-exercise regression equations for the prediction of $\dot{V}O_{2max}$. Age, gender, level of activity, and percent body fat were used as the independent or predictor variables. Results showed the equations to be more closely related to submaximal and maximal $\dot{V}O_2$ values and to have less error than those developed by Jackson et al. (1990) (R=0.88; SEE= 4.90 ml/kg/min). Results were verified in a cross-validation sample of 65 men and women (r = 0.93; SEE=4.46 ml/kg/min).

Although it was found that both sets of equations can be highly accurate when estimating $\dot{V}O_{2max}$, one major drawback has been found. Kolkhorst and Dolgener (1994) revealed that the non-exercise models developed by Jackson et al. (1990) poorly predicted $\dot{V}O_{2max}$ in highly trained college-age participants. They reported that the average difference between the non-exercise percent fat and BMI models and the measured $\dot{V}O_{2max}$ was 11.73 ml/kg/min and 9.77 ml/kg/min, respectively. The researchers concluded that the non-exercise equations developed by Jackson et al. (1990) are not valid for young participants with higher than average measured $\dot{V}O_{2max}$.

Kolkhorst and Dolgener (1994) postulated that the differences they found could have resulted from several sources. First, their sample was rather homogeneous with respect to age and fitness level. A more heterogeneous sample similar to that of Jackson et al. (1990) may have reduced the discrepancy. Second, the sample chosen by Kolkhorst and Dolgener (1994) was composed of nearly 41% females. Jackson et al. (1990) studied a sample that contained only 9% women. However, a second cross validation done by Williford et al. (1996) using only women revealed that the equations were indeed valid for females as well.

Perhaps the most serious limitation involves the activity code used to estimate daily energy expenditure. The activity code scale was developed at NASA/Johnson Space Center in Houston, Texas. Participants were asked to rate their level of weekly physical activity on a scale of 0 to 7. A score of "0" constituted no activity or avoidance of activity altogether, while a "7" meant the individual ran over ten miles per week or spent over three hours per week in a comparable activity (Baumgartner and Jackson, 1991). It is apparent that the upper end of this scale does not represent the portion of individuals who are highly fit and spend much more time per week in heavy physical activities. For this reason, it is thought that the non-exercise equations from both Jackson et al. (1990) and Heil et al. (1995) underestimate the $\dot{V}O_{2max}$ of highly fit individuals, but are still excellent estimators of $\dot{V}O_{2max}$ in low to moderately fit individuals.

CARDIOVASCULAR DISEASE RISK

The risk of developing cardiovascular disease in the future is an important factor when determining the health status of an individual. Many elements of an individual's life have been targeted as possible factors for increasing the risk of cardiovascular disease. These elements may be a reflection of a person's lifestyle choices (e.g., smoking, overweight, physical inactivity). Other elements are simply things that cannot be changed (i.e., age, gender, and family history) (Pollock and Wilmore, 1990).

Risk factors are generally divided into two groups: primary and secondary risk factors. The secondary factors are thought to be related in some way to the development of cardiovascular disease but have not been definitively implicated. These include diabetes, stress, obesity, age, gender, and heredity. The primary factors have been proven to play a major causal role in the development of cardiovascular disease and are hypertension, abnormal plasma lipid and lipoprotein concentrations, and smoking (Pollock and Wilmore, 1990).

Hypertension, or high blood pressure, can range from mild to severe, and results from general vasoconstriction. Although the exact mechanism responsible for the vasoconstriction is not fully known and understood, it is thought to be related to a high level of sympathetic tone (Franklin, Gordon, and Timmis, 1991). Depending upon the severity, hypertension is generally managed with medication and dietary modification, although recent research has shown that regular aerobic exercise and physical activity can help reduce resting blood pressure in normotensive to moderately hypertensive adults (Kelley and Tran, 1995; Martin, Dubbert, and Cushman, 1990).

The second major primary risk factor for cardiovascular disease is an abnormal plasma lipid and lipoprotein profile. A poor profile will include elevated levels of cholesterol, triglycerides, and low-density lipoproteins (LDL) and lowered high-density lipoproteins (HDL). These factors will help to promote the formation of the atherosclerotic lesions that often lead to heart attacks, stroke, and other cardiovascular problems (Grundy et al., 1993).

Cholesterol, when carried by low-density lipoproteins (LDL-C), is generally thought to be the undesirable type of cholesterol and is thought to be responsible for the build-up of plaque in the arteries (Pollock and Wilmore, 1990). The higher the LDL-C concentration the greater chance there is for cholesterol deposition in the arteries leading to subsequent cardiovascular disease. It should be noted, however, that regular aerobic exercise has been shown to decrease the plasma concentration of LDL-C (Durstine and Haskell, 1994). Although the mechanism for this is poorly understood, it may be the result of increased uptake and breakdown of LDL-C by the liver (Ross, 1986).

In comparison to LDL-C, cholesterol carried by the high-density lipoproteins (HDL-C) is considered the "good" cholesterol and is thought to be involved in reverse cholesterol transport (Durstine and Haskell, 1994). In other words, HDL actually picks up cholesterol that has been deposited in the arteries, taking it to the liver to be catabolized (Pollock and Wilmore, 1990). Higher HDL concentrations presumably indicate a more efficient reverse cholesterol transport system and lower cardiovascular disease risk.

An additional lipid category pertinent to the discussion of cardiovascular disease risk is plasma triglycerides; inactivity contributes to an increase in plasma triglyceride concentrations (Durstine and Haskell, 1994). High levels of triglycerides in the blood can have effects ranging from increased risk for the development of atherosclerotic lesions to acute pancreatitis (Grundy et al., 1993). Regular aerobic activity has been shown to decrease levels of triglycerides but this may depend upon initial levels as well as the amount of exercise in which one is involved. This decrease in triglyceride concentrations is thought to be due to increased lipoprotein lipase activity which enhances uptake of triglycerides for use in the tissues (Durstine and Haskell, 1994).

The third primary cardiovascular disease risk factor is smoking. Cigarette smoking significantly increases the risk of both cardiovascular disease and death (Rifkind, 1990). This is not confined to smokers, however; non-smokers who are chronically exposed to cigarette smoke are also at an increased risk for cardiovascular disease and death

(Svendsen, Kuller, Martin, and Ockene, 1987). Like the other factors, the mechanism for this effect is not clearly understood, but it is thought that tobacco smoke may damage the arterial wall leading to eventual atherosclerotic lesions (Caro, Lever, Parker, and Fish, 1987). This process may be accelerated by decreased levels of HDL caused by smoke inhalation (Rifkind, 1990).

When assessing the risk of an individual for the development of cardiovascular disease, it is important to determine the status of that person with regard to the primary and secondary risk factors. The American Heart Association has developed several assessment tools to ascertain cardiovascular disease risk. The simplest to administer to a large group is the RISKO survey (American Heart Association, 1981). This worksheet uses information about gender, age, weight for height, total cholesterol, systolic blood pressure, smoking habits, and estrogen use in women. Points are assigned and tallied, with the individual's risk for the development of cardiovascular disease classified as "low", "moderate" or "high" (Appendix D).

The RISKO survey is very useful for obtaining data on large numbers of people. However, risk can be over- or underestimated if all the information is not accurate. The American Heart Association has developed a new version of the RISKO worksheet that more closely estimates risk for both coronary heart disease and stroke (American Heart Association, 1990). The worksheet requires participants to supply information about total cholesterol, HDL-C concentrations, and electrocardiogram abnormalities. For many potential participants, this information is not easily obtained.

PHYSICAL ACTIVITY AND EXERCISE

Although lack of physical activity and exercise is not, as of yet, considered to be a primary risk for cardiovascular disease, it is quite evident that exercise and activity have a profound impact on disease and risk of disease.

Physical activity has been defined as “any bodily movement produced by skeletal muscles that results in energy expenditure” (Caspersen, Powell, and Christenson, 1985). Exercise differs from activity in that it pertains to planned, structured and repetitive bodily movements and is oriented toward improving or maintaining physical fitness levels (Caspersen et al., 1985). It is important to make the distinction between these two terms as each will impact disease and risk differently.

Physical activity is usually done in a more leisurely manner and does not result in the same type of physiological changes and adaptations resulting from exercise; therefore, activity may or may not contribute to overall fitness levels. A study by Goldsmith and Hale (1971) examined this relationship. They studied the habitual physical activities of eighteen police officers to determine whether varying degrees of physical activity would cause concomitant degrees of physical fitness. They compared fitness levels between officers who were assigned to office work, car patrol, or foot patrol and found that differing physical activities and levels did not consistently provide increases in fitness levels.

Despite the minimal relationship between activity and fitness, several studies have shown that physical activity, even in small amounts, will provide some protection against disease. Several large prospective studies have provided data relating to physical activity and disease. Perhaps the best know of these is the Harvard Alumni Health Study, where Paffenbarger and his colleagues collected physical activity, fitness, exercise, disease, and mortality data on 16,936 Harvard University alumni from 1962 through 1985 (Paffenbarger, Jung, Leung, and Hyde, 1991). These data have been analyzed repeatedly. In one of the earlier reports (Paffenbarger, Wing, and Hyde, 1978) an inverse relationship between energy expenditure and the risk of first heart attack was described. The activities analyzed in this study were stairs climbed, blocks walked, and strenuous sports played. They found that the greater the number of kilocalories reported to be expended during a week, the lower the risk for a heart attack. Those who expended less than 2000 kilocalories per week in physical activities were at a 64% higher risk of heart attack.

The Harvard data were also used investigate the relationship between physical activity and mortality. Lee, Hsieh, and Paffenbarger (1995) found an inverse relationship between energy expenditure and all-cause mortality. In other words, as weekly energy expenditure increased, mortality rate decreased.

Another well-known large, prospective study frequently cited is the Multiple Risk Factor Intervention Trial (MRFIT). Leon, Connett, Jacobs, and Rauramma (1987) attempted to determine the relationship between leisure-time physical activity (LTPA) and coronary heart disease (CHD) and all-cause mortality. The researchers found an inverse relationship between level of LTPA and both coronary heart disease events (heart attack) and all-cause mortality. Folsom et al. (1985) with the Minnesota Heart Survey also found that greater LTPA was associated lower coronary risk factors.

Other studies have shown similar results. Blair et al. (1989) studied fitness levels as a measure of physical activity and all-cause mortality in 13,344 men and women. A decline in mortality rates over increasing fitness quintiles was reported. They concluded that physical fitness status was an important risk factor for death from all causes in both men and women. Lakka et al. (1994) concurred with this conclusion in their study of the relationship between activity levels, cardiovascular fitness and the risk of heart attack in men. They, too, found that the incidence of myocardial infarction decreased as LTPA and cardiovascular fitness levels increased.

Several of the studies discussed above found more protection was afforded against disease and death with higher doses or greater intensities of exercise or activity. For that reason, physical exercise is usually prescribed to attenuate the risks of cardiovascular and other disease. Siscovick, LaPorte, and Newman (1985) reported that physical inactivity positively influences the development and severity of coronary heart disease, hypertension, diabetes mellitus, and osteoporosis. They recommended engaging in specifically designed and regular aerobic exercise programs to reduce the risk of development and advancement of these conditions.

Reports and studies such as these have prompted exercise physiologists and fitness specialists to modify recommendations of the amount and type of exercise in which adults should engage. Previous recommendations for the improvement of cardiovascular fitness and modification of disease risk were to engage in large muscle, repetitive, aerobic exercises (walking/jogging, cycling) three to five times per week, twenty to thirty minutes per session at 55 to 85% of maximum heart rate reserve (American College of Sports Medicine, 1990). New recommendations have recently been endorsed by the Centers for Disease Control and Prevention (CDCP) and the American College of Sports Medicine (ACSM) (Pate et al., 1995). The CDCP and ACSM encourage adults to engage in at least 30 minutes of moderate-intensity aerobic exercise that equals approximately 3.0 to 6.0 METs (one MET is the approximate rate of oxygen consumption of a seated adult at rest and is equal to 3.5 ml/kg/minute). This activity should preferably be done on all days of the week.

Because of the importance attributed to participation in physical activity and exercise, it is becoming increasingly crucial to be able to measure the amount of activity and exercise in which individuals are involved. There are several methods for doing this. Many of the most accurate and reliable methods are very expensive and time consuming and can only be used with small groups or single participants (e.g., calorimetry, doubly-labled water, and behavioral observations) (LaPorte, Montoye, and Caspersen, 1985). By far the most widely used method for assessing daily physical activity is recall questionnaires and surveys.

These are minimally intrusive and require a relatively small time commitment. Subjects are asked to recall and record information regarding typical physical activity and exercise frequency, intensity, and duration. Participants are often required to record activities of daily living as well.

Although not as accurate as other methods, recall surveys and questionnaires have proven valid and reliable for large study samples. Taylor et al. (1984) compared a seven-day recall interview and a self report log with a direct measure of physical activity and energy expenditure. They found that both methods were significantly correlated with the direct measure of energy expenditure and the best recalled activities were exercise or conditioning activities. It was concluded that a combination of methods (interview and log) may enhance recall. Moderate correlations ($r=0.14$ to 0.41) between measured and self-assessed physical activity were also found by Weiss et al. (1990).

Given the apparent validity and reliability of recall surveys for estimating energy expenditure, other researchers have used similar techniques to help estimate physical fitness status. Siconolfi, Lasater, Snow, and Carleton (1985) measured maximal oxygen uptake and compared it to the Paffenbarger Physical Activity Index Questionnaire. A moderate correlation ($r=0.46$) was found between the direct fitness measure and a sweat-inducing physical activity frequency question. They concluded that fitness status may be estimated easily and rapidly using this single recall question. Similar results were reported by Lamb and Brodie (1991) when they compared a 14-day recall questionnaire with direct measures of fitness status. It was concluded that this type of recall questionnaire was both reliable and valid.

Research has shown that using recall questionnaires is a valid and reliable method measuring the physical activity habits of individuals. However, a review of the ten most popular questionnaires (Jacobs, Ainsworth, Hartman, and Leon, 1993) revealed that there are several dimensions to physical activity that cannot all be measured with one survey. These dimensions included light, moderate, and heavy intensity leisure activities, household chores, and job related tasks. They found that most questionnaires tended to be related to heavy intensity activity and little else. For this reason it is important for each researcher to determine the specific data needs for a study and choose a questionnaire accordingly.

BLOOD PRESSURE

Blood pressure is a tool that can be used to follow changes or alterations in cardiovascular health and fitness. Blood pressure readings are generally divided into four categories. The first is "normal" blood pressure and includes readings of 140/90 or below. Individuals in this group are considered to be relatively healthy and fit. The second category is "mild hypertension". People in this group have blood pressures in the range of 140-159/90-104. "Moderate hypertensives" and "severe hypertensives" show readings of 140-159/105-114 and above 160/115, respectively (Pollock and Wilmore, 1990).

Individuals classified as hypertensives generally have idiopathic hypertension where the cause is unknown. However, it is thought that many lifestyle choices contribute to the problem. The results of these choices include obesity, psychological stress, physical inactivity, and smoking.

Although blood pressure measurement is a good tool for tracking the progress of hypertension and its subsequent problems, changes in blood pressure do not always occur with progressing cardiovascular disease. Sano, Kataoka, Ikuyama, Wada, et al. (1986) demonstrated that in some patients with worsening cardiovascular disease, blood pressure was maintained in the "normal" range or did not get progressively higher as the disease advanced. Therefore they concluded that blood pressure should not be used as the primary diagnostic tool for cardiovascular disease.

Despite these findings, blood pressure measurement still has an important function. Because hypertension is a primary risk factor for the development of cardiovascular disease, blood pressure measurements should be obtained on a regular basis in order to determine risk for disease. By measuring blood pressure, inferences about both health and fitness status can be made. Cardiovascular disease risk can be estimated and regular fitness habits can be approximated using blood pressure.

CONCLUSION

Health and fitness are both multidimensional concepts that can be measured using a variety of both direct and indirect techniques. Determining the relationship between the APG index and selected health and fitness measurement techniques will give some insight into the validity of accelerated plethysmography in the determination of health and fitness status. If the Precaregraph is, in fact, found to be valid and reliable, it may replace some current methods of measuring health and fitness.

CHAPTER III

METHODS AND PROCEDURES

PILOT STUDY

SUBJECTS

A pilot study was undertaken to evaluate the reliability of the Precaregraph accelerated plethysmograph. For this study, participants were tested twice per day for two consecutive days. Because it was important that each subject be tested at the same time each day and that each subject would need to follow the same regimen during both days of testing, volunteer subjects were selected from a convenience sample. It was deemed unnecessary to randomly select subjects because the hypothesis to be tested for this portion of the study was that scores collected four times in two days would be similar. Health and fitness status were not elements of the pilot study and were not measured.

DATA COLLECTION

Eight volunteer subjects were tested four times on two consecutive days. To control for possible circadian fluctuations, subjects were tested in the morning and evening at the same time each day. Participants were also asked to follow the same routine on both days (i.e., exercise, dietary, sleep, and work habits).

An identical data collection methodology was used with each subject and at each collection time. Participants were seated in a comfortable chair with the right arm elevated to heart level and the right index finger inserted in the Precaregraph finger receptacle according to the manufacturer's instructions. While in this position, the subjects were asked to remain motionless and relax for approximately five minutes. At the end of this period, APG measurements were made. After the first trial, subjects removed and immediately replaced the index finger in the receptacle. The procedure was repeated for a second trial. Approximately 50 waveforms were collected from each trial.

PRINCIPAL STUDY

SUBJECTS

Forty-three individuals (26 women and 17 men) volunteered to participate in the principal investigation. Three primary methods were used to recruit the widest variety of participants possible. First, fliers were posted on several information boards throughout the Portland State University campus. These fliers briefly described the study and participant requirements. The second method was through classroom presentations. A short five-minute explanation of the study and subject requirements was given to the PHE 295 classes as well as several PE activity classes. Phone numbers were provided on an informational hand-out. The final recruitment strategy involved placing an informational flier in the Sunday bulletin of East Vancouver Community Church. This insert contained study and subject information as well as phone numbers.

DATA COLLECTION

An initial group of subjects was recruited through fliers and classroom presentations. As these were being tested, continued recruitment occurred, thus providing a constant pool of individuals from which to choose. Those selected for participation were tested either in the kinesiotherapy laboratory at Portland State University or in their homes; procedures were identical for all those involved regardless of where data were collected.

Testing sessions began with a thorough explanation of the study and testing procedures. A short demonstration of the Precaregraph was also provided by having the participant place his or her index finger in the receptacle to run a mock test. After the demonstration, subjects were given an opportunity to ask questions before reading and signing the informed consent form. Participants were then assigned a confidential identification number; names and ID numbers were recorded on a master list, whereas data sheets contained only ID numbers. Only the principal investigator and the University Human Subjects Research Review Committee had access to the master list.

Height, weight, and age data were obtained first. Height was measured and recorded to the nearest 0.25 inch. Weight was measured to the nearest 0.5 pound. Age was reported by the participant and rounded up to the nearest year if he or she was within six weeks of a birthday. Table 1 contains descriptive statistics for all 43 volunteers in this investigation.

Table 1
Characteristics for all study participants

	MEAN	SD		MEAN	SD
Age (yr)	37.9	12.1	DBP (mmHg)	72.0	10.0
Height (in)	67.3	3.7	$\dot{V}O_{2max}$ (ml/kg/min)	37.0	9.7
Weight (lb)	156.8	31.6	RISKO	6.5	2.0
BMI	24.2	3.5	Code	4.0	2.0
RHR (bpm)	67.6	9.4	APG	34.4	42.3
SBP (mmHg)	120.4	17.2			

Participants then completed the American Heart Association's RISKO questionnaire and a daily physical activity survey where they were asked to recall average physical activity and exercise over the past 14 days (Appendix E). Completing the surveys first allowed subjects an opportunity to become more comfortable with the lab setting, thereby reducing test anxiety. Resting heart rate and blood pressure data were collected next using an Omron portable battery-powered sphygmomanometer. The blood pressure cuff was placed on the left arm of each subject according to the manufacturer's instructions. Two measurements were made on each subjects, with the first trial used for data analysis.

Because two regression equations were available to estimate non-exercise $\dot{V}O_{2max}$, participants were given the option of having subcutaneous body fat measured or body mass index (BMI) calculated. Subjects were encouraged to have body composition measured due to the higher validity of that equation. For those who were adamant about not wanting body composition measured, BMI was used.

For subjects who chose to have skinfolds measured, Lange skinfold calipers were used. Data from male subjects were obtained from the chest, abdomen, and thigh; females were measured at the tricep, supraillium, and thigh (Baumgartner and Jackson, 1991). The average of three measurements was recorded and used in the regression equation.

Finally APG index data were collected. As described above, each subject was asked to sit quietly and comfortably for five minutes. During this time, the subject was seated with the right arm at heart level and right index finger in the Precaregraph receptacle. At the conclusion of the rest period, measurement began and approximately 50 to 100 pulse waveforms were recorded. The participant then removed his or her finger from the receptacle and replaced it. Another rest period was given after which a second set of data was collected. This testing process was concluded with the participants being told they could receive a copy of their results, thanked for their participation, and allowed to leave.

DATA ANALYSIS

The data were analyzed using the Statview Student statistical software package for Macintosh computers (Abacus Concepts, Inc., Berkeley, CA., 1991). Both descriptive and inferential statistical techniques were used, with a probability level of .05 used to denote statistical significance. The dependent variable in this study was the mean APG index for each participant. The independent variables were the measures of health and fitness. These included a non-exercise estimate of $\dot{V}O_{2max}$, weekly physical activity level, magnitude of cardiovascular disease risk, and blood pressure.

The pilot data were analyzed with intraclass correlation using repeated measures ANOVA (Baumgartner and Jackson, 1991).

After appropriate means and standard deviations were calculated for the principal study, a correlation matrix was used to examine relationships between age, body mass index (BMI), systolic blood pressure (SBP), diastolic blood pressure (DBP), $\dot{V}O_{2max}$, RISKO, and APG. A table containing critical values of the correlation coefficients was then used to determine statistical significance of the Pearson Product-Moment correlation coefficients.

Data were also analyzed after being dichotomized into younger and older groups and high-fit and low-fit groups. Correlation matrices were constructed and differences between group means were examined using unpaired two-tailed t-tests.

Analysis of covariance (ANCOVA) was used to further evaluate differences between the APG index of younger vs older subgroups (with estimated $\dot{V}O_{2max}$ as a covariate) and high-fit and low-fit subgroups (with age as a covariate). Finally, regression analysis was used to explore the degree to which the independent variables could account for variability in the APG index.

CHAPTER IV

RESULTS AND DISCUSSION

PILOT STUDY

After the pilot data were analyzed it was found that no significant mean difference existed among the four APG trials obtained for each subject ($F=0.983$; $p=.467$). Furthermore, the intraclass correlation indicated that the APG index demonstrated acceptable reliability ($R=0.999$) and could therefore be used in the principal study.

PRINCIPAL INVESTIGATION

The primary focus of this investigation was to evaluate the validity of the APG index. The developers of this index contend that it can be used to reflect health and fitness status. It was the purpose of this study to examine this claim by determining the relationship between the APG index and previously validated indicators of health and fitness.

Duplicate measurements of the APG index for each subject were examined for reliability. Results were similar to those of the pilot study

(F=1.61; p=0.212; and R=0.978) providing further evidence of the reliability of the Precaregraph.

As noted in Table 2, the correlation matrix constructed with data from all 43 participants, the APG index was significantly inversely related to age (r=-0.780) and significantly positively related to $\dot{V}O_{2max}$ (r=0.709) and physical activity score (r=0.328). However, APG scores were not related to systolic or diastolic blood pressure, cardiovascular disease risk, or body mass index (see Appendix F for full correlation matrix).

Table 2
Correlations between mean APG index and independent variables

Variable	r
AGE (yr)	-.780*
BMI	-.153
SBP (mmHg)	.018
DBP (mmHg)	-.209
$\dot{V}O_{2max}$ (ml/kg/min)	.709*
RISKO	-.029
CODE	.328*

*p<.05

AGE AND APG

Because a significant relationship was found between the APG index and age, the sample was divided into two age groups for further analysis. The "younger" group included participants between 20 and 39 years; the "older" group included those 40 to 59 years of age.

Analysis revealed correlations in the age-dichotomized subsample that were similar to those in the entire group with slight variations. In the "older" group, APG was significantly related only to BMI (r=0.607) and systolic blood pressure (r=0.511). In the "younger" group, APG was related to age (r=-0.482) as well as $\dot{V}O_{2max}$(r=0.531). All other variables were found not to be significantly related to APG in either group (Table 3).

Table 3
Correlations between mean APG index and independent variables in older and younger subsamples.

Variable	Older (n=16)	Younger (n=27)
AGE (yr)	-.051	-.482*
BMI	.607*	-.087
SBP (mmHg)	.511*	-.044
DBP (mmHg)	.126	-.119
$\dot{V}O_{2max}$ (ml/kg/min)	.134	.531*
RISKO	.489	-.017
CODE	.088	.170

*p<.05

The unpaired two-tailed t-tests revealed significant differences between the mean APG index of the "older" and "younger" groups. The two groups also differed significantly in their estimated $\dot{V}O_{2max}$ and physical activity score (Figure 1). Mean differences for the remaining variables (BMI, blood pressure, RISKO scores, and resting heart rate) were not significantly different (Appendix G).

These data were further examined using analysis of covariance (ANCOVA). It was revealed that the difference in the mean APG index between the younger and older groups remained significant, even when estimated $\dot{V}O_{2max}$ was held constant ($F=18.58$; $p<.0001$).

$\dot{V}O_{2max}$ AND APG

The sample was also separated by fitness levels according to estimated $\dot{V}O_{2max}$ scores. Subjects were ranked according to their estimated $\dot{V}O_{2max}$. Approximately the lowest and the highest 46% of subjects were included in the analysis. Subjects were included in the "low-fit" group (LF) if their estimated $\dot{V}O_{2max}$ was less than or equal to 36.5 ml/kg/min. The cut-off for the "high-fit" (HF) group was 39.9 ml/kg/min. These data were also analyzed with linear correlations and unpaired t-tests.

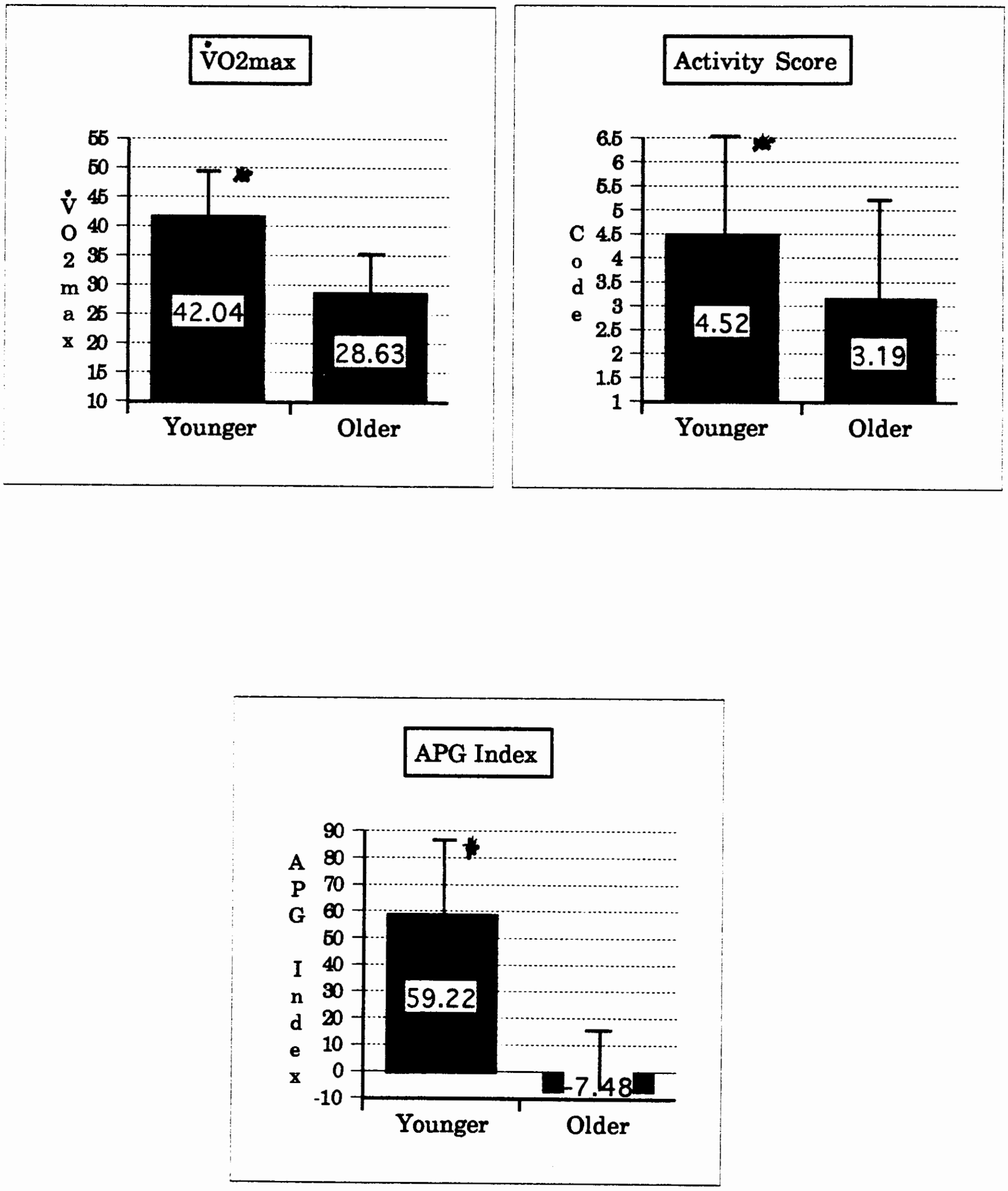

Figure 1. APG index, estimated $\dot{V}O_{2max}$, and activity score in younger and older subgroups (mean ± SD; *p<.05).

In each group, APG was significantly inversely related to age. Similarly, a significant positive correlation between the APG index and estimated $\dot{V}O_{2max}$ was noted in both fitness subgroups (Table 4).

Table 4
Correlations between mean APG index and independent variables in high-fit and low-fit subgroups.

Variable	High-fit (n=20)	Low-fit (n=19)
AGE (yrs)	-.641*	-.694*
BMI	.426	.035
SBP (mmHg)	.298	-.092
DBP (mmHg)	-.019	-.146
$\dot{V}O_{2max}$ (ml/kg/min)	.551*	.731*
RISKO	.436	.081
CODE	-.102	.167

* $p<.05$

When the two fitness groups were compared using t-tests, several significant differences were noted. Mean APG indices were found to be significantly different, with the HF group being younger and having a higher APG index. The LF group had a significantly higher mean resting heart rate, body mass index, and a significantly lower mean physical activity score (Figure 2).

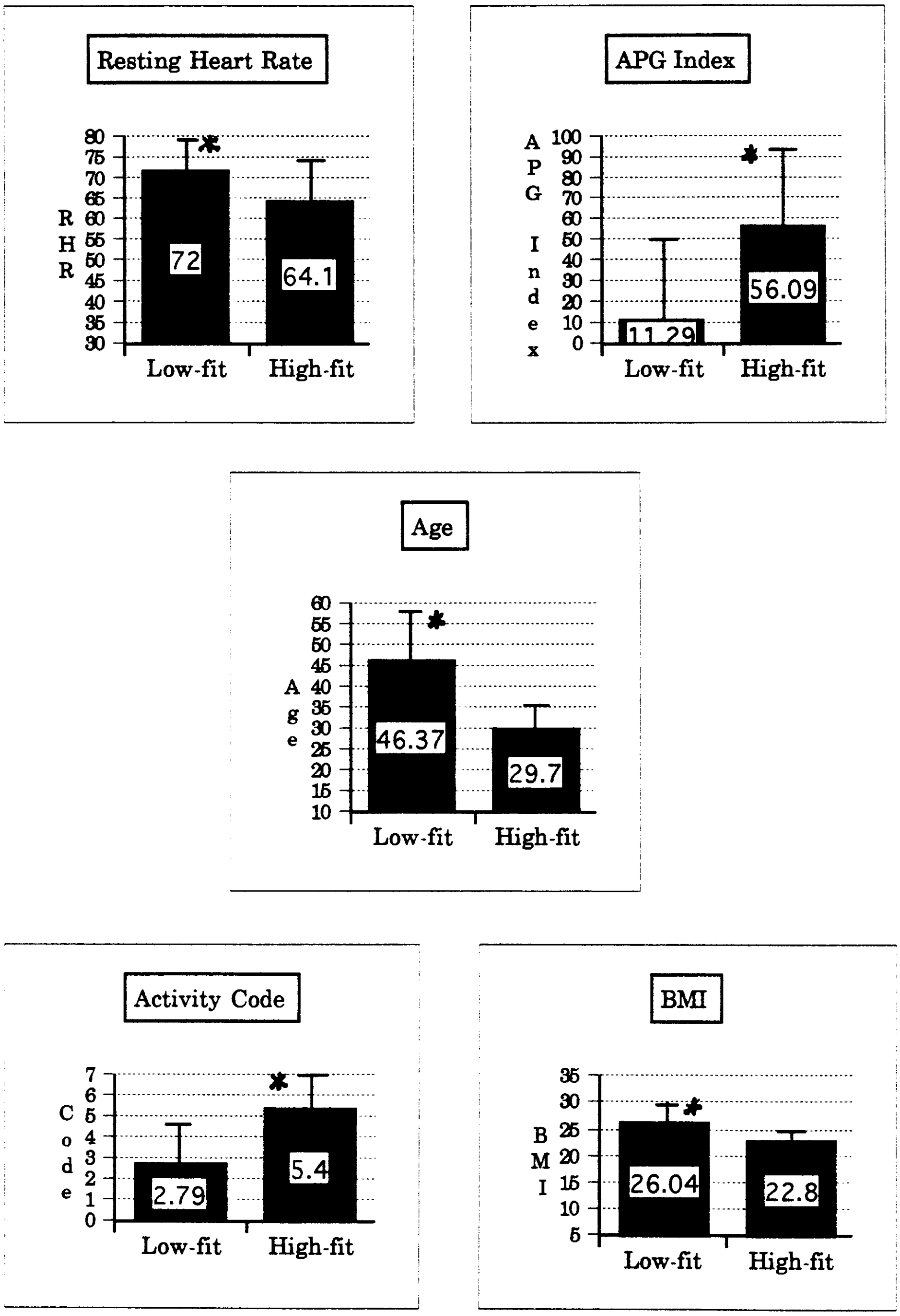

Figure 2. Resting heart rate, APG index, age, activity code, and BMI in low-fit and high-fit subgroups (mean ± SD; *p<.05).

The effects of age and fitness on the APG index was further examined using analysis of covariance (ANCOVA). The APG indices of the HF and LF groups were compared with age as a covariate. Analysis revealed no significant difference between the group means ($F=.001$; $p=0.953$).

PHYSICAL ACTIVITY AND APG

Each participant was asked to complete a 7-day recall questionnaire concerning the intensity, frequency, and duration of regular physical activities and exercise. This survey was then used to assign a physical activity score reflecting the amount or level of weekly activity. A weak but statistically significant positive correlation was found between the APG index and amount of activity in which a subject regularly participated during a 7-day period ($r=0.328$; $p<.05$).

Participants were grouped according to their assigned physical activity code. "Low" activity included subjects identified with a score of 0 to 2. "Medium" activity included subjects scoring 3 to 4, and "heavy" activity included subjects scoring 5 to 7. Once data were regrouped, analysis of variance (ANOVA) was performed to determine whether mean APG indices were significantly different among the three groups. No significant differences were found (Figure 3).

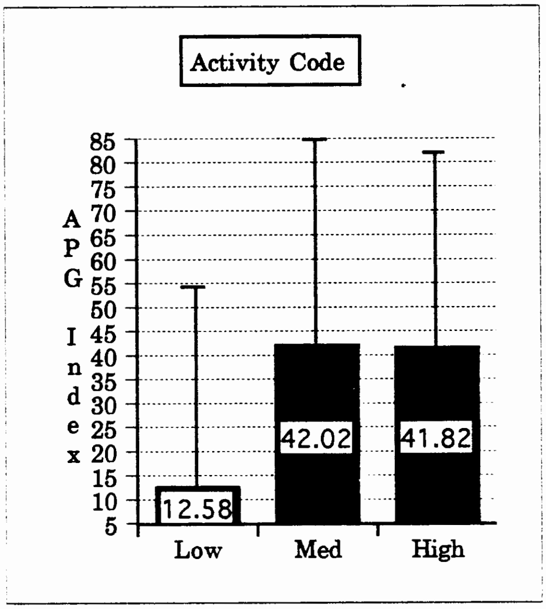

Figure 3. APG index in low, medium, and high activity subgroups (mean ± SD).

APG, FITNESS, AND HEALTH

Finally, multiple regression analysis was also used to explore how the independent variables contributed to "explaining" the variance in the APG index. Results of a forward selection procedure indicated that the three most important variables were age, $\dot{V}O_{2max}$, and RISKO. Age accounted for approximately 61% of the variance in APG (R^2=0.609), while $\dot{V}O_{2max}$ (R^2=0.671) and RISKO (R^2=0.710) added about 6% and 4%, respectively.

DISCUSSION

The APG index was found to be significantly correlated with age, estimated $\dot{V}O_{2max}$, and weekly physical activity level in the total sample. In most of the subgroup samples (with the exception of the older subgroup) the APG index was significantly correlated only with age and $\dot{V}O_{2max}$. However, no other significant relationships were found between the APG scores and any other variables in the younger, low-fit, and high-fit subgroups.

AGE AND APG

The APG index was related to age in all groups examined with the exception of the "older" subgroup. As humans age, blood vessel elasticity decreases and muscle mass is lost. These changes may initiate changes in circulatory functioning as well. If this is correct, the Precaregraph would be ideal for measuring the effects of aging on circulatory dynamics. This was supported with results from the analysis of covariance (ANCOVA) and multiple regression. ANCOVA revealed a significant difference in mean APG scores between age subsamples when fitness level (estimated $\dot{V}O_{2max}$) was held constant. In the multiple regression analysis, age was shown to share approximately 61% common variance with the APG index. In other words, circulatory changes appeared to be resulting primarily from age and age-related factors.

However, the fact that no significant relationship was found between APG and age in the "older" group may illuminate one problem with this technique. Declining scores due to aging, while different from lowered scores due to fitness level, may be indistinguishable from declining scores due to advancing disease. If used as a diagnostic tool, further testing is need in order to determine whether low scores are a result of the natural aging process or whether the initial stages of cardiovascular disease are present.

$\dot{V}O_{2max}$ AND APG

In this study, the APG index was highly correlated with estimated $\dot{V}O_{2max}$, the criterion indicator of fitness status. It is well known that improvements in $\dot{V}O_{2max}$ are the result of improvements in transporting and extracting oxygen. It could be hypothesized that as cardiovascular fitness improves so will peripheral blood flow dynamics. The Precaregraph appeared able to reflect these improvements in the cardiovascular system; a higher APG index and improved waveform classification was associated with a higher estimated $\dot{V}O_{2max}$. Sano, Kataoka, and Osanai (1993a, 1993b, 1993c) and Sano, Kataoka, Ikuyama, and Osanai (1993) reported similar findings after acute bouts of exercise and after aerobic exercise training.

As with age, no significant correlation was found between APG scores and $\dot{V}O_{2max}$ in the "older" subsample. This again may show the difficulty in determining the etiology of poor or declining APG scores. Analysis of covariance revealed that after controlling for age the difference between the APG index in the two fitness groups was no longer statistically significant. Lower $\dot{V}O_{2max}$ and fitness levels may be the cause of poor scores or again, they may be the result of progressing cardiovascular disease or age related degeneration in peripheral circulation.

Results are clear that the Precaregraph should only be used for preliminary investigation and/or testing and further evaluation of this tool is needed to identify mechanisms underlying the APG index.

PHYSICAL ACTIVITY AND APG

It is interesting to note that weekly physical activity levels as defined by the physical activity code were correlated with the APG index in the overall sample analysis only. Neither subgroup analysis revealed any statistically significant relationship. This may have been because the relationship was not very strong in the heterogeneous sample.

However, the limitations of the physical activity code discussed by Kolkhorst and Dolgener (1994) may be more pertinent. A scale including more categories for people engaging in activities that are more frequent, longer in duration, and more intense than activities comparable to running 10 miles per week may be needed.

APG, FITNESS, AND HEALTH

Although the APG index supposedly measures health status with regard to disease states, the relationship between the APG index and resting blood pressure has been shown to be weak. In one study the original Japanese developers wrote that there was "no direct relation between blood pressure and APG" (Sano, Kataoka, Ikuyama, Wada, et al., 1986). However, they did find a weak inverse relationship between the two parameters in studies that focused on exercise and the APG index (Sano, Kataoka, Ikuyama, and Osanai, 1993; Sano, Kataoka and Osanai, 1993a, 1993b).

Because blood pressure is considered a primary risk factor for cardiovascular disease, it should be negatively correlated with the APG index. In other words, an individual with high blood pressure -- generally thought of as unhealthy -- should demonstrate a low (unhealthy) APG index. Likewise, a person with low to normal blood pressure should demonstrate higher a APG index. Because alterations in blood pressure exert a direct influence over peripheral blood flow dynamics, a correlation should be apparent. Interestingly, the APG index was not related to diastolic blood pressure in any of the groups tested and systolic blood pressure was related to the APG index in only the "older" subgroup.

Likewise, analysis performed to determine the significance of the differences between the high- and low-fit groups showed mean differences in RISKO scores and BMI. Again, as measures of health and predictors of fitness status, it was hypothesized that a significant relationship would exist between the APG index, cardiovascular disease risk and body composition. Except for the "older" group, correlation coefficients did not reach statistical significance even though RISKO scores were found to explain approximately 4% of the variance in the APG index. The complex interrelationships among variables used as indicators of health and fitness may necessitate the use of more advanced statistical techniques and/or more sensitive measurement instruments.

CONCLUSION

The studies reported by Sano and his colleagues focused primarily on how the APG index and APG waveforms are altered by disease as well as by exercise. They found the Precaregraph to be sensitive to these conditions and concluded that the machine could be used as a predictor of disease as well as a measurement device for the evaluation of fitness. This study was not designed to replicate previous studies that have examined the instrument's ability to predict disease states, but revealed little relationship between the APG index and measures of health status. However, indicators of fitness appeared to be related to the APG index.

It is apparent that the Precaregraph measures changes in peripheral blood flow dynamics. What is not apparent is what is causing these changes to occur. It is difficult to determine whether changes are due to age, fitness, or disease related degeneration. Current results suggest that use of this machine be restricted primarily to the baseline and follow-up measurement of fitness status until more definitive studies are able to confirm the validity of the APG index for the evaluation of health status.

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

The results obtained from this study, provided some initial insight into the capabilities and potential of the Precaregraph accelerated plethysmograph. While it is necessary to keep in mind that the present study was undertaken to provide initial exploratory data, future study in this area may improve upon this design in several ways. First, in order to ensure more accurate body composition measurements, hydrostatic weighing should be incorporated into future studies. Skinfold measurements may grossly over- or underestimate percent fat.

Second, because the APG index was found to be related to estimated $\dot{V}O_{2max}$, further study should use maximal exercise testing to obtain true $\dot{V}O_{2\,max}$ data instead of using an estimation. This would be more critical when testing highly fit participants, as both the non-exercise estimation models and submaximal testing may underestimate $\dot{V}O_{2max}$ in this group.

Finally, if incorporating heart disease risk as an independent variable, a more accurate and in depth survey should be used. The

RISKO survey used for this study made an approximation of cholesterol levels if the measured value was not available. This may have contributed to an over or underestimation of a subject's risk. Future studies in this area should require participants to obtain total cholesterol measurements as well as high density lipoprotein (HDL) and low density lipoprotein (LDL) assessments.

Future studies with the Precaregraph should incorporate the above suggestions while continuing to evaluate its validity and reliability. Other research in this area should examine the effect of known cardiovascular disease, age, or $\dot{V}O_{2max}$ on the APG index.

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APPENDIX A

TRADITIONAL, IMPEDANCE, AND ACCELERATED PULSE WAVEFORMS


Traditional plethysmogram
Velocity plethysmogram
(Single differential plethysmogram)
Acceleration plethysmogram
(Double differential plethysmogram)

APPENDIX B

WAVEFORM PATTERN CLASSIFICATION

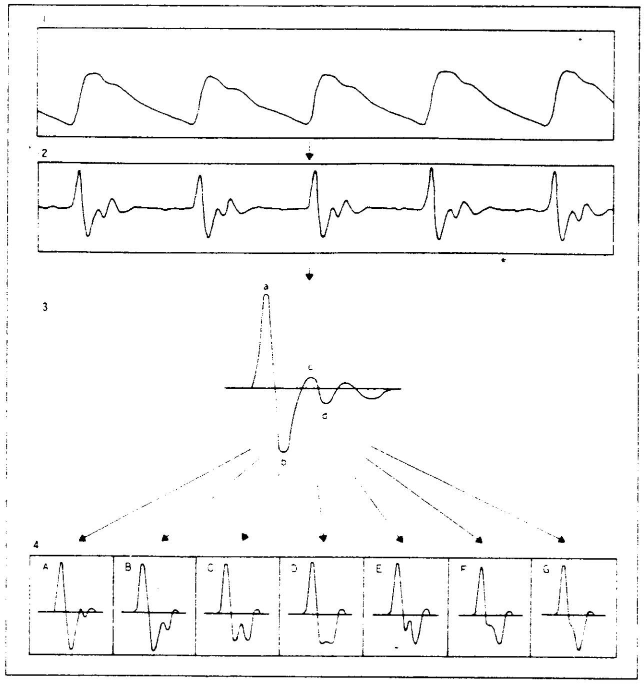

Fig. 2 Principle of acceleration pulse waveform analysis

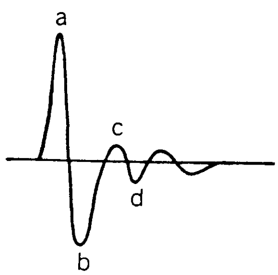

Fig. 2. Turning point a, b, c and d of acceleration plethysmogram

$$\text{APG Index} = (-b + c + d)/a \times 100$$

APPENDIX C

NON-EXERCISE PREDICTION OF FUNCTIONAL AEROBIC CAPACITY

Non-exercise equation for the prediction of $\dot{V}O_{2peak}$ using body mass index (Jackson et al., 1990):

$$\dot{V}O_{2peak} = 56.363 + 1.921(\text{PA-R}) - 0.381(\text{Age}) - 0.754(\text{BMI}) + 10.987(F=0, M=1)$$

Non-exercise equation for the prediction of VO_{2peak} using percent fat (Heil et al., 1995):

$$\dot{V}O_{2peak} = 36.580 - 0.541(\%\ \text{Fat}) + 1.347(\text{PA-R}) + 0.558(\text{Age}) - 0.00781\ (\text{Age})^2 + 3.706(F=0, M=1)$$

PA-R: Physical activity scale code (Baumgartner and Jackson, 1991)

0	Avoid walking or exertion
1	Walk for pleasure, Occasionally exercise enough to cause heavy breathing or perspiration
2	Participate in moderate activity 10 to 60 min/week
3	Participate in moderate activity over 60 min/week
4	Run less than 1 mile/week or spend less than 30 min/week in a comparable activity
5	Run 1 to 5 miles/week or spend 30 to 60 min/week in a comparable activity
6	Run 5 to 10 miles/week or spend 1 to 3 hours/week in a comparable activity
7	Run over 10 miles/week or spend over 3 hours/week in a comparable activity

Age: Rounded to the closest year

BMI: Body Mass Index = weight (kg)/height^2 (m)

APPENDIX D

CARDIOVASCULAR DISEASE PREDICTION:

RISKO WORKSHEET

WOMEN

Find the column for your age group. Everyone starts with a score of 10 points. Work down the page *adding* points to your score or *subtracting* points from your score.

		54 OR YOUNGER	55 OR OLDER
		STARTING SCORE 10	STARTING SCORE 10

1. WEIGHT

Locate your weight category in the table below. If you are in . . .

	54 OR YOUNGER	55 OR OLDER
weight category A	SUBTRACT 2	SUBTRACT 2
weight category B	SUBTRACT 1	SUBTRACT 1
weight category C	ADD 1	ADD 0
weight category D	ADD 2	ADD 1
	EQUALS	EQUALS

2. SYSTOLIC BLOOD PRESSURE

Use the "first" or "higher" number from your most recent blood pressure measurement. If you do not know your blood pressure, estimate it by using the letter for your weight category. If your blood pressure is . . .

	54 OR YOUNGER	55 OR OLDER
A 119 or less	SUBTRACT 2	SUBTRACT 3
between 120 and 139	SUBTRACT 1	ADD 0
between 140 and 159	ADD 0	ADD 3
D 160 or greater	ADD 1	ADD 6
	EQUALS	EQUALS

3. BLOOD CHOLESTEROL LEVEL

Use the number from your most recent blood cholesterol test. If you do not know your blood cholesterol, estimate it by using the letter for your weight category. If your blood cholesterol is . . .

	54 OR YOUNGER	55 OR OLDER
A 199 or less	SUBTRACT 1	SUBTRACT 3
between 200 and 224	ADD 0	SUBTRACT 1
between 225 and 249	ADD 0	ADD 1
D 250 or higher	ADD 1	ADD 3
	EQUALS	EQUALS

4. CIGARETTE SMOKING

If you . . .

	54 OR YOUNGER	55 OR OLDER
do not smoke	SUBTRACT 1	SUBTRACT 2
smoke less than a pack a day	ADD 0	SUBTRACT 1
smoke a pack a day	ADD 1	ADD 1
smoke more than a pack a day	ADD 2	ADD 4
	EQUALS	EQUALS

5. ESTROGEN USE

*Birth control pills and hormone drugs contain estrogen. A few examples are: *Premarin *Ogan *Menstranol *Provera *Evex *Menest *Estinyl *Meurium*

- Have you ever taken estrogen for five or more years in a row?
- Are you age 35 years or older and are now taking estrogen?

	54 OR YOUNGER	55 OR OLDER
No to both questions	ADD 0	ADD 0
Yes to one or both questions	ADD 1	ADD 3
	FINAL SCORE EQUALS	FINAL SCORE EQUALS

WEIGHT TABLE FOR WOMEN

Look for your height (without shoes) in the far left column and then read across to find the category into which your weight (in indoor clothing) would fall.

YOUR HEIGHT FT IN	WEIGHT CATEGORY (lbs.) A			D
4 8	up to 101	102-122	123-143	144 plus
4 9	up to 103	104-125	126-146	147 plus
4 10	up to 106	107-128	129-150	151 plus
4 11	up to 109	110-132	133-154	155 plus
5 0	up to 112	113-136	137-158	159 plus
5 1	up to 115	116-139	140-162	163 plus
5 2	up to 119	120-144	145-168	169 plus
5 3	up to 122	123-148	149-172	173 plus
5 4	up to 127	128-154	155-179	180 plus
5 5	up to 131	132-158	159-185	186 plus
5 6	up to 135	136-163	164-190	191 plus
5 7	up to 139	140-168	169-196	197 plus
5 8	up to 143	144-173	174-202	203 plus
5 9	up to 147	148-178	179-207	208 plus
5 10	up to 151	152-182	183-213	214 plus
5 11	up to 155	156-187	188-218	219 plus
6 0	up to 159	160-191	192-224	225 plus
6 1	up to 163	164-196	197-229	230 plus
ESTIMATE OF SYSTOLIC BLOOD PRESSURE	119 or less			160 or more
ESTIMATE OF BLOOD CHOLESTEROL	199 or less			250 or more

Because both blood pressure and blood cholesterol are related to weight, an estimate of these risk factors for each weight category is printed at the bottom of the table.

MEN

Find the column for your age group. Everyone starts with a score of 10 points. Work down the page *adding* points to your score or *subtracting* points from your score.

	54 OR YOUNGER	55 OR OLDER
STARTING SCORE	10	10

1. WEIGHT

Locate your weight category in the table below. If you are in . . .

	54 OR YOUNGER	55 OR OLDER
weight category A	SUBTRACT 2	SUBTRACT 2
weight category B	SUBTRACT 1	ADD 0
weight category C	ADD 1	ADD 1
weight category D	ADD 2	ADD 3
	EQUALS	EQUALS

2. SYSTOLIC BLOOD PRESSURE

Use the "first" or "higher" number from your most recent blood pressure measurement. If you do not know your blood pressure, estimate it by using the letter for your weight category. If your blood pressure is . . .

	54 OR YOUNGER	55 OR OLDER
A 119 or less	SUBTRACT 1	SUBTRACT 5
between 120 and 139	ADD 0	SUBTRACT 2
between 140 and 159	ADD 0	ADD 1
D 160 or greater	ADD 1	ADD 4
	EQUALS	EQUALS

3. BLOOD CHOLESTEROL LEVEL

Use the number from your most recent blood cholesterol test. If you do not know your blood cholesterol, estimate it by using the letter for your weight category. If your blood cholesterol is . . .

	54 OR YOUNGER	55 OR OLDER
A 199 or less	SUBTRACT 2	SUBTRACT 1
between 200 and 224	SUBTRACT 1	SUBTRACT 1
between 225 and 249	ADD 0	ADD 0
D 250 or higher	ADD 1	ADD 0
	EQUALS	EQUALS

4. CIGARETTE SMOKING

If you . . .

(If you smoke a pipe, but not cigarettes, use the same score adjustment as those cigarette smokers who smoke less than a pack a day.)

	54 OR YOUNGER	55 OR OLDER
do not smoke	SUBTRACT 1	SUBTRACT 2
smoke less than a pack a day	ADD 0	SUBTRACT 1
smoke a pack a day	ADD 1	ADD 0
smoke more than a pack a day	ADD 2	ADD 3
	FINAL SCORE EQUALS	FINAL SCORE EQUALS

WEIGHT TABLE FOR MEN

Look for your height (without shoes) in the far left column and then read across to find the category into which your weight (in indoor clothing) would fall.

WEIGHT CATEGORY (lbs.)

YOUR HEIGHT FT IN	A	[illegible]	[illegible]	D
5 1	up to 123	124-148	149-173	174 plus
5 2	up to 126	127-152	153-178	179 plus
5 3	up to 129	130-156	157-182	183 plus
5 4	up to 132	133-160	161-186	187 plus
5 5	up to 135	136-163	164-190	191 plus
5 6	up to 139	140-168	169-196	197 plus
5 7	up to 144	145-174	175-203	204 plus
5 8	up to 148	149-179	180-209	210 plus
5 9	up to 152	153-184	185-214	215 plus
5 10	up to 157	158-190	191-221	222 plus
5 11	up to 161	162-194	195-227	228 plus
6 0	up to 165	166-199	200-232	233 plus
6 1	up to 170	171-205	206-239	240 plus
6 2	up to 175	176-211	212-246	247 plus
6 3	up to 180	181-217	218-253	254 plus
6 4	up to 185	186-223	224-260	261 plus
6 5	up to 190	191-229	230-267	268 plus
6 6	up to 195	196-235	236-274	275 plus
ESTIMATE OF SYSTOLIC BLOOD PRESSURE	119 or less			160 or more
ESTIMATE OF BLOOD CHOLESTEROL	199 or less			250 or more

Because both blood pressure and blood cholesterol are related to weight, an estimate of these risk factors for each weight category is printed at the bottom of the table.

WHAT YOUR SCORE MEANS

Score	Meaning
0-4	You have one of the lowest risks of Heart Disease for your age and sex.
5-9	You have a low to moderate risk of Heart Disease for your age and sex but there is some room for improvement.
10-14	You have a moderate to high risk of Heart Disease for your age and sex, with considerable room for improvement on some factors.
15-19	You have a high risk of developing Heart Disease for your age and sex with a great deal of room for improvement on all factors.
20 & over	You have a very high risk of developing Heart Disease for your age and sex and should take immediate action on all risk factors.

WARNING

- If you have diabetes, gout or a family history of heart disease, your actual risk will be greater than indicated by this appraisal.
- If you do not know your current blood pressure or blood cholesterol level, you should visit your physician or health center to have them measured. Then figure your score again for a more accurate determination of your risk.
- If you are overweight, have high blood pressure or high blood cholesterol, or smoke cigarettes, your long-term risk of heart disease is increased even if your risk in the next several years is low.

HOW TO REDUCE YOUR RISK

- Try to quit smoking permanently. There are many programs available.
- Have your blood pressure checked regularly, preferably every twelve months after age 40. If your blood pressure is high, see your physician. Remember blood pressure medicine is only effective if taken regularly.
- Consider your daily exercise (or lack of it). A half hour of brisk walking, swimming or other enjoyable activity should not be difficult to fit into your day.
- Give some serious thought to your diet. If you are overweight, or eat a lot of foods high in saturated fat or cholesterol (whole milk, cheese, eggs, butter, fatty foods, fried foods) then changes should be made in your diet. Look for the American Heart Association Cookbook at your local bookstore.
- Visit or write your local Heart Association for further information and copies of free pamphlets on many related subjects including:
  - Reducing your risk of heart attack.
  - Controlling high blood pressure.
  - Eating to keep your heart healthy.
  - How to stop smoking.
  - Exercising for good health.

SOME WORDS OF CAUTION

- If you have diabetes, gout, or a family history of heart disease, your real risk of developing heart disease will be greater than indicated by your RISKO score. If your score is high and you have one or more of these additional problems, you should give particular attention to reducing your risk.
- If you are a woman under 45 years or a man under 35 years of age, your RISKO score represents an upper limit on your real risk of developing heart disease. In this case your real risk is probably lower than indicated by your score.
- If you are a woman whose use of estrogen has contributed to a high RISKO score, you may want to consult your physician. Do not automatically discontinue your prescription.
- Using your weight category to estimate your systolic blood pressure or your blood cholesterol level makes your RISKO score less accurate.
  - Your score will tend to overestimate your risk if your actual values on these two important factors are average for someone of your height and weight.
  - Your score will underestimate your risk if your actual blood pressure or cholesterol level is above average for someone of your height or weight.

APPENDIX E

PHYSICAL ACTIVITY SURVEY

"Evaluation of Accelerated Plethysmography as a Measure of Health and Fitness"

Activity Information

Do you engage in a formal exercise program? Yes No

Please explain the activities in which you regularly engage.

Do you engage in some type of regular physical activity? Yes No

Please describe your regular activities.

How would you describe the intensity of your exercise and/or activity?

light moderate heavy very vigorous

How often do you engage in regular activity?

1-2 days 3-5 days 6-7 days

What is the duration of your activity?

1-30 min 31-60 min 61-90 min >90 min

How many miles do you walk per day (include any walking activity)? ________

How would you describe the intensity of your job or occupation?

sedentary light moderate heavy very vigorous

Please explain your job or occupation.

APPENDIX F

CORRELATION MATRIX FOR TOTAL SAMPLE

Variables	1	2	3	4	5	6	7	8
1. AGE	1.000	.256	.188	.351*	-.673*	.144	-.416*	-.780*
2. BMI		1.000	.536*	.470*	-.460*	.755*	-.289	-.153
3. SBP			1.000	.781*	-.091	.655*	-.133	.018
4. DBP				1.000	-.203	.487*	-.253	-.209
5. $\dot{V}O_{2max}$					1.000	-.381*	.556*	.709*
6. RISKO						1.000	-.365*	-.029
7. CODE							1.000	.328*
8. APG								1.000

*$p<.05$; df = 41

APPENDIX G

T-TEST RESULTS FOR AGE AND FITNESS SUBSAMPLES

	OLDER (n = 16)		YOUNGER (n = 27)		
Variables	$\overline{X}$	SD	$\overline{X}$	SD	t
BMI	25.5	2.7	23.5	3.8	-1.84
SBP (mmHg)	122.5	17.4	119.2	17.4	-0.60
DBP (mmHg)	75.4	11.8	70.1	8.6	-1.70
$\dot{V}O_{2max}$ (ml/kg/min)	28.6	6.9	42.0	7.6	5.79*
RISKO	6.9	2.1	6.3	2.0	-1.06
RHR (bpm)	71.1	8.0	65.6	9.7	-1.91
CODE	3.2	2.0	4.5	2.0	2.12*
APG	-7.5	25.1	59.2	28.6	7.74*

*p ≤ .05

	LOW-FIT (n = 19)		HIGH-FIT (n = 20)		
Variables	$\overline{X}$	SD	$\overline{X}$	SD	t
AGE (yr)	46.4	11.2	29.7	6.0	5.85*
BMI	26.0	4.1	22.8	2.1	3.12*
SBP (mmHg)	120.6	19.2	119.7	16.5	0.15
DBP (mmHg)	73.2	9.1	69.4	8.5	1.34
RISKO	7.2	2.5	6.0	1.4	1.85
RHR (bpm)	72.0	7.4	64.1	10.2	-10.34*
CODE	2.8	1.6	5.4	1.6	-5.17*
APG	11.29	38.59	56.09	35.68	-3.77*

*p ≤ .05