THE ASSESSMENT OF CARDIOVASCULAR FITNESS THROUGH ANALYSIS OF THE LEFT VENTRICULAR TIME COMPONENTS

By

HARRY S. WOHLERT

Bachelor of Science
Oklahoma State University
Stillwater, Oklahoma
1964

Master of Arts
University of Oklahoma
Norman, Oklahoma
1967

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF EDUCATION
December, 1975

THE ASSESSMENT OF CARDIOVASCULAR FITNESS
THROUGH ANALYSIS OF THE LEFT
VENTRICULAR TIME COMPONENTS

Thesis Approved:

Aix B. Harrison
Thesis Adviser

Lloyd H. ...

John G. Bayless

Thomas ...

N. N. Durham
Dean of the Graduate College

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to Dr. Aix B. Harrison, whose research experience was an invaluable aid throughout this investigation, for his untiring willingness to assist in solving the numerous problems that always occur in such studies.

My appreciation is also extended to Dr. George H. Oberle, Dr. G. Bayless, and Dr. Thomas A. Karman for their many helpful suggestions and encouragements during the completion of this study.

To my wife, Hilde, and our children, Christina and Martin, I can only express my deepest gratitude for their willingness to sacrifice so much during the last three years.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure	Page

CHAPTER I

INTRODUCTION

This research was designed to determine whether a relationship existed between the left ventricular systolic time intervals and selected factors of cardiovascular fitness, respiratory indexes, and body measurements. It was also attempted to determine whether significant correlations existed between the systolic time intervals and the selected fitness indexes for the assessment of cardiovascular fitness.

The constantly decreasing physical effort demanded of modern man has created a proportionally increasing number of men and women who will describe themselves as feeling physically unfit. New efficient tests, possibly based on the left ventricular systolic time intervals, need to be developed for better early detection or even prediction of cardiovascular disease which frequently is the result of being physically unfit.

Even though the American Heart Association reported recently that the continuous rise of heart disease has been stopped and has even declined slightly,[1] the 74,000 deaths from heart disease in 1974--twice as many as from cancer--should remove any thoughts of neglecting the efforts to overcome various cardiovascular problems which still account for more loss of life than all other diseases combined. While the report speculated that preventive medicine was mainly responsible for the reduction of heart attacks, governments in several European countries such as Germany, Switzerland, and Austria give considerable credit to physical fitness and have, therefore, established government-supported programs of physical fitness which try to reach every citizen.

That prevention is not only desirable but also possible can best be shown by the following massive study of 461,440 individuals (Table I):

TABLE I

DEATH PER 100 MEN BY DEGREES OF EXERCISE
(N = 461,440)

Age	No Exercise	Slight	Moderate	Heavy
45-49	1.06	0.56	0.38	0.23
50-54	2.08	0.80	0.55	0.33
55-59	3.60	1.58	0.85	0.59
60-64	4.90	2.32	1.09	0.92
65-69	10.33	3.58	1.74	1.38
70-74	11.02	4.92	2.60	1.56
75-79	16.05	6.55	3.46	1.96
80-84	16.43	8.49	3.96	4.49
85-plus	22.13	12.08	5.67	2.78

Source: F. G. Hammond, "Some Preliminary Findings on Physical Complaints from a Prospective Study of 1,064,004 Men and Women," American Journal of Public Health, LIV (1964), pp. 11-29.

A multitude of existing tests of physical fitness generally substantiate frequently heard complaints about low fitness with scores which are indicative of the non-exercisers in Table I. A group of such tests deals with the efficiency of the cardiovascular system, which is recognized today as probably the most significant index of physical fitness. This aspect of fitness is measured by various methods, of which especially one--the test of maximum oxygen consumption--has gained a prominent position. In the quest for further improvement on the method of assessing cardiovascular fitness, the analysis of the left ventricular cardiac dynamic cycle by means of simultaneous recording of the EKG, phonocardiogram, and indirect carotid pulse wave has recently attracted widespread attention.

Physical Fitness

This state of human well-being and efficiency is generally described in terms of certain physiological variables which Ricci[2] considered relatively meaningless in that context. He eloquently denied that man's physiological fitness can be reduced to a single score, and contested the use of the term "physical fitness" on the ground that it eludes precise definition in a cognitive sense. In the same publication, he stated that the tests do not measure physical fitness but psychophysiological adaptation to increased metabolic demands imposed by exercise which can be assessed by:

1. The oxygen consumed and the carbon dioxide produced during execution of and recovery from a given exercise task.
2. The changes in blood chemistry.
3. The changes in pulmonary responses.
4. The changes in cardiovascular responses.
5. The changes in heat regulating mechanisms.

6. The changes in urine composition.

7. The changes in somatotype.

8. The changes in neuromuscular responses.

9. The changes in strength of muscle groups.[3]

The above not withstanding, the usefulness of such terms as "cardiovascular" or "cardiorespiratory" or "cardiopulmonary" fitness have been adequately demonstrated because they permit individuals or groups to be meaningfully classified. Cooper,[4] for example, employed these terms to place 80 percent of the American population into fitness categories ranging from very poor to fair solely on indirect measures of maximum oxygen uptake. Based on Cooper's classification system, most physical educators or physicians would therefore conclude that the maximum oxygen consumption of the individuals in the poor group is below 34 ml/kg/min, i.e., the condition of their hearts, lungs, and blood vessels had deteriorated to the point where their lives could be endangered if they had to act under severe stress. Balke[5] described such a low fitness score as a sign of "reduced ability to survive under extraordinary biological demands".

Johnson et al.[6] accepted a fitness score as valid if it could meet the demands of the following principles upon which a good fitness test should be based:

1. Athletes in training should, on the average, get much better scores than men not in training.

2. For a large group of untrained men, the scores should range widely from bad to good.

3. Normal men, not in training, should be able to improve their scores by following a program of hard physical work.

4. In the case of any given man, the score should, in general, agree in the judgment of trained observers, with the results of other reliable tests, and most important of all, with the man's demonstrated physical capacities in actual performance of hard work.

Numerous investigations and testing programs in the physiology laboratory of Oklahoma State University, as well as a large number of supportive studies, have shown that measures of maximum oxygen uptake indeed do not violate the above principles.

Analysis of the Left Ventricular Systolic Time Intervals

A complete cardiac cycle presents the period from the onset of one heart beat to the next succeeding beat including all electrical, mechanical, and auditory events. This cycle can be divided into systole--the ejection of blood via contraction of the atria and ventricles--and diastole--the return of the blood to the atria. This investigation will concentrate on the left ventricular aspect of the cardiac cycle which will be analyzed as previously mentioned by means of the simultaneous recording of the electrocardiogram, phonocardiogram, and the indirect carotid pulse wave.

The Electrocardiogram

The so-called EKG is a graphical recording of certain electrical activities originating in the sino-atrial (S-A) node at the junction of the superior vena cava with the right atrium. The spread of the change in electrical potential moving down across the heart causes the cardiac muscle fibers to shorten. This reaction of the fibers to the electrical stimulation results in the contraction of the atria as well as the ventricles. Currents from the electrical activity spread to the body surface where sensitive electrodes can pick them up and feed them into an electrocardiograph machine. The electrical impulses are then amplified and recorded as an EKG. The EKG is therefore recorded electrical activity such as atrial depolarization (P wave), and ventricular depolarization (QRS complex), and repolarization (T wave), which initiate and precede the mechanical events of the cardiac cycle (Figure 1).

The excitation current originating in specialized pacemaker cells of the S-A node (Figure 2) spreads over the atrial myocardium along special pathways. The following illustration shows the sinus node and the antrioventricular node. The impulse emitted from the former will reach the A-V node after an average transmission time of about 40 milliseconds (msec). During this period a P wave is being picked up on the EKG while the atria depolarize (average duration 100 msec) and is then followed by a mechanical contraction.

After an average delay of 110 msec, which gives the atria time to empty, the impulse is transmitted from the A-V node along the bundle of His (both are components of the A-V junction) across a ring of nonconducting fibrous tissue, the only muscular connection between the upper and lower chambers of the heart, to the Purkinje fibers where it again obtains the same velocity observed in the atrial region. The dense and widely-spread fibers of the Purkinje system conduct the impulse so rapidly through the entire ventricular endocardium that an almost simultaneous depolarization of both ventricles takes place which can be recorded as QRS complex. The ensuing repolarization is generally the last electrical event (T wave) which the EKG will pick up.[7, 8]

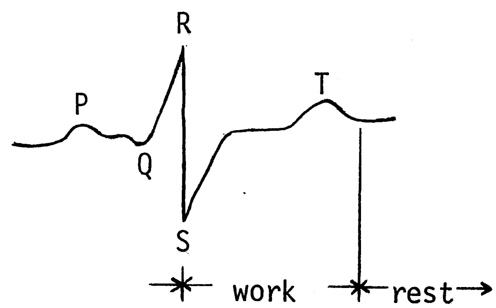


Figure 1. A Normal EKG Recording of a Complete Cardiac Cycle

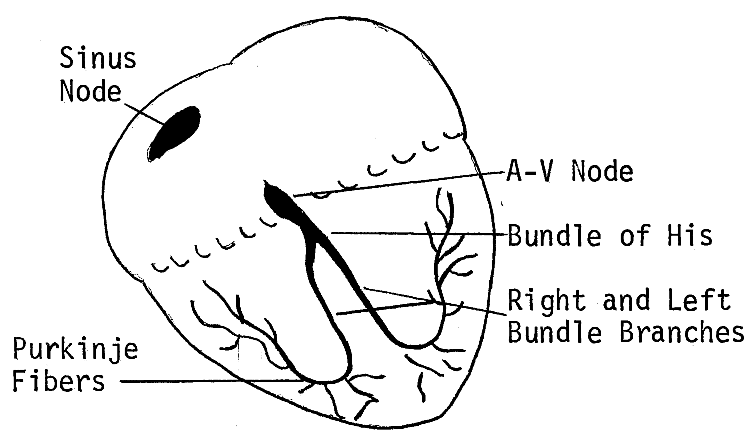


Figure 2. The Heart and Its Major Electrical Conductors

The Phonocardiogram

A mechanical recording of the heart sounds can distinguish four elements which are classified under the nomenclature S_1 (first heart sound) through S_4 (fourth heart sound).

An early rapid filling of the ventricles and atrial contraction can occasionally produce the S_3 and S_4 sounds, respectively. However, they are beyond the scope of the present investigation. The first two heart sounds, on the other hand, are essential elements in the analysis of the cardiac dynamic cycle. The general descriptions of the relationship between the two sounds and their preceding mechanical events are as follows:

(a) The first sound, S_1, occurs shortly after the onset of ventricular contraction when the ventricular pressure exceeds the atrial pressure. At this point the mitral and tricuspid valves close, producing the first heart sounds.

(b) The opening of the aortic and pulmonary valves is inaudible and occurs just after S_1.

(c) When the aortic and pulmonic pressures are greater than left and right ventricular pressures, the aortic and pulmonary valves close, producing the second heart sound, S_2.

(d) The mitral and tricuspid valve opening is normally inaudible and occurs just after S_2.[9, 10]

Tavel[11] stated in a well documented discussion of the heart sounds that the S_1 sound is composed of four distinct elements which are displayed during an average period of 0.1 to 0.12 seconds. The end of the mitral valve closure is represented by the second element--the major component of the first sound. It is preceded by the first element (0.2 second) which is probably caused by muscular contractions starting the early phase of ventricular systole.

The second heart sound is composed of two distinct elements indicating aortic valve closure (A_2) and pulmonary valve closure (P_2). According to Tavel, the two elements are mainly separated--in some instances up to 0.1 second--because P_2 is delayed by intrathoracic pressure changes occurring with the inspiration. The A_2 element does not contribute significantly to the splitting of S_2 and when therefore observed in relationship to the carotid pulse wave, it will precede the dicrotic notch by a constant interval. P_2, on the other hand, will precede the dicrotic notch, fall on it, or even follow it.

<u>The Indirect Carotid Pulse Wave</u>

The external (indirect) measurement of change in pressure at a determined point over one of the carotid arteries during one cardiac cycle will yield a record similar to that presented in Figure 3.

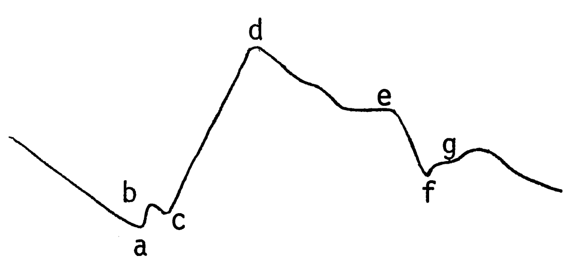


Figure 3. Indirect Carotid Pulse Wave

The pickup for measuring the pressure change is often placed over the common carotids ascending at the sides of the larynx where the pulsation can be readily seen or felt.

Placed on a time continuum (see Figure 4), it is clear that the pulse wave follows the electrical stimulus, the mechanical contraction, and the first heart sound, for the transmission of the pressure pulse is caused by the ejection of the blood from the left ventricle.

The individual points of the carotid pulse wave outlined in Figure 3 were discussed in The Heart and Sports, a translation from Russian by the National Aeronautics and Space Administration.[12]

According to the essay, the so-called a-b-c wave was determined by Frank[13, 14] to be a small preliminary oscillation caused by the isometric contraction of the heart. The sharp rise (c-d) is known as the anacrotic elevation which signifies the movement of blood into the aorta. At point e, the authors considered the expulsion phase as well as the mechanical ventricular systole completed. The incisure e-f-g represents the closure of the semilunar valve of the aorta with point e signaling the beginning and the dicrotic notch f the end of closure.

The Left Ventricular Systolic Time Intervals

According to the method used by Blumberger,[15, 16] the simultaneous recording of the previously described EKG, phonocardiogram, and indirect carotid pulse wave allows a fairly precise determination of the left ventricular time intervals, of which the EP, the EML, and the ICP discussed below were selected to be the parameters for this investigation (Figure 4).

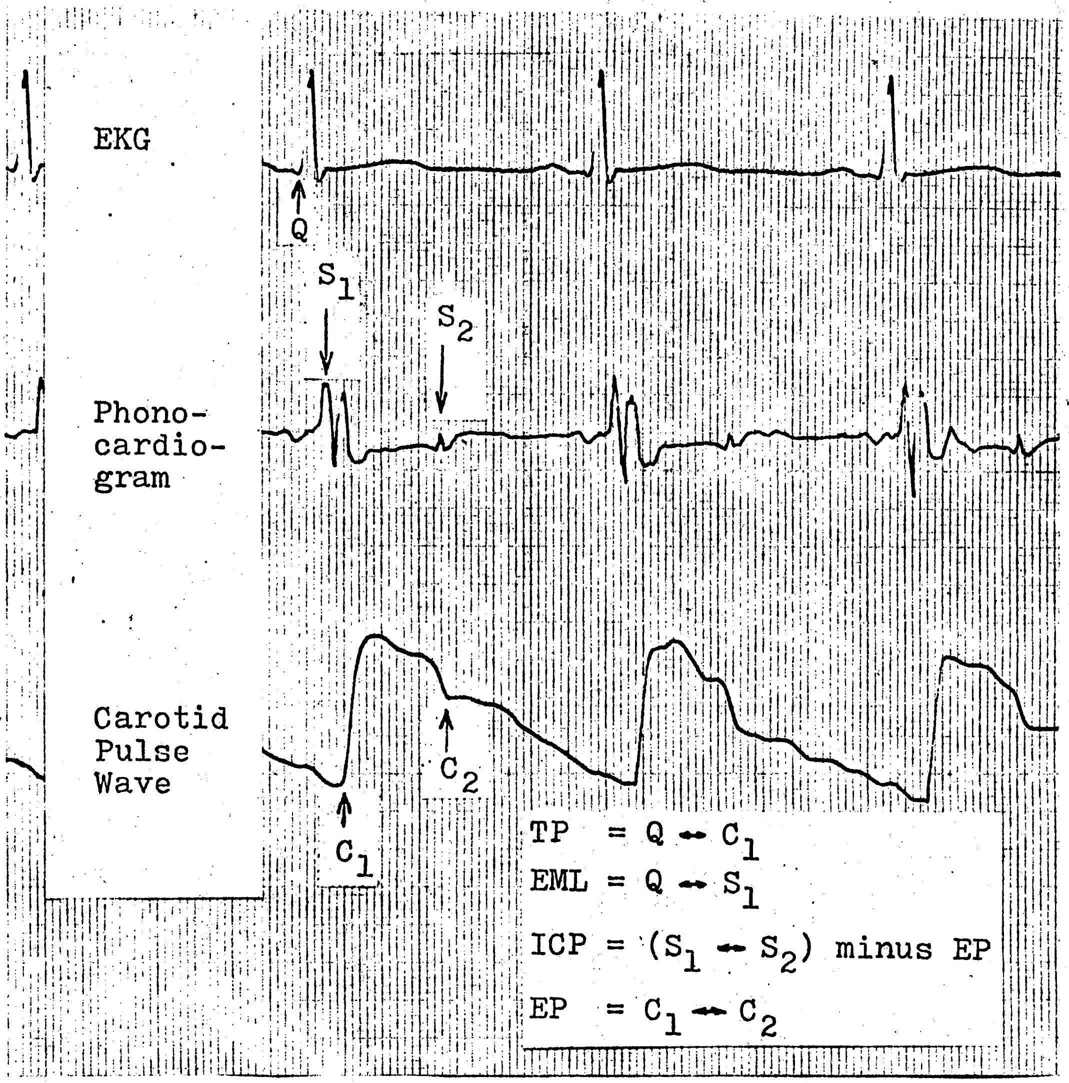


Figure 4. The Measurement of the Left Ventricular Time Intervals--EML, ICP, and EP

The total systole (QS_2) is presented by the interval measured from the Q wave to the first frequency vibration of the second heart sound (S_2). The total systole TS can be further divided into two intervals.

1. The nomenclature used in the modern German literature lists exclusively the term Anspannungszeit (tension period) which Raab[17] translated as isometric tension period (TP). In recent American medical literature, the term pre-ejection period (PEP) seems to be preferred. It represents the interval measured from the onset of stimulation (Q wave) to the rise of aortic pressure, i.e., the beginning of the ejection period.

2. The second interval is the so-called ejection period (EP) according to Raab, or another frequently-used term is left ventricular ejection time (LVET). According to Figure 3, the interval is measured from point c to point f, i.e., from the thinning at the beginning of the steep systolic ascent of the indirect carotid pulse wave to the dicrotic notch.[18]

To obtain the isometric tension period, the ejection period is subtracted from the total systole:

$$TP = TS - EP \quad or \quad TP = QS_2 - LVET$$

The isometric tension period can be further subdivided into two or more intervals:

1. The nomenclature of the German literature lists exclusively the term Umformungszeit (transformation time) for the first interval. Raab[19] translated it as electromechanical lag (EML). This interval is measured from the onset of the Q wave to the first high frequency component of the first heart sound (S_1) and is therefore also called the Q First Heart Sound (Q-IHSI) according to Hyman.[20] The EML supposedly represents the

time required for the spread of the changing potential, the electrical stimulation, to travel from the S-A node across the atrial myocardium, down the bundle of His, the right and left bundle branches into the Purkinje fibers which are the terminal conducting fibers.[21]

2. The nomenclature used for the second interval is Druckanstiegszeit (time of pressure rise) in the German literature. Raab's[22] translation was isometric contraction period which in the earliest literature was sometimes mistakenly used for the isometric tension period. In recent literature the term isovolumetric or isovolumic period seems to be preferred. The isovolumetric contraction period (ICP) is obtained by measuring S_1S_2 and subtracting the ejection period (EP).

It is believed that the ICP interval reflects sympathetic stimulation of the left ventricle by the sympathetic nerves. The pulse wave is immediately formed by the following ejection period.[23]

Nature of the Problem

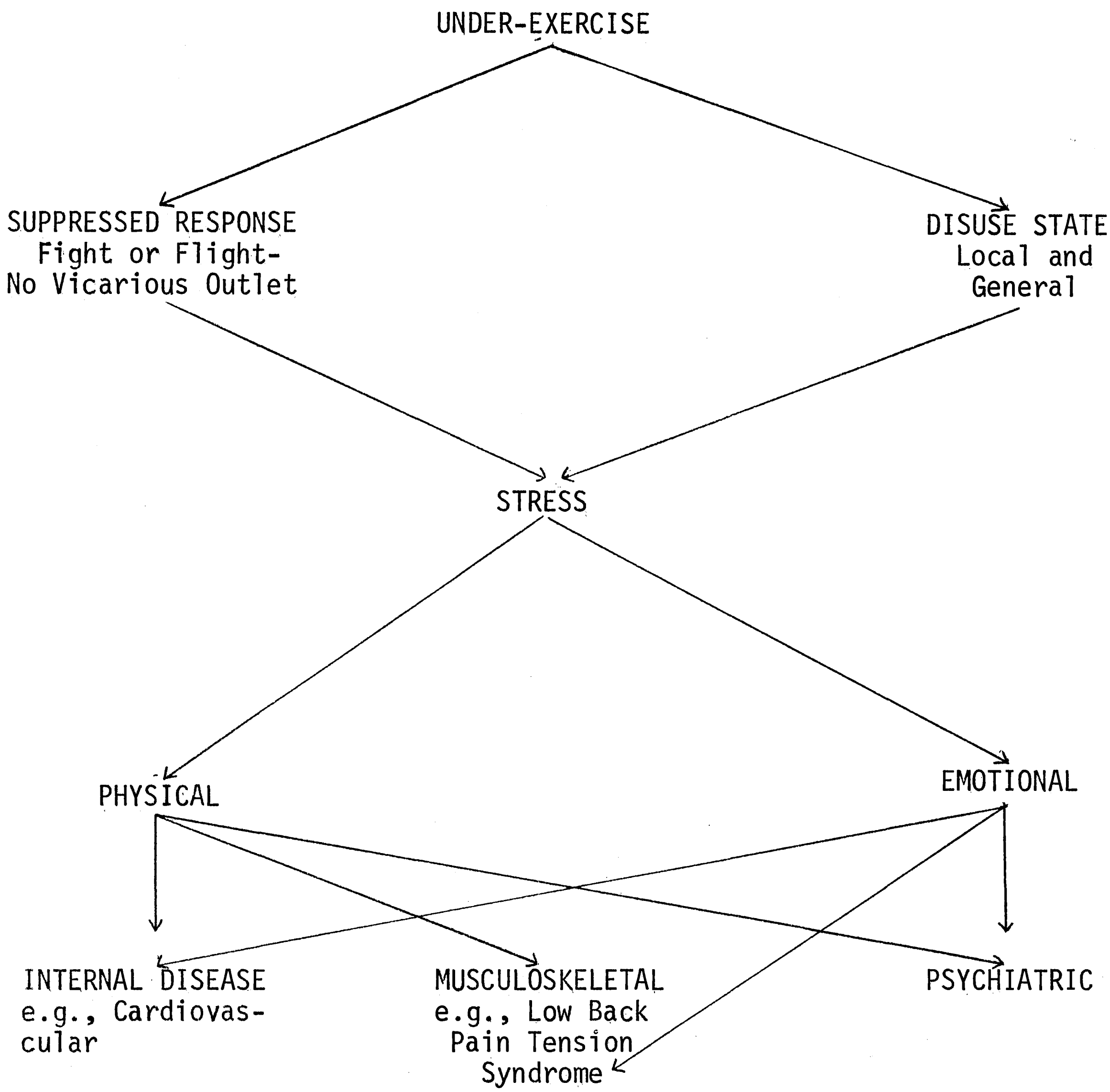
The left ventricular time intervals and their relationship to cardiovascular fitness have been investigated intensively during recent years. The impetus for this intensified research comes probably from the great incidence of heart disease, which has caused researchers to look for improved diagnostic tools to predict and determine cardiac problems as well as simplified methods to obtain accurate and detailed measurements of cardiovascular fitness. The principal concern of this investigation was the latter aspect; however, it has been demonstrated throughout the history of physical education that there is a wide common area of interest and concern which demands the cooperation of the medical and physical education professionals.

Kraus and Raab[24] outlined this common ground in their well-known discussion about hypokinetic disease, a term they chose to describe diseases related to the lack of sufficient habitual exercise. They could demonstrate the importance of physical fitness during the Convention of the American Medical Association of 1956 when the various reports on the protective value of exercise against chronic and acute back ailments were summarized. This seemingly strictly orthopedic problem spread, to the surprise of the investigators, into numerous areas of medicine when the effect of under-exercise was more fully investigated. The effect of under-exercise, or "low fitness," was outlined as follows (Figure 5). It can be said, therefore, that not only does poor physical fitness contribute to orthopedic problems, but also that overwhelming evidence is being accumulated which indicates it is a central factor in reduced cardiovascular efficiency or disease.[25]

Kraus and Raab, opposing the orthodox school of cardiology of mechanistic thinking, attributed the cause of many cardiovascular problems to the pathogenic significance of cardiac adrenergic preponderance. In other words, stress causes a preponderance of certain hormones, for example epinephrine and norepinephrine, which in turn provide a constant stimulation for certain neurological effector cells (adrenergic) until enzyme actions in the heart break down these drugs. The ensuing series of physiological changes is outlined by the authors as follows:

> . . . it has at long last become fairly common knowledge that profound disturbances of cardiac oxygen economy, intermediary metabolism, energy production and utilization, and structural integrity can take place independently of changes in coronary flow and hemodynamic conditions.[26]

The question arises then, how is psychological or physical stress related to all these disturbances? Research has shown that the adrenal-



Source: H. Kraus, S. Weber, K. Hirschhorn, and B. Prudden, After Exhibit on Hypokinetic Disease (AMA Convention, 1956), Institute for Physical Medicine and Rehabilitation, New York University, Bellevue Medical Center, New York, N.Y.

Figure 5. Hypokinetic Disease

sympathogenic catecholamines, especially epinephrine and norepinephrine, are some of the main factors involved.[27, 28] The former reaches the heart via the blood stream after being released from the adrenal medulla, and the latter is released directly by the post-ganglionic sympathetic nerve terminals into the myocardial cells. Both drugs are described as very powerful and potentially cardiotoxic neuro-hormones which will accelerate the heart beat (positive chronotropic action) and increase the force of contraction (positive inotropic action). At this point, the seemingly paradoxical cardiac problems of the physically unfit group becomes visible, for the positive inotropism decreases the efficiency of the heart, which wastes some of the vital oxygen for the myocardium. To describe it another way, the coronary flow is increased by the introduction of the catecholamines; however, research has discovered that with the increase in oxygen saturation in the coronary venous blood, there is a surprising concomitant increase in the lactic acid content of the blood in the coronary sinus. Kraus and Raab have concluded that this is conclusive evidence of heart muscle hypoxia or anoxia, since a normal or even a reduced arterio-venous oxygen difference does not eliminate the possibility of lack of oxygen in the myocardium. With the following hypothesis, the authors provided the groundwork for the nature of the problem of this study:

> It is most probable that the subendocardial tissue whose capillaries are maximally subject to compression by rising intraventricular pressure, and especially myocardial cells located unfavorably near the end of long capillaries, will be handicapped under oxygen-wasting catecholamine action, and thus, contribute unoxidized lactic acid to the coronary venous blood. Accordingly, the subendocardial layers of the heart muscle have a characteristic tendency to display multiple scattered foci of necrosis after having been exposed to exaggerated catecholamine action.[29]

Based on this hypothesis, one would expect differences between various levels of cardiovascular efficiency in regard to the intervals of the four parameters of the left ventricular contraction. The isometric tension period (TP) did show such a gradation as indicated by a study by Raab et al.[30] (Table II).

TABLE II

ISOMETRIC TENSION PERIOD AND FITNESS

Strenuous sports training	TP ave. = 101 msec
Regular light sports training	TP ave. = 94 msec
Occasional light sports, walking, etc.	TP ave. = 85 msec
Sedentary	TP ave. = 81 msec

Source: W. Raab et al., "Cardiac Adrenergic Preponderance Due to Lack of Physical Exercise and Its Pathogenic Implications," _American Journal of Cardiology_, V (1960), p. 300.

Hyman,[31] investigating the EML, which he called the Q-First Heart Sound Interval, obtained the data shown in Table III.

With respect to the isolation of cardiac disease by means of the parameters of the left ventricular time intervals, it should be pointed out that the causes might well be due to factors different from those produced by adrenergic preponderance, because only an unphysiologically large injected dose of epinephrine or norepinephrine will precipitate necrosis in the myocardium. However, if the catecholamine action, the waste of oxygen, combines with coronary sclerosis, arterial hypertension, and other factors which further reduce the oxygen supply to the myocardium, one might follow the advice of Cooper:

> A classic coronary-prone type is one who eats too much, worries too much, and does next to nothing. If his family has a positive history of cardiacs, then he had better recruit six good friends and have them stand by for pallbearers. Because the . . . elements--and statistics prove it--don't just add to one another, they tend to multiply one another.[32]

TABLE III

ELECTROMECHANICAL LAG AND FITNESS

Athletes	ave. EML = 58 msec
Normal subjects in good physical condition	ave. EML = 72 msec
Normal subjects in poor physical condition	ave. EML = 80 msec
Hypertensive HD	ave. EML = 82 msec
Mitral valvular HD	ave. EML = 84 msec
Aortic valvular HS	ave. EML = 88 msec
Coronary HD	ave. EML = 90 msec

Source: Albert S. Hyman, "The Q-First Heart Sound Interval in Athletes at Rest and After Exercise," Journal of Sports Medicine and Physical Fitness, IV (1964), pp. 199-203.

On the other hand, the question might emerge, why does mental or emotional stress contribute to cardiac inefficiency, when physical stress of strenuous exercise produces the same catecholamine action? The answer lies in the fact that habitual physical exercise produces a state of physical fitness which has characteristics of antiadrenergic preponderance, or as Raab[33] identified it, vagal plus sympathoinhibitory preponderance. It might be recalled that the vagi, the parasympathetic nerves of the heart, cause the release of the hormone acetycholine which, with its supraventricular effect of negative chronotropism, counteracts the sympathetic nervous system. In other words, the drug slows the rate of the sinus node and decreases the rate of conduction through the A-V node.[34] This, then, is the cause for the well-known bradycarida in athletes and the inotropic feature seen in the prolongation of the isometric tension period (TP).

Although the previous discussion seems to validate as a proven method the technique of measuring the parameters of the left ventricular contraction for precise determination of cardiovascular fitness, research has not yet provided conclusive evidence. While a number of studies have shown the expected change in the intervals of the parameters after subjects completed physical fitness programs, other investigations could not provide such evidence. Further research is therefore necessary to answer the questions about the relationship of the left ventricular systolic time intervals to cardiovascular fitness.

Statement of the Problem

The purpose of this study was to investigate the relationship between the left ventricular systolic time intervals--i.e., the EML, ICP, EP, TP, the ratios EP/ICP, EP/TP, and EP/HR, and to an index of cardiovascular fitness--maximum oxygen intake--as well as the following indexes for broad classification of general fitness:

1. Vital capacity
2. Forced vital capacity

3. Systolic blood pressure
4. Diastolic blood pressure
5. Pulse pressure
6. Schneider Index
7. Resting heart rate
8. Rest/Work ratio
9. Resting T wave amplitude
10. Weight residual
11. The sum of the per cent deviation from the norm of
    a. Vital capacity
    b. Maximum breathing capacity
    c. Maximum oxygen intake
12. Classification indexes
    a. Fitness levels
    b. Age
    c. Exercisers/Nonexercisers

Significance of the Study

The dissemination of various research data about the effect of insufficient physical exercise has brought ever increasing numbers of individuals, especially middle aged men and women, into vigorous endurance-type fitness programs mainly to forestall or prevent possible cardiovascular problems.

The left ventricular systolic time intervals investigated in this study might be of major importance in assessing an individual's cardiovascular condition and in ensuring his or her safety and proper placement in a fitness program.

The time intervals have already shown themselves to be of considerable value as an aid in the diagnosis of certain heart diseases. In an effort to detect cardiac abnormalities, for example, Spodick, Dorr, and Calbreses[35] studied 200 unselected patients without giving the investigators access to any of the patients' clinical data. They discovered a shortened left ventricular ejection period (EP) in 88 per cent of the patients who were later, after extensive tests, classified as cardiacs.

However, a recent editorial in Circulation, the official journal of the American Heart Association, felt it necessary to comment on a series of new research reports dealing with the use of left ventricular systolic time intervals in the diagnosis of heart disease.[36] After reviewing a number of studies, the authors of the editorial believed that a sufficient number of observations are not now at hand to permit critical assessments and meaningful conclusions. The editorial staff summarized their thoughts by stating that:

> . . . while systolic time intervals undoubtedly reflect alterations in left ventricular performance in acute myocardial infarction, they do not yet consistently distinguish among individual patients with acute infarcts of varying severity in a practical way. To do so may require more data. . . .[37]

While it is not the purpose of this investigation to enter the specific clinical realm of the cardiologist, heart disease is related to the area of cardiovascular fitness and is therefore a major concern of the physical educator whose task it should be to help in the prevention of cardiovascular problems. It is in this area that this study can offer a significant contribution, i.e., in addition to presenting data for fitness evaluation and the detection of heart disease, it could possibly provide a basis for future investigations which try to employ the measurement of the left ventricular systolic time intervals as a noninvasive technique to predict cardiovascular disease (see discussion on pages 17 and 18) emanating particularly from arterio and atherosclerosis.

Definition of Terms

Vital capacity. The greatest volume of gas that can be expelled by voluntary effort after maximal inspiration.

Forced vital capacity. The maximum air that can be forcefully and as rapidly expired as possible in a given time.

Maximal breathing capacity. The maximum air that can be moved in and out of the lungs in a given time.

Systolic blood pressure. The pressure which the blood exerts on the vessel walls during systole, the working cycle of the heart.

Diastolic blood pressure. The pressure which the blood exerts on the vessel walls during diastole, the resting cycle of the heart.

Pulse pressure. The difference between systolic and diastolic blood pressure.

Schneider Index. An estimation of the condition of the autonomic nervous system, the heart, and the respiratory mechanism.

Resting heart rate. The frequency of the heart beat per minute when the subject is at rest.

Rest/Work ratio. An arbitrary mathematical ratio of the heart's resting period over its working period, the interval measured from the end of the T wave to the end of the QRS complex over the interval measured from the S to the T wave (ST segment).

Resting T wave amplitude. The amplitude of T wave in an electrocardiogram measured from the isoelectric line to the apex of the wave.

Weight residual. The difference between the actual and predicted weight. The predicted weight is the average of all equivalent weights in an analysis of body build by anthropometric fractionation of body weight.

Assumptions of the Study

1. The subjects will follow all pretest instructions in regard to diet and physical activity.

2. Testing apprehension will not affect measured data significantly.

3. The maximum oxygen uptake and the other physical fitness screening tests are useful and valid indexes of physical fitness.

Limitations

1. The subjects were volunteers and not randomly selected.

2. The subjects were relatively fit providing insufficient data in the lower fitness rankings.

FOOTNOTES

[1]"Latest in Fight Against Heart Attacks," U. S. News and World Report, LXXVI (February 3, 1975), pp. 42-43.

[2]Benjamin Ricci, Physiological Basis of Human Performance (Philadelphia, 1967), p. 234.

[3]Ricci, p. 235.

[4]Kenneth H. Cooper, Aerobics (New York, 1968), p. 36.

[5]Bruno Balke, "The Effect of Physical Exercise on the Metabolic Potential, a Crucial Measure of Physical Fitness," Exercise and Fitness, ed. The Athletic Institute (Illinois, 1960), p. 73.

[6]R. E. Johnson, L. Brouha, and R. C. Darling, "A Test of Physical Fitness for Strenuous Exertion," Review of Canadian Biology, I (1942) pp. 491-503.

[7]Kathleen G. Andreoli et al., Comprehensive Cardiac Care (2nd ed., St. Louis, 1971), pp. 1-11.

[8]Edwin G. Zalis and Mary H. Conover, Understanding Electrocardiography (St. Louis, 1972), pp. 1-9.

[9]Andreoli et al., p. 11.

[10]Morton E. Tavel, Clinical Phonocardiography and External Pulse Recording (2nd ed., Chicago, 1973), pp. 35-37.

[11]Tavel, p. 38.

[12]V. L. Karpman and G. M. Kukolevskiy ed., The Heart and Sports, Essays on Cardiology in Sports, tr. National Aeronautics and Space Administration (Washington, D.C., 1971), pp. 220-221.

[13]O. Frank, Zeitschrift für Biologie, XXXVII (1899), pp. 483-529, quoted in Karpman and Kukolevskiy, p. 221.

[14]O. Frank, Zeitschrift für Biologie, XLVI (1905), pp. 441-553, quoted in Karpman and Kukolevskiy, p. 221.

[15]Karljosef Blumberger, "Die Untersuchung der Dynamic des Herzens beim Menschen. Ihre Anwendung als Herzleistungsprüfung," Ergebnisse der Inneren Medizin und Kinderheilklinik, XLII (1942), p. 424.

[16]Kj. Blumberger and S. Meiners, "Studies of Cardiac Dynamics," *Cardiology: An Encyclopedia of the Cardiovascular System*, II, ed. A. Luisada (New York, 1959), pp. 372-377.

[17]W. Raab, "Training, Physical Inactivity, and the Cardiac Dynamic Cycle," *Journal of Sports Medicine*, VI (1966), p. 39.

[18]Henry J. Montoye et al., "Systolic Preejection Period: Relation to Habitual Physical Activity," *Medicine and Science in Sports*, IV (1972), p. 78.

[19]Raab, p. 39.

[20]Albert S. Hyman, "The Q-First Heart Sound Interval in Athletes at Rest and After Exercise," *Journal of Sports Medicine and Physical Fitness*, IV (1964), pp. 199-203.

[21]Thomas Kirk Cureton, *The Physiological Effects of Exercise Programs on Adults* (Springfield, 1969), p. 49.

[22]Raab, p. 39.

[23]Cureton, p. 48.

[24]H. Kraus and W. Raab, *Hypokinetic Disease* (Springfield, Illinois, 1961), p. 8.

[25]Canadian Medical Association (1967), "Proceedings of the International Symposium on Physical Activity and Cardiovascular Health," *Canadian Medical Association Journal*, IVC (1967), pp. 695-917.

[26]Kraus and Raab, p. 83.

[27]W. Raab, "Adrenergic-Cholinergic Control of Cardiac Metabolism and Function," *Advances of Cardiology*, Vol. 1 (New York and Basel, 1956), p. 65.

[28]Symposium on "The Catecholamines in Cardiovascular Pathology," University of Vermont, Aug. 23-26, 1956, *American Journal of Cardiology*, V (1960), pp. 571-665.

[29]Kraus and Raab, pp. 83-85.

[30]W. Raab et al., "Cardiac Adrenergic Preponderance due to Lack of Physical Exercise and Its Pathogenic Implications," *American Journal of Cardiology*, V (1960), p. 300.

[31]Hyman, pp. 199-203.

[32]Cooper, p. 121.

[33]Raab, pp. 38-47.

[34]Zalis and Conover, p. 7.

[35]D. H. Spodick, C. A. Dorr, and B. F. Calbrese, "Detection of Cardiac Abnormalities by Clinical Measurement of Left Ventricular Ejection Time," Journal of the American Medical Association, CCVI (1969), pp. 239-242.

[36]Joseph K. Perloff and Nathaniel Reichek, ed., "Value and Limitations of Systolic Time Intervals (Preejection Period and Ejection Time) in Patients With Acute Myocardial Infarction," Circulation, XLV (1972), pp. 929-932.

[37]Perloff and Reichek, p. 931.

CHAPTER II

REVIEW OF RELATED LITERATURE

It was pointed out in the foregoing discussion that the practical application of the analysis of the left ventricular systolic time intervals dealt either with the recognition and prediction of heart disease or with the assessment of cardiovascular fitness. The purpose of this chapter was therefore to review related literature from a historical, medical, and physical fitness perspective to justify and aid the design of this study.

The Left Ventricular Systolic Time Intervals

A Historical Review

Chaveau and Marey were credited by Emmrich[1] to be the first investigators who, in 1863, divided the systole into the TP (isometric tension period) and the EP (ejection period). The TP was seen as the time interval which the heart needed from the beginning of systole to exert the diastolic pressure upon the aortic valves (opening of the valves). The EP was defined as the period during which the heart ejected its respective volume of blood into the peripheral system, in other words, the time interval from the opening of the aortic valves to their closing.

Hürthle's[2] basic research, which was reported in 1891, dealt with the establishment of average TP intervals as well as the various influences on the consecutive phases of systole. He contended, for example, that the height of the initial pressure within the ventricle at the moment of systole is the fundamental factor which is responsible for the shortening of the ICP observed under various experimental conditions. His thoughts and ideas, derived mainly from his research with dogs have provided--with the later publications by Wiggers,[3] Blumberger,[4] and Holldack[5]--the basic concepts and methodology for the research dealing with the phases of the cardiac cycle.

In 1910, Robinson and Draper[6] introduced this research in the hospital where, for the first time, the TP's were measured in cardiac patients. For normal healthy individuals, they reported TP's ranging from 70 msec to 85 msec. They determined these values by recording simultaneously the pulse curves of the carotid, brachial, and the radial arteries from which they were able to determine the pulse wave velocity needed to estimate the isometric tension period.

In 1921, Carl Wiggers[7] substantiated not only the findings of Hürthle and others, but he investigated by invasive methods various influences upon the phases of the cardiac cycle. Some of his findings were stated as follows:

1. An increase in venous return above normal causes a lengthening of ventricular systole, quite independent of diastole length. This occurs as a result of the prolongation of the ejection phases, the isometric phase of contraction having a tendency to be abridged.

2. An increase in arterial resistance acts to abbreviate systole, independently of changes in diastolic length. This abbreviation of systole takes place in spite of a slight tendency of the isometric phase to lengthen and is therefore due to a shortening of the ejection phase.

3. When the increase in arterial resistance is of such grade and type that the ventricle cannot empty itself effectively, a marked retention of blood occurs, and the diastolic

volume and initial tension increase, in consequence. As such an increase in initial pressure has a tendency to lengthen systole. . . .

4. The duration of systole is determined solely by changes in the length of previous diastole only when the initial intraventricular pressures and the aortic pressure at the beginning of diastole remain nearly constant.

5. . . . the systolic portion of the ventricular volume curves cannot be regarded as superimposable at different rates of beat.

6. . . . the phases of diastole alter so little in duration. . . .

Some sixteen years later, in 1937, Schulz[8] with the cooperation of the electronics division of the renowned Siemens company in Germany was able to develop the technology for the noninvasive method of determining the phases of the cardiac cycle by simultaneously recording the carotid pulse wave, EKG, and PKG.

Blumberger[9] followed the suggestion of his teacher Eden, who at the time was the clinical director of the institute where Schulz conducted his research, to use the method developed by Schulz for the investigation of the phases of the cardiac cycle in relation to various physiological and pathological factors.[10] The significance of Blumberger's research is underlined by the frequent references made to him by contemporary investigations. Karpman and Kukolevskiy[11] summarized it as follows:

> In spite of the more than 100 years of study of the phase structure of the cardiac cycle, Blumberger (1942) first demonstrated the significance of phase analysis for evaluation of the contractive activity of the heart only in the 1940's. His work aided in the introduction of phase analysis to clincial practice.

Below are two recordings (Figures 6 and 7) with which Blumberger investigated the isometric tension period and the ejection period in normal individuals and cardiacs.

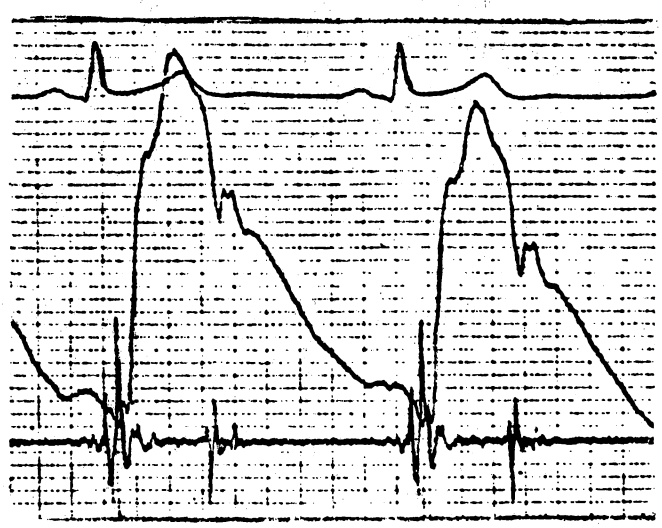


Figure 6. A Simultaneous Recording of the Carotid Pulse Wave, the EKG, the PKG. The Paper Speed was 5 cm/sec Which Blumberger Considered to be a Minimum but Sufficient for Clinical Analysis

Source: Karljosef Blumberger, "Die Untersuchung der Dynamik des Herzens beim Menschen. Ihre Anwendung als Herzleistungsprüfung," Ergebnisse der Inneren Medizin und Kinderheilklinik, XLII (1942), p. 440.

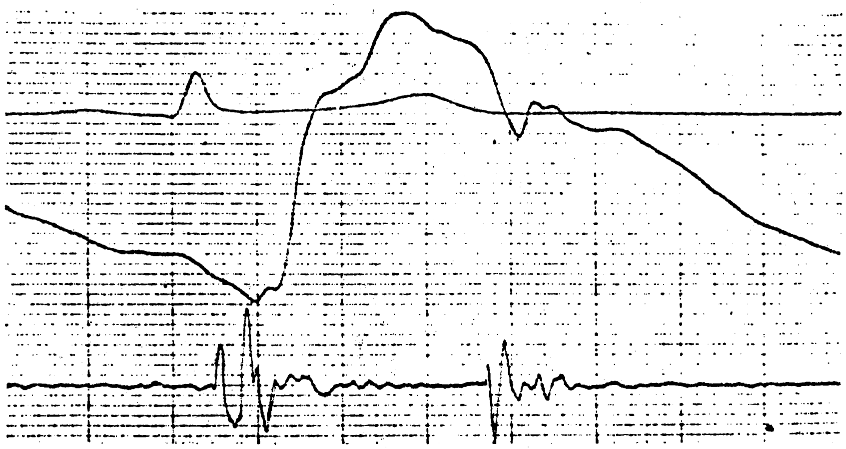


Figure 7. The Same Recording as in Figure 6 but Taken at 16 cm/sec. Blumberger Considered Paper Speeds of 10 cm/sec or Above Only Necessary for Scientific Investigations

Source: Karljosef Blumberger, "Die Untersuchung der Dynamik des Herzens beim Menschen. Ihre Anwendung als Herzleistungsprüfung," Ergebnisse der Inneren Medizin und Kinderheilklinik, XLII (1942), p. 440.

For normal subjects of both sexes, he reported resting TP's ranging from 50 ms to 100 ms with most of the cases falling into the 60 ms to 90 ms range. The values for the EP intervals fell between 200 ms and 310 ms. He measured, however, lower intervals at very high heart rates.

The main objective of Blumberger's investigations was the early detection of decreased myocardial efficiency by observing changes in the TP and EP intervals.

Holldack[12] investigated some ten years later the isometric tension period (TP), the electromechanical lag (EML), the isometric contraction period (ICP), and the ejection period (EP) by the indirect method developed by Schulz.

Holldack emphasized that the TP--measured from the Q wave or in its absence from the beginning of the R wave to the steep rise of the carotid pulse wave--should be corrected for the pulse transmission time from the heart to the site of the recording.

Considering the TP in the light of Hess'[13] work about the origin of the S_1 sound, Holldack recognized the isometric tension period as the sum of two phases, the EML and the ICP. He considered the EML to be influenced above all else by the filling pressure and the ICP mainly by the contractility of the myocardium.

In cases where the filling pressure of the left ventricle was reduced as in mitral stenosis or absolute arrhythmia, the EMI intervals were found to be greater than average.

The ICP, on the other hand, had longer intervals when the contractility of the left ventricle was reduced. A shorter ICP, however, was seen in cases of aortic insufficiency (see Table IV).

TABLE IV

SELECTED AVERAGE VENTRICULAR
TIME INTERVALS

Classification	EML	ICP	TP	EP
Normal	51	37	87	290
Hypertension	53	47	100	281
Absolute arrhythmia	73	29	102	235
Mitral stenosis	59	28	98	270
Mitral stenosis and insufficiency	64	35	99	267
Mitral insufficiency	70	25	95	250
Aortic insufficiency	55	18	73	287
Aortic insufficiency with stenosis	53	7	60	327
Aortic stenosis	52	30	82	335

Source: K. Holldack, "Die Bedeutung der 'Umformungs- und Druckanstiegs-zeit' für die Herzdynamik," Deutsches Archiv für klinische Medizin, IICC (1951), pp. 71-90.

Holldack was aware that the small number of cases upon which these data were based did not permit him to draw definite conclusions about the relationship between the EML and ICP intervals and any physiological or pathological condition of his subjects.

However, while he refused to speculate about the EML, he thought a shortening of the ICP below 20 msec might be an indication of aortic insufficiency and a prolongation above 55 msec damage to the left ventricle.

The Left Ventricular Systolic Time Intervals and Their Physiological Significance

In the 1950's the research dealing with the phases of the cardiac cycle was still concentrated mainly in Germany. Investigating the TP and its division into EML and ICP according to Holldack,[14] and Emmrich, Klepzig and Reindell[15] reported their findings on 52 cardiacs, 20 normal individuals, 10 champion athletes, 10 hypertensives, and 10 patients with nephrogenic hypertension. They summarized their results as follows:

. . .

3. For individuals who were healthy in respect to cardiovascular criteria, the values obtained ranged from 36 ms to 61 ms for the EML, and 16 ms to 67 ms for the ICP.

4. With top flight athletes, a prolongation of the ICP was found, while the EML corresponds to the values measured in normal individuals.

5. In the case of sudden changes of circulatory conditions due to injection of Aterenol which increased the resistance of the peripheral arterial system to cause hypertension, the ICP interval was prolonged and the EML remained constant.

6. With reduced filling of the heart as it occurs when raising oneself into the upright position, the ICP is also prolonged while the EML remains constant.

7. In the case of two traumatic aerteriovenous aneurisms, the ICP shortened according to the increased volume load of the left ventricles. With manual compression or surgical occlusion of the aneurism, the ICP was lengthened according to the increase in blood pressure. The EML remained nearly constant in both cases.[16]

The longer ICP found in athletes supplemented earlier findings reported by Reindell and Klepzig.[17] Their investigation of the TP and EP in athletes showed that through training the cardiac dynamic process was shifted toward longer intervals. The longer TP interval was, of course, due to the longer ICP since the EML remained nearly constant.

However, the value of using the EP interval to differentiate between fit and unfit individuals was considered questionable because this interval was shown to be dependent not just on the heart rate but also on several other haemodynamic factors--ejection volume, peripheral impedance, and others.

Millahn[18] was not able to detect longer EP intervals during his investigation of young athletes and nonathletes. But he pointed out that the athletes might have been only mildly trained. It should be further added that the young German men not participating in organized activities were probably also quite fit.

Millahn's statistical analysis, however, agreed with the previously reported dependence of the EP on the heart rate.

Lang[19] in a well-designed study was able to determine that not only the EP, which decreases with increasing heart rate, but also the TP depends to a large extent on the heart rate. The inverse relationship of the EP to pulse frequency was shown to be a linear correlation which is in agreement with Millahn's findings mentioned above.

Lang also attempted to isolate the partial phase of the TP (EML and ICP) responsible for this correlation. While there was no significant correlation for the EML, the ICP showed a low correlation to heart rate, indicating that this phase is partially responsible for the pulse frequency dependence of the TP.

With subjects over 50 years old having normal heart rates, the TP was significantly prolonged. Lang speculates that the physiological changes of aging cause cardiac insufficiency which is responsible for the lengthening of the TP.

For normal healthy individuals, he reported the following time intervals (Table V):

TABLE V

MEAN SYSTOLIC TIME INTERVALS

STI	n	x	s	s+2s
TP (msec)	180	85.90	10.76	64.30 - 107.50
EML (msec)	123	56.00	9.90	36.20 - 75.80
ICP (msec)	123	31.35	10.65	10.05 - 52.65
EP (msec)	180	274.40	28.63	217.20 - 331.60
EP/TP	180	3.24	0.45	2.34 - 4.14

Source: E. Lang, "Einfluss der Pulsfrequenz auf die Kontraktionsphasen des Herzens," Zeitschrift für Kreislaufforschung, LIV (1965), p. 481.

In the United States, the impetus to accelerate research dealing with the various phases of the cardiac cycle came most likely from Raab.[20] In a speech to the gathering of cardiologists at the Second National Convention on Cardiovascular Disease, he stated that most investigations were concentrating their efforts on coronary artery atherosclerosis during the last decade but indicating little interest in the myocardium and its oxygen consumption.

In the same year, Hyman[21] read a paper called "The Q-First Heart Sound Interval in Athletes at Rest and After Exercise (A new method of estimating ventricular functional capacity)." He suggested to his audience at a meeting of the American College of Sports Medicine that the data of the Q-first heart sound (EML) may be utilized by physicians and physical educators in the examination of candidates for athletic activities, and that the use of the data may even be extended to the evaluation of work capacity for cardiac patients.

In this paper, he presented data on 1085 subjects taken at rest (see page 17) as well as EML intervals taken at one and five minutes after exercise. The exercises were based on 5000 ft/pds of work-stair-climbing. The results showed the athletes at the one-minute post-exercise to have average time intervals of 42 msec, which then progressively lengthened according to the state of fitness and disease of the subjects to 128 msec for the more severe cardiac cases. Moreover, while the athletes and normal subjects with good fitness obtained the pre-exercise interval length at five minutes post-exercise, the other groups still showed longer time intervals. Hyman concluded then that the time interval will be lengthened when some of the following factors are altered:

1. The spread of the stimulus from the A-V node through the main bundle of His, thence through the left and right bundles, and finally, through the terminal Purkinje system [see page 6];
2. the synaptic reaction of the myocardial reception system;
3. the responsiveness of heart muscle contraction;
4. integrity of the mitral valve;
5. atrial pressure gradient.[22]

Raab reviewed pertinent German, Russian, and American research in addition to his own in order to establish a relationship of the isometric tension period (TP) and the isometric contraction period (ICP) to groups of trained and untrained individuals (Table VI).

This survey of research studies comparing the TP and ICP among groups of trained and untrained subjects clearly indicates longer average intervals for the latter group for both ventricular components. The Millahn study, as also reported on page 35 showed a definite shortening of the TP and ICP with increasing heart rates. Based on these findings Raab et al.[31] calculated correlations according to the method of Lang[32] which, with the TP difference of the 9 msec between their untrained and trained groups, should have established a heart rate difference of 20 beats per minute. The experimental data, however, indicated a difference of only 7 beats per minute.

Checking for other correlations indicating major changes in the time intervals because of age, Raab et al. noticed only a slight prolongation of the TP. In regard to the EML, however, they suggested further study since the findings of the Shkhavatsabaya investigation revealed low average values (50 and 51 msec) in nonathletic subjects and higher ones (58 to 65 msec) in athletes. This was in direct contrast to the data reported by Hyman (see page 18).

Raab et al. concluded that an increasing heart rate without prominent participation of the adrenergic chronotropic mechanism would lengthen the TP because of various hemodynamic factors, such as reduced ventricular filling. On the other hand, direct inotropic catecholamine action (see pages 16 and 19) shows an opposite effect, a shortened TP.

Pointing to the considerable overlap of ventricular function measurements between fit and nonfit subjects, Tharp[33] conducted a study to determine cardiovascular fitness by correlating the TP and Q-first heart

TABLE VI

SYSTOLIC TIME INTERVALS OF TRAINED AND UNTRAINED SUBJECTS

	Authors	TP (msec)		ICP (msec)	
		Untrained Subjects	Trained Subjects	Untrained Subjects	Trained Subjects
I.	Emmrich et al.[23]	90 (72-107) 20 cases	106 (82-140) 10 cases	40 (16-67) 20 cases	48 (35-79) 10 cases
II.	Blumberger[24]	85 (70-106) 20 cases	97 (81-120) 10 cases	--	--
III.	Maass[25]	83 (68-97) 20 cases	99 (74-134) 10 cases	--	--
IV.	Shkhvatsabaya[26]	82[a] ? ?	114 (90-150) 246 cases	31[a] ? ?	49 (20-90) 246 cases
V.	Raab et al.[27]	89[b] (53-126) 113 cases	98[c] (62-154) 247 cases	--	--
VI.	Raab and Krzywanek[28]	93[d] (71-116) 79 cases	99[e] (90-135) 29 cases	--	--
VII.	Raab et al.[29]	90[f] (73-110) 20 cases	97[f] (83-125) 20 cases	--	--
VIII.	Millahn[30]	82[g] 86 cases	85[g] 109 cases	--	--

[a]Data for untrained subjects quoted from another Russian author, Karpman.

[b]Group of sedentary persons and others, engaging irregularly in light sports.

[c]Group of persons engaging in regular light to strenuous training.

[d]Sedentary (30 minutes rest in semi-darkness preceding test).

[e]Moderately trained (30 minutes rest in semi-darkness preceding test).

[f]Identical group before and after intensive training for 6 to 12 weeks.

[g]Teen-age boys (14 to 19 years).

Source: W. Raab, "Training, Physical Inactivity and the Cardiac Dynamic Cycle," Journal of Sports Medicine, IV (1968), pp. 38-47.

sound (EML) with the subject's score on a standard physical work capacity test. His time interval measurements taken at rest were correlated with data from a physical work capacity test on the Monarch bicycle ergometer. The results indicated a correlation of only r = .21 between PWC-150 and TP as well as R = .13 between PWC-150 and EML. He concluded, therefore, that the cardiac function test did not appear to offer a good substitute for the more strenuous tests of cardiovascular fitness.

Tharp's views were in conflict with the data obtained from a ten-week endurance training investigation by Wiley.[34] He reported that an analysis confirmed no existing significant differences between the two groups before the beginning of the training program. After the experimental group had gone through the endurance training, however, an inhibition of the cardiac rhythm while resting, and during as well as after submaximal exercise on a bicycle ergometer, was observed. Statistically, the results revealed for the experimental group significantly longer cycle time, diastole, and EP at rest, during a submaximal ride on a bicycle ergometer, and at 30 seconds and five minutes post-exercise. The analysis for differences in weight, height, and age provided no significant differences. For the EML, Wiley reported only a trend for the interval to lengthen with training.

In another study--an unpublished dissertation to which Wiley greatly contributed--Molnar[35] found no significant correlation between the components of the left ventricular cardiac dynamic cycle and specified measures of physical fitness. Molnar used a sample of 122 college physical education students in an attempt to establish a correlation between the left ventricular time intervals and maximum oxygen consumption, triceps skinfold test, and height. For all criteria, regression equations indicated only statistically insignificant correlations.

Fardy,[36] on the other hand, found results similar to those reported by Wiley. He noted that pre-ejection intervals (TP and ICP) lengthened in response to training.

In a follow-up study, Fardy[37] investigated the influence of physical activity on selected cardiac phases. The results of the statistical analysis indicated that the EML decreased significantly. The MS (mechanical systole), TS (total systole), Q-E (EML + ICP + pulse transmission time), and 1-E (ICP + pulse transmission time) increased significantly as the result of habitual strong physical activity. However, while Fardy concluded that the time intervals were useful in evaluating ventricular performance and cardiovascular efficiency, the results could distinguish only between nonactive subjects and active ones. There was no significant difference between those who trained either three days or five days a week.

The contradiction of the various reports is underlined by the results of an investigation by Montoye et al.[38] in which the relationship of the cardiac time intervals of habitual physical activity was investigated. They found no significant relationships between any of the systolic time intervals and habitual physical activity.

There are probably two factors that could be the cause of the contradicting results. While Fardy did not seem to have corrected his data for heart rate as Montoye et al. had done, he had an excellent classification of physical activity, i.e., subjects not participating in any activity, cross country runners training five days a week, and individuals participating in regular endurance training three times a week. Montoye et al. used a questionaire classifying individuals according to items such as doing major home repairs and maintenance, gardening, and others. These are, of course, categories which might not be sufficient to distinguish cardiovascular differences.

The Left Ventricular Systolic Time Intervals and Their Pathological Significance

The editorial of the official journal of the American Heart Association, discussed on page 21 in Chapter I, also indicated conflicting results in regard to the usefulness of the systolic time intervals for the detection and prognosis in patients with acute myocardial infarction.[39] However, a majority of reports seems to indicate the usefulness of systolic time intervals as a reflection of functional states and as a practical screening procedure for detecting cardiac abnormalities.[40]

In a frequently-quoted investigation by Spodick et al.[41] 200 unselected patients were studied, but the investigators had no prior knowledge of the subject's clinical data. They discovered a short EP in 77 of 97 (88%) subjects who were later diagnosed as cardiac patients, while a normal EP was recorded in 92 of 103 (89%) subjects who were later found to be noncardiac patients. The EP was considered "normal" for heart rate when it fell within one standard deviation of the line determined by the following regression equation:

$$\text{LVET (EP)} = 376 - 1.2\ \text{hr} \pm 12\ \text{msec.}$$

This equation of normals was based on a previous publication by Spodick and Kumar.[42]

It was emphasized during the previous discussion that heart rate directly influenced the length of the ejection period, although the authors pointed out that in the event the EP becomes abnormal for heart rate, other factors contributing to its variance have to grow correspondingly in importance. The principal factor affecting the EP was thought to be stroke volume. This conclusion was consonant with the results reported by Weissler, Peeler, and Roehll.[43]

The connection to physical fitness seems to be apparent at this point since a large stroke volume might also indicate better endurance fitness according to the literature. Ricci[44] referred in this report to the superbly conditioned marathon runner De Mar, who was measured to have twice the stroke volume of a nonathlete. Recognizing the need for additional research on the dynamics of cardiac output, he could nevertheless summarize--on the strength of available data--that "individuals exhibiting good cardiovascular-pulmonary response to work . . . possess larger stroke volume . . . than their less-trained counterparts."[45]

However, since Spodick et al. were concerned with the clinical aspects of their data, they concluded that left ventricular ejection time can be seen as a nontraumatic screening test for cardiac malfunction.

Aronow, Bowyer, and Kaplan[46] in a 1971 publication supported the above conclusions in a study dealing with the assessment of myocardial contractility. Using a test group of 21 men with coronary heart disease, the investigators measured external isovolumic contraction times (EICT = ICP) and left ventricular ejection time (LVET = EP) immediately after and three minutes after exercise. The results were used to correlate the ratio EP/ICP to ejection fraction and end-diastolic volume. The analysis showed that the ratio EP/ICP correlated with ejection fraction $r = 0.71$ immediately after and $r = 0.69$ three minutes after exercise.

The correlation with end-diastolic volume was r = -0.79 immediately after and -0.80 three minutes after exercise.

Based on these data, the conclusion was drawn that the EP/ICP ratio after exercise is a good noninvasive measurement for the assessment of myocardial contractility.

Similar results were obtained by Armstrong, Lewis, and Gotsman[47] investigating the PEP (TP) and SEP (EP) in constrictive pericarditis and severe primary myocardial disease. They observed that patients with congestive cardiomyopathy had an ejection fraction of less than 0.50 and an EP of more than 110 msec (mean 131 msec); patients with constrictive pericarditis had an ejection fraction greater than 0.50 and an EP of less than 110 msec (mean 89 msec).

According to the authors, the main characteristic of congestive cardiomyopathy is a decrease in contractility with low ejection fraction, while in constrictive pericarditis the ventricles contract well as indicated by normal or near normal ejection fractions; however, stroke volume is reduced and cardiac output is maintained by an increase in heart rate.

Hamosh et al.[48] concluded that the systolic time intervals were not reliable indexes of left ventricular performance. They observed a prolonged TP only in patients with significantly elevated ventricular end-diastolic pressure and clinical signs of congestive heart failure, but patients with acute myocardial infarction, like normal individuals, did not show this prolongation. They hypothesized that the normal TP in myocardial damage might be due to adrenergic stimulation offsetting the effect of the impairment.

Whitsett and Naughton[49] studied the effect of mild exercise on systolic time intervals in active and sedentary healthy normals and cardiacs. The authors reported that the TP was longer at rest for sedentary and active cardiac groups than in the sedentary and active healthy groups. The so-called ejection time index EP + (1.7 x HR) showed no significant differences among the groups at rest.

The exercise shortened the EP significantly in all groups while the ETI, the ejection time index, decreased in accordance with the relative state of physical activity and health of the individual. Because both active groups indicated a significant shortening--the cardiac patients actually exhibited a prolongation of the ETI--Whitsett and Naughton concluded that a shortening of the ETI following exercise could be accepted as a sign of fitness, that is, an indication of improved left ventricular function.

Ahmed et al.[50] investigated the relationships in normal and diseased hearts--pure mitral stenosis, cardiomyopathy, hypertensive heart disease, and aortic valve disease--between systolic time intervals and direct measurements of myocardial contractility obtained by invasive techniques. Among several parameters, they reported the following data on normal subjects (group I), pure mitral stenosis (group II), left ventricular disease, compensated (group III), and left ventricular dysfunction, decompensated (group IV)(see Table VII).

The ICP and the ratio TP/EP seemed to be more closely correlated with measures of contractility than with measures of performance. The research group concluded on the basis of all these data that "the non-invasive measurement of these intervals should provide a valid assessment of the contractile state of the left ventricular myocardium in man,

TABLE VII

MEAN VALUES OF SYSTOLIC TIME INTERVALS
FOR GROUPS AT REST

	I	II	III	IV
TP/EP	0.379	0.414	0.460	0.513
TP (msec)	107	109	122	141
EP (msec)	284	267	271	299

Source: S. Sultan Ahmed et al., "Systolic Time Intervals as Measures of the Contractile State of the Left Ventricular Myocardium in Man," Circulation, XLVI (1972), p. 569.

suitable for comparing patient or groups of patients in whom cardiac pathology is confined to the myocardium."[51]

Parasi et al.[52] concentrated their research efforts on determining the usefulness of the TP as an index to thyrotoxicosis. Hyperthyroidism, as the authors emphasized, is associated with certain hemodynamic changes such as increased oxygen consumption, heart rate, cardiac output, left ventricular ejection rate, and the rate of rise of left ventricular pressure.

According to the results of their study, patients with thyrotoxicosis showed a marked shortening of the TP which seemed to be caused by a decrease of the ICP.

In light of these findings as well as those obtained from serial observations, Parasi et al. concluded that this noninvasive method of determining systolic time intervals may have several unique advantages over other standard diagnostic methods. Among them, the authors believe, the time intervals may reveal clues to thyroid dysfunction when abnormal iodine loads, serum protein changes, or drug administration render routine laboratory methods useless.

In reference to the findings of Parasi et al., it might be appropriate at this point to review Karpman's and Kukolevskiy's[53] discussion of the phase syndrome of myocardial hypodynamia (diminished muscular power or energy) which is frequently observed in highly trained athletes (see also page 45).

Muscular work, emotional stress, and certain pathological conditions like high temperature or the thyrotoxicosis discussed above cause resistance loading (arterial tension, high blood pressure), resulting in compensatory hyperfunction which can be recognized by reinforced cardiac contractions.

The ICP, EP, and MS shorten in response to this reinforcement which the authors consider an essential part of the phase syndrome of myocardial hyperdynamia.

The increased strength of the myocardial contraction during this syndrome is due to the positive inotropy of nervous stimulation--release of catecholamines--acting on the myocardium. The same effect is achieved by the direct release of catecholamines into the blood stream.

However, when the power of the cardiac contraction is decreased and extracardiac conditions remain unchanged, an individual would exhibit the phase syndrome of hypodynamia, the ICP prolonged, the EP shortened, the MS sometimes shortened, and myocardial stress increased.

Insufficient filling of the ventricles will cause a so-called functional hypodynamia which can be observed during the Valsalva Maneuver or mitral stenosis.

In respect to very well conditioned individuals, the authors state:

> In highly trained athletes at rest, characteristic signs of the phase syndrome of myocardial hypodynamia are observed. Reinforced activity of the sympathetic-inhibitor mechanism and cholinergic influences, and increase in the central tone of the vagus nerve (V. Raab, 1959, 1963) lead to a reduction in the rate of intraventricular pressure rise and phase shift delays. Thus, the phase syndrome of myocardial hypodynamia develops in athletes as a result of changes in the regulation of cardiac activity related to the effects of systematic training, while in certain patients, similar phase shifts result from disruption of the contractability of the myocardium. This distinction is important: a change in regulatory action such as this provides high functional reserve of the myocardium.[54]

This selected review of established and contemporary research into cardiac dynamics seem to support the assumption that the left ventricular systolic time intervals, their changes, and ratios could be used to assess cardiovascular fitness. But since a number of investigations could not establish such relationships, further investigation to resolve these differences is necessary.

Maximum Oxygen Consumption

Numerous studies dealing with an individual's maximal oxygen capacity have reported sufficient evidence for its acceptance as a superior indicator of physical fitness. Buskirk and Taylor,[55] applying the laws of physics, defined the unit of measure ml/kg/min of oxygen as the amount of oxydative energy immediately available to the body to move one kg of its weight from one place to another.

However, the maximum oxygen uptake is not just a definition of work but an indicator of endurance. Wilmore[56] tested 30 male university students in this respect and was able to report a substantial relationship between maximum VO_2 and endurance capacity.

Looking at a different parameter, Costill[57] tested the Portland State College cross-country team and found that the maximum VO_2 uptake in ml/kg/min demonstrated a direct relationship to running performance. Costill, Thomason, and Roberts[58] reported in a later study that their results clearly demonstrated a close relationship between maximum VO_2 and performance in an endurance running event.

The same results, however, could not be obtained among highly trained athletes. The nine United States athletes selected for the 1968 Olympic Games, for example, showed no greater maximum VO_2 uptake than the other fifteen runners who did not qualify.[59]

Kearney and Burnes[60] also investigated the relationship between running performance and predicted maximum oxygen uptake. They tested divergent ability groups, ranging from normal untrained undergraduate college students to the varsity cross-country runners. The data of the investigation revealed that the predicted oxygen uptake-performance relationship decreased as a function of increasing performance capabilities and increased as a function of distance.

Astrand and Rodahl[61] surveyed a number of representative studies dealing with the effect of endurance training on the maximum oxygen capacity. After completion of the endurance training prescribed, the data indicated an improvement of the oxygen uptake ranging from 7% to 33%. After bed rest a decline was registered ranging from 17% to 31%. The magnitude of the increase or decrease was probably due to the initial training state of the individuals.

That heredity is not the only major determinant of an individual's VO_2 uptake was indirectly emphasized by the results cited above. Saltin et al.[62] underlined the same conclusion in the official journal of the American Heart Association by referring to the effects of various periods of training and detraining (bed rest) which they had investigated. According to their findings, it was clearly evident that the maximum VO_2 uptake can be altered over a wide range in normal subjects, within relatively short periods of time, by marked alterations in activity pattern.

The T Wave

According to Messerle[63] it was Kraus and Nicolai who first used the electrocardiogram for clinical diagnosis and the systematic study of various physiological and pathological conditions affecting the heart.

In the course of their investigations Kraus and Nicolai[64] found lower amplitudes of the T waves for the aged. Looking at the other side of the spectrum, they discovered to no surprise that the amplitudes of T waves taken from resting EKG's were higher for athletes than for untrained subjects. The authors concluded, therefore, that high T waves were indicators of good hearts.

Hexheimer[65] compared T waves of normal individuals with those of champion athletes. He reported that the amplitude of the T waves was higher in the latter group in 51% of all cases. On the basis of X-rays and recorded pulse waves, he concluded that the power of contraction of the heart (see also page 48) is higher in athletes and therefore responsible for the greater amplitude of the T waves.

Hoogerwerf[66] studied 260 athletes participating in the 1928 Olympics at Amsterdam. His data revealed very large T waves not only in the resting EKG's but also in the post-exercise recordings. Tuttle and Krons,[67] on the other hand, measured increases of T waves as the result of training in only 2 out of 48 athletes. Katz[68] and E. von Csinady[69] also claimed that there exists no relationship between the height of the T wave and the work capacity of the heart.

A more recent study[70] investigated athletic disciplines which could be grouped according to their aerobic or anaerobic characteristics. Both investigators found that athletes competing in the endurance-type events had, as a group, significantly larger T waves.

Karpman and Kukolevskiy[71] compared electrocardiographic data from Butschenko's[72] investigation of 528 athletes with those of 116 untrained subjects reported by Waquero et al.[73] They concluded that the T wave in monopolar chest leads as well as standard leads were significantly larger in athletes than in the untrained group.

✓ Cureton and Phillips[74] investigated the effect of training and detraining on various electrocardiographic and physiological variables. In the case of the T wave amplitude, they supported the findings of an earlier study[75] which showed an increase in amplitude with training and a corresponding decrease with detraining.

Yet, in spite of the supportive data, it should be pointed out that individual differences apparently cannot be determined on the basis of small variances in T wave amplitudes. However, there seems to be a general consensus that small T waves (2 mm) constitute low work capacity of the heart.[76]

The Rest/Work Ratio

Since well-conditioned athletes have longer cardiac cycles, lower heart rates, and longer diastole than untrained individuals, it is frequently assumed that the athlete's rest/work ratio is somewhat greater.[77]

Investigating physiological differences between variously conditioned groups, Cureton[78] included such an assumption in his research and analyzed data of three groups--track and field champions, swimming champions, and normal young males as control subjects. He could not, however, detect any significant difference among the three groups for the average work time as well as the rest period.

Resting Heart Rate

The heart rate can vary over a considerable range depending on a multitude of factors such as age, sex, body size, intensity of metabolic processes, level of daily motor activity, and physical fitness.[79] It is especially the latter influence upon the pulse frequency which is an aspect of this investigation.

The relationship between fitness and heart rate was briefly discussed in the previous chapter on page 19. The thoughts of Raab and others discussed there were probably the basis for the observations expressed by Karpman and Kukolevskiy[80] as follows:

> In athletes, due to their training, powerful cholinergic reactions are developed, one result of which is the negative chronotropic effect and, consequently, the decrease in pulse frequency. There is a definite relationship between the intensity of the negative chronotropic effect and the nature of the training. Athletes training for endurance . . . show particularly great decreases in pulse frequency. Their pulses vary between 30 and 66 beats per minute, while the mean value (according to the data of various authors) rarely exceeds 50 beats per minute. Athletes who have trained for speed do not show such a great decrease in pulse frequency (the range varies between 48 and 78 beats per minute).

The two authors considered the dynamics of cardiac rhythm to be a gauge for estimating the functional state of the athlete. Referring to the research of Letunov and Motylyanskaya[81] and others, they concluded that the pulse frequency of athletes is an indicator of fitness, or in their words, ". . . bradycardia observed in sportsmen indicates an 'economy' of the activity of the circulatory apparatus at rest."[82]

McCurdy[83] studied the lying pulse rate of actively walking newsboys, athletic boys, and a general sample of boys. Summarizing his data, he concluded that pulse rate for these post-pubescent boys was an indicator of fitness, i.e., high rate revealing poor and low rate good condition.

Dawson[84] tested the effect of training upon heart rate, and he reported that training slowed the resting rate by an average of 9 beats per minute.

Cotton[85] reported on champion swimmers who had a mean of 47.5 (range 40 to 53) beats per minute. His other data showed that normal young men averaged,

with slight athletic experience . . . . . . 66 beats per minute,

with some experience . . . . 63 beats per minute,

with average experience . . . . 57 beats per minute,

with relatively greater experience . . . . . 53 beats per minute

Olympic athletes . . . . 50 beats per minute,

and Olympic swimmers with an average of

ten years of training . . . . 47 beats per minute.

Costill[86] investigated the possibility of predicting performance of a 4.7 mile cross-country run by determining the relationship between 16 test items and running time. While the maximal oxygen uptake proved to be almost a perfect predictor, he stated that the average resting heart rate was lower for the better runners and appeared to be closely related to distance running performance.

Bloomfield and Sigerseth[87] supported the conclusion previously drawn that heart rate is an indicator of endurance by testing differences between the heart rate means of sprint and middle distance swimmers. The difference--lower rate for middle distance swimmers--was significant at the 0.01 level of confidence.

Taylor[88] divided 18 varsity wrestlers into two groups to test the effect of different training programs. One of the parameters was the resting pulse rate. He found at the end of the training period that the group following a strength-cardiovascular program had a significantly lower resting pulse rate ($P < 0.05$) in relation to the other group which followed a muscular endurance-interval training program.

In a kind of reverse approach, a number of studies[89] have shown that the heart rate increases considerably (rates up to 140 were reported) with variously restricted physical activity or with prolonged bed rest.

However, using heart rate as the sole predictor or evaluator of physical fitness can pose a problem. While low heart rates in the absence of any pathology signify good cardiovascular fitness, a "high" rate does not necessarily mean low fitness. As a case in point, one might look again at the pulse frequency range of the Russian sprinters mentioned in a previous quotation (see page 53) which was 48 to 78 beats per minute. If this range is compared with the average heart rate of 72 beats per minute of a normal untrained person, it can be seen that there exists a considerable overlap.

Nevertheless, the overwhelming evidence presents heart rate as a good indicator of cardiovascular fitness, especially when used with group averages.

Resting Blood Pressure

In a review of literature of early research on resting systolic blood pressure, Cureton[90] cited various authors whose findings led him to conclude that male athletes cannot be distinguished from nonathletes.

Yet, more recent research data seem to draw a somewhat more positive conclusion regarding the use of blood pressure as an indicator of physical fitness.

One might look at what Kraus and Raab[91] called "our super-civilized contemporaries, . . . referring exclusively to their physical habits as contrasted to those of a small athletic minority" with some primitive societies which are highly active physically. While the former show a steady increase in blood pressure as a "function" of age--this was the reason for the recently rejected formula for normal systolic pressure: 100 plus age--such blood pressure increases were not observed in primitive (physically fit) societies.[92, 93] The blood pressure even decreased with age, as Truswell et al.[94] reported on 15 to 83 year-old !Kung bushmen in northwestern Ngamiland, Botswana. Moreover, Kaminer and Lutz[95] found no correlation between blood pressure and weight-height ratio of the bushmen in the Kalahari Desert.

That physical activity might be indeed the major reason for lower pressure was supported by the well-known Tecumseh Community Health Study. Montoye et al.[96] studied 1700 males, age 16 and over, to compare their pressure readings with the results of a number of previous studies reporting on physical activity and blood pressure. They arrived at the following conclusion:

> In summary, most studies, including our own, indicate that active men have lower blood pressures than more sedentary people. In most previous studies, the number of cases have been too small to isolate the relationship of body fatness to blood pressures. From our analysis, physical activity and body fatness are clearly each related to blood pressure, the former inversely and the latter directly.

Other supportive studies come from Mellerovicz[97] reporting lower systolic and slightly higher diastolic pressures for sportsmen in comparison to the average population.

Taylor[98] tested active railroad switchmen and lean active clerks when they were first hired. The two groups showed no difference in blood pressure, yet with the passing years, the switchmen remaining active had lower pressure than the clerks. This study is especially important because it suggests that the differences found in later life were not due to selection.

The effect of physical training on blood pressure has also found the interest of numerous investigators. Brown et al.[99] studied the effect of eight weeks of pre-season training on university basketball players. The investigators found a 7.2 mm Hg drop of the diastolic pressure. Similar results were obtained by Buccola and Stone[100] who measured the effect of jogging and cycling programs on physiological and personality variables in aged men. Kasch[101] enlisted a group of men, 50 years and older, into a training program. He reported that the pressures decreased from an average of 155/103 to an average of 144/94. In another basketball study, Michael and Gallon[102] discovered a significant decrease in the systolic pressure, but no change in the resting diastole after the 16 weeks of training.

Resting Pulse Pressure

The pulse pressure is defined as the difference between the systolic and the diastolic blood pressures and can be described as an expression of the tone of the arterial walls. According to contemporary opinion, the normal pulse pressure should be about 40 with values over 50 or under 30 being considered abnormal.[103]

Cureton[104] stated that according to a number of studies high pulse pressure is seen frequently in athletes and is moderately correlated with endurance. However, a study of 55 marathon runners by Barach et al.[105] measured an average lying pulse pressure of only 30.3 before the race. Since low pulse pressures are not normal, they were interpreted to represent a semi-fatigued state brought about by hard training.

Cureton's own study[106] included 12 groups of various physical fitness classifications--endurance-running champions, college freshmen, and others. He found that the results confirmed his earlier statement, that some positive correlation between resting pulse pressure and endurance performances of various kinds exists.

Bloomfield's and Siegerseth's[107] study of sprint and middle-distance swimmers showed a small difference in pulse pressure, but that proved to be statistically insignificant.

According to a German study by Hollman,[108] the peak levels of systolic pressures revealed no difference during exercise between untrained and trained individuals, but the pulse pressures of the athletes were considerably increased over those of the less fit.

A multiple factor analysis was made of 104 cardiovascular test variables by Cureton and Sterling.[109] Of all the factors contributing most significantly to the complex area of cardiovascular fitness, the pulse pressure ranked third right after the oxygen requirement, giving these two variables added importance in fitness evaluations.

Schneider Index Test

To the resting pulse rate and systolic pressure, which have been discussed previously in relation to physical fitness, Schneider[110] added postural pressure changes--lying systolic minus standing systolic blood pressure--and recovery pulse rate for which many studies have reported positive correlations to fitness.[111, 112]

In an attempt to identify from 410 men those who had passed their flight physical, Scott[113] evaluated Crampton's Blood Ptosis Test and the Schneider Index Test. While the former failed to accomplish this task, the Schneider Test identified to a significant degree those who failed or passed the flight physical.

In a comprehensive review of analytical and normative studies dealing with the Schneider Test, Cureton et al.[114] summarized the research. They found that the best of three tests given under good conditions correlated 0.80 with an endurance criterion.

Vital Capacity

In a detailed historical review of the literature up to 1937 dealing with vital capacity (VC) as a test of fitness, Cureton[115] cited Hutchinson[116] as the pioneer in this area of research. Hutchinson summarized the results of his studies as early as 1846 by stating that VC is a strong indicator of fitness.

Numerous other studies that had investigated various aspects of VC as well as Cureton's[117] survey of swimmers at the 1936 Olympics in Berlin generally supported Hutchinson's conclusions. However, Gordon[118] detected no difference between the VC of marathon runners and average individuals, while Newman[119] reported no difference between middle distance runners and nonathletes.

These results contrast with those of Bloomfield and Siegerseth[120] who established a significantly higher VC in middle distance swimmers than in the sprint swimmers.

Wilmore et al.[121] found significant increases in VC as the result of a ten-week jogging program, while Carey[122] as well as Sessa and Vallario[123] recorded similar results showing significant increases in VC due to skin diving.

Mathews and Fox[124] stated that various lung volumes, among them VC, under resting conditions are larger in trained than in untrained men. They contributed this fact to superior pulmonary function and therefore larger lung volumes brought about by training.

Forced Expiratory Volume

Few investigations dealt with FEV_T in relation to physical fitness. However, Berglund et al.,[125] among others, had shown that the timed vital capacity (forced expiratory volume) began decreasing at age 35. Yet, Durusoy and Özgönül[126] emphasized at the XVIII World Congress of Sports Medicine that this decrease in pulmonary performance seems to be less a cause of age than one of decreasing fitness brought about by physical inactivity. The authors tested 26 soccer referees age 22 to 50 who were, with the exception of 16%, still in the normal range.

The FEV_T of this fit group of referees was also compared with the FEV_T of 200 healthy male nonathletes of the same age. The results indicated higher values for the athletes, the differences getting even larger among the older groups.

This report corroborates the results obtained by Grimby and Saltin[127] who found that forced expiratory volume in 1 second is higher in athletes than nonathletes.

Maximum Breathing Capacity

At the same World Congress of Sports Medicine mentioned above, Durusoy and Özgönül[128] in a review of recent literature, stated that most investigators found the maximum breathing capacity (MBC) to be significantly higher in athletes. In their own investigation of soccer referees, all of whom were former athletes, they detected higher MBC values for the athletes, especially in the 40-50 age group. All the data were corrected for age and body size.

Weight Residual

Anthropometrical observations are the mathematical factors in the determination of weight residual (Appendix D) used in the analysis of obesity in relation to fitness. A number of studies investigated the effect of various exercises on body weight and composition and reported significant decreases in body fat with concomitant increases in muscular mass.[129] Keys[130] summarized his research and stated in this respect that weight change promoted by physical exercise is mainly a function of the proportional changes of the two factors, muscular mass and body fat.

A number of studies supported this conclusion with data showing that exercise induces significant decreases in skinfold fat measurements and increases in limb circumferences or body density due to greater muscular mass.[131, 132]

The preceding discussion raises the question of whether the greater fitness of the leaner individuals is partially a result of low body fat, or whether low body fat is a result of fitness based on physical exercise.

Welch et al.[133] investigated the relationship of maximal VO_2 consumption to body composition and found that the effect of body mass on the oxygen consumption diminished with increasing work intensity. However, when maximal VO_2 was expressed in ml/kg/min, the effect of body fat was significant at the 0.01 level of confidence. The authors concluded that:

> . . . while fat may not have an effect on the absolute ability of the tissues to extract oxygen, it does have an effect on the relative circulatory capacity of the individual. The fact is obvious when one observes the limited capacity of obese individuals for prolonged strenuous work which involves lifting their bodies. This is because fat increases weight. . . .[134]

These speculations in regard to the excessive weight load were earlier shown to be true in an investigation by Miller and Blyth.[135] But according to Dempsey[136] as significant might be the dimension of the peripheral vascular bed which greatly influences the quantity of blood returning to the heart and thus, in case of obesity, reduces cardiac output.

Summary of Related Literature: Systolic Time Intervals

The review of established and contemporary literature concerning the left ventricular time intervals revealed two areas of interest--improved methodology and the use of the intervals for diagnostic as well as for physical fitness evaluations.

The analysis of the cardiac dynamic cycles--that is, the division of the systolic phase into the EP, TP, EML, ICP, and other intervals--was pioneered mainly by Hürthle, Schulz, Blumberger, Wiggers, Holldack, and Raab.

Blumberger concentrated his work mainly on establishing relationships between the time intervals and heart disease, i.e., to detect decreased myocardial efficiency by observing changes in TP and EP intervals.

While Tharp, Molnar, Montoye, and Homash could not establish any useful relationship between the various phases of the cardiac dynamic cycle and cardiovascular fitness, health, or cardiac disease, some trends or many positive relationships could be observed by numerous other investigators. The conflicting results necessitate further research on the parameters of the cardiac cycle and their relationship to cardiovascular fitness.

A short synopsis of the influences and effects of the individual systolic time intervals under investigation in this study is given below.

The Electromechanical Lag (EML)

1. The EML is influenced by and varies with filling pressure. With reduced filling pressure as in stenosis, the EML average is longer.

2. The EML has no significant correlation with heart rate (Lang, page 35).

3. The EML shortens as the result of physical training (Farday, page 41) .

4. The EML, ranging from 36 msec to 61 msec, was considered an indicator for healthy normals (Emmrich, Klepzig, and Reindell, page 34).

5. The EML ranged from 42 msec for athletes to 128 msec for cardiacs (Hyman, page 18).

The Isometric Contraction Period (ICP)

1. The ICP is influenced by the contractility of the myocardium, a decreased contractility increases the ICP. In aortic insufficiency, the ICP shortens (Holldack, page 33).

2. The ICP will shorten with increased venous return and prolonged ejection period (EP). The ICP will slightly lengthen when systole is

shortened because of increased arterial resistance--EP probably shortens (Holldack, page 33).

3. The ICP is prolonged in hypertension and reduced filling; however, it shortens with increased volume load (Emmrich, Klepzig, and Reindell, page 34).

4. The ICP revealed only a low negative correlation to heart rate (Lang, page 35).

5. The ICP was reduced in untrained and prolonged in trained individuals (Emmrich, Shkhatsabaya, page 39).

6. The ICP is prolonged as the result of physical training (Farday, Wiley, pages 40, 41).

7. The ICP indicates aortic insufficiency with 20 msec or less, 55 msec indicate damage to the left ventricle (Holldack, page 33).

8. The ICP in healthy normals is indicated by a range of 16 msec to 67 msec. It is prolonged in athletes (Emmrich, Klepzig, and Reindell, page 34).

The Tension Period (TP)

1. The TP at age 50 or above is frequently prolonged. It seems to be due to cardiac insufficiency, however (Lang, page 35).

2. The TP is longer in trained individuals averaging 97 msec to 106 msec. Untrained individuals averaged 82 msec to 93 msec. Millahn's averages were 82 msec as the lowest and 85 msec as the highest (Raab's survey, page 39).

3. The TP lengthened as the result of physical training (Farday, Wiley, pages 40, 41).

4. The TP up to 107 msec indicated healthy normals, but cardiacs registered averages ranging from 109 msec to 141 msec (Ahmed, page 45).

<u>The Ejection Period, EP/ICP, EP/TP, TP/EP, and ETI</u>

1. The EP/ICP ratio is an indication of myocardial contractility. The ratio has a good correlation with the ejection fraction ($r = 0.80$) after exercise (Aronow, page 45).

2. The EP/TP ratio for normals was given as 3.24 (Lang, page 35).

3. The TP/EP ratio, like the reciprocal above, seems to be a measure of contractility. A value of .379 was obtained for healthy normals and a range of .414 to .513 for cardiacs (Ahmed, page 45).

4. The EP has a linear negative correlation with heart rate (Lang, page 35).

5. The EP was used highly successfully in a diagnosis of cardiacs who were recognized if the time interval fell below one standard deviation of the regression line 376 -1.2 HR $\pm$ 12 sec (Spodick, page 42).

6. The EP was recorded at 89 msec to 131 msec for cardiacs with low ejection fraction (Armstrong, Lewis, and Gotsman, page 44).

7. The ejection time index (ETI) shortens for athletes after exercise, changes little for sedentary normals, and increases for unfit individuals (Whitsett and Naughton, page 45).

FOOTNOTES

[1]Johannes Emmrich, "Zur Frage der klinischen Bedeutung einer Unterteilung der Anspannungszeit des linken Ventrikels in Umformungszeit und Druckanstiegszeit" (unpub. M.D. dissertation, University of Freiburg, Germany, 1955), p. 1.

[2]K. Hürthle, "Beiträge zur Hamodynamiks," Pflügers Archiv für die gesamte Physiologie, XLXI (1891), pp. 29-104, quoted in V. L. Karpman and G. M. Kukolevskiy, eds., The Heart and Sports. Essays on Cardiology in Sports, tr. National Aeronautics and Space Administration (Washington, D. C., 1971), p. 20.

[3]Carl J. Wiggers, "Studies on the Consecutive Phases of the Cardiac Cycle," American Journal of Physiology, LVI (1921), pp. 439-459.

[4]Karljosef Blumberger, "Die Untersuchung der Dynamik des Herzens beim Menschen. Ihre Anwendung als Herzleistungsprüfung," Ergebnisse der Inneren Medizin und Kinderheilklinik, XLII (1942), p. 424.

[5]K. Holldack, "Die Bedeutung der 'Umformungs- und Druckanstiegszeit' für die Herzdynamik," Deutsches Archiv für klinische Medizin, IICC (1951), pp. 71-90.

[6]C. Robinson, G. Canby, and G. Draper, Deutsches Archiv für die klinische Medizin, C (1910), p. 347, quoted in Emmrich, p. 1.

[7]Wiggers, p. 459.

[8]Hanns Schulz, "Über die Bestimmungsmöglichkeit der Anspannungszeit des Herzens," Zeitschrift für Kreislaufforschung, XII (1937), pp. 427-434.

[9]Blumberger, pp. 424-531.

[10]Holldack, p. 71.

[11]Karpman and Kukolevskiy, p. 24.

[12]Holldack, pp. 71-90.

[13]W. R. Hess, Deutsches Archiv für klinische Medizin, CXXLII (1920), p. 69, quoted in Holldack, p. 73.

[14]Holldack, pp. 71-90.

[15]J. Emmrich, H. Klepzig, and H. Reindell, "Zur Frage der klinischen Unterteilung der Anspannungszeit des linken Ventrikels in Umformungszeit und Druckanstiegszeit," Archiv für Kreislaufforschung, XXIV (1956), pp. 177-204.

[16]Ibid., p. 202 (tr. H. Wohlert).

[17]H. Reindell and H. Klepzig, "Untersuchungen über die Anspannungs- und Austreibungszeit des Herzens bie Herzmuskelschädigung und bei veränderter Kreislaufregulation," Zeitschrift für Kreislaufforschung, XXXVIII (1949), p. 146.

[18]H. P. Millahn, "Die Kontraktionsphasen des jugendlichen Herzens und ihre Beziehung zur Hämodynamik," Zeitschrift für Kreislaufforschung, LIII (1964), pp. 179-187.

[19]E. Lang, "Einfluss der Pulsfrequenz auf die Kontraktionsphasen des Herzens," Zeitschrift für Kreislaufforschung, LIV (1965), pp. 479-487.

[20]W. Raab, "Exercise and Ischemic Heart Disease," Proceedings, Second National Conference on Cardiovascular Disease (Washington, D. C., 1964), pp. 356-357, quoted in H. J. Montoye et al., "Systolic Preejection Period: Relation to Habitual Physical Activity," Medicine and Science in Sports, IV (1972), p. 77.

[21]Albert S. Hyman, "The Q-First Heart Sound Interval in Athletes at Rest and After Exercise," Journal of Sports Medicine and Physical Fitness, IV (1964), pp. 199-203.

[22]Ibid., pp. 200-201.

[23]Emmrich, Klepzig, and Reindell, p. 177.

[24]K. Blumberger and S. Effert, quoted by Emmrich, Klepzig and Reindell, pp. 177-204.

[25]H. Maass, "Über ein Verfahren zur Messung der Anspannungszeit und Austreibungszeit beim Menschen," Zeitschrift für Kreislaufforschung, XXXVIII (1949), p. 228.

[26]Yu. K. Shkhavatsabaya, "Investigation of the Length of Phases of the Cardiac Cycle During Muscular Exercise," Kardiologiya, IV (1964), pp. 62-68.

[27]W. Raab et al., "Cardiac Adrenergic Preponderance Due to Lack of Physical Exercise and Its Pathogenic Implications," American Journal of Cardiology, V (1960), p. 300.

[28]W. Raab and H. J. Krzywanek, "Cardiovascular Sympathetic Tone and Stress Response Related to Personality Patterns and Exercise Habits. A Potential Cardiac Risk and Screening Test," American Journal of Cardiology, XVI (1965), p. 42.

[29]Raab et al., p. 300.

[30]Millahn, p. 178.

[31]Raab et al., pp. 300-320.

[32]Lang, pp. 479-487.

[33]Gerald Tharp, "Cardiac Function Tests as Indexes of Fitness," Research Quarterly, XL (1970), pp. 818-823.

[34]Jack Wiley, "Effects of 10 Weeks of Endurance Training on Left Ventricular Intervals," Journal of Sports Medicine, XI (1971), pp. 104-111.

[35]S. Molnar, "Relationship Between Cardiac Time Components, Maximal Oxygen Consumption and Endurance Performance" (unpub. Ph.D. dissertation, University of Illinois, 1970).

[36]Paul S. Fardy, "The Effects of Soccer Training and Detraining Upon Selected Cardiac and Metabolic Measures," Research Quarterly, XL (1969), pp. 502-509.

[37]Paul S. Fardy, "The Influence of Physical Activity on Selected Cardiac Cycle Time Components," Journal of Sports Medicine, XI (1971), pp. 227-233.

[38]Montoye et al., pp. 77-84.

[39]Joseph K. Perloff and Nathaniel Reichek, eds., "Value and Limitations of Systolic Time Intervals (Preejection Period and Ejection Time) in Patients with Acute Myocardial Infarction," Circulation, XV (1972), pp. 929-932.

[40]Priya S. Nandi and David Spodick, "Determination of Systolic Intervals Utilizing the Carotid First Derivative," American Heart Journal, XXCVI (1973), p. 495.

[41]D. H. Spodick, C. A. Dorr, and B. F. Calbrese, "Detection of Cardiac Abnormalities by Clinical Measurement of Left Ventricular Ejection Time," Journal of the American Medical Association, CCVI (1969), pp. 239-242.

[42]D. H. Spodick and S. Kumar, "Left Ventricular Ejection Period: Results in Normal Young Men and Comparison of Methods of Calculation," American Heart Journal, LXXVI (1968), pp. 70-73.

[43]Arnold Weissler, Robert Peeler, and Walter Roehll, "Relationships Between Left Ventricular Ejection Time, Stroke Volume, and Heart Rate in Normal Individuals and Patients With Cardiovascular Disease," American Heart Journal, LXII (1961), pp. 367-378.

[44]Benjamin Ricci, Physiological Basis of Human Performance (Philadelphia, 1967), pp. 106-107.

[45]Ibid., p. 107.

[46]W. Aronow, A. Bowyer, and M. Kaplan, "External Isovolumic Contraction Times and Left Ventricular Ejection Time/External Isovolumic Contraction Time Ratios at Rest and After Exercise in Coronary Heart Disease," Circulation, XLIII (1971), pp. 59-67.

[47]T. G. Armstrong, B. S. Lewis, and M. S. Gotsman, "Systolic Time Intervals in Constrictive Pericarditis and Severe Primary Myocardial Disease," American Heart Journal, XXCV (1973), pp. 6-12.

[48]Paul Hamosh et al., "Systolic Interval and Left Ventricular Function in Acute Myocardial Infarction," Circulation, XLV (1972), pp. 375-380.

[49]Thomas L. Whitsett and John Naughton, "The Effect of Exercise on Systolic Time Intervals in Sedentary and Active Individuals and Rehabilitated Patients With Heart Disease," The American Journal of Cardiology, XXVII (1971), pp. 352-358.

[50]S. Sultan Ahmed et al., "Systolic Time Intervals as Measures of the Contractile State of the Left Ventricular Myocardium in Man," Circulation, XLVI (1972), pp. 559-571.

[51]Ibid., p. 569.

[52]Alfred F. Parisi et al., "The Short Cardiac Pre-Ejection Period, an Index to Thyrotoxicosis," Circulation, XLIV (1974), pp. 900-904.

[53]Karpman and Kukolevskiy, pp. 24-25.

[54]Ibid., p. 25.

[55]E. Buskirk and H. L. Taylor, Journal for Applied Physiology, XI (1957), p. 72, quoted in A. Ryan and F. Allman, Jr., eds., Sports Medicine (New York, 1974), p. 527.

[56]J. H. Wilmore, "Maximal Oxygen Intake and Its Relationship to Endurance Capacity on a Bicycle Ergometer," Research Quarterly, XL (1969), pp. 203-210.

[57]David L. Costill, "The Relationship Between Selected Physiological Variables and Distance Performance," Medicine and Science in Sports, VII (1967), pp. 61-66.

[58]D. Costill, H. Thomason, and E. Roberts, "Fractional Utilization of the Aerobic Capacity During Distance Running," Medicine and Science in Sports, V (1973), pp. 248-252.

[59]J. Daniels, "Aerobic and Anaerobic Performance Characteristics of Champion Runners at Sea Level and Moderate Altitude" (unpub. Ph.D. dissertation, University of Wisconsin, 1969).

[60]Jay T. Kearney and William C. Byrnes, "Relationship Between Running Performance and Predicted Maximum Oxygen Uptake Among Divergent Ability Groups," Research Quarterly, XLV (1974), pp. 9-15.

[61]P. O. Astrand and K. Rodahl, Textbook of Work Physiology (New York, 1970), quoted in Ryan and Allman, p. 528.

[62]B. Saltin et al., "Response to Exercise After Bed Rest and After Training," Circulation, XXXVIII (1968), No. 5 (Supplement VII), pp. 48-50.

[63]N. Messerle, "Die Veränderung im Elektrokardiogramm bei Körperarbeit," Zeitschrift für die gesamte Experimentelle Medizin, LX (1928), pp. 490-501.

[64]F. Kraus and G. Nicolai, Das Elektrokardiogramm (Leipzig, 1910), quoted in Messerle, p. 491.

[65]H. Hexheimer, *Zeitschrift für klinische Medizin* (1923), p. 484, quoted in Messerle, p. 498.

[66]S. Hoogerwerf, "Elektrokardiographische Untersuchungen der Amsterdamer Olympiade Kämpfer," *Arbeitsphysiologie*, II (1929), pp. 61-76.

[67]W. W. Tuttle and H. M. Korns, "Electrocardiographic Observations on Athletes Before and After Season of Physical Training," *American Heart Journal*, XXI (1941), pp. 104-107.

[68]L. N. Katz, *Electrocardiography*, 2nd ed. (Philadelphia, 1947), p. 80.

[69]E. von Csinady, "Sportärztliche Untersuchungen, III. Mitteilung: vergleichende elektrokardiographische Untersuchungen an Sporttreibenden bei besonderer Berücksichtigung der EKG-Zeitwerte," *Arbeitsphysiologie*, III (1930), pp. 579-595.

[70]J. Bloomfield and P. Sigerseth, "Anatomical and Physiological Differences Between Sprint and Middle Distance Swimmers at the University Level," *Journal of Sports Medicine*, V (1965), pp. 76-81.

[71]Karpman and Kukolevskiy, pp. 117-119.

[72]L. A. Butschenko, *Elektrokardiografiya v Sportivnoy Meditsine* (Leningrad, 1963), quoted in Karpman and Kukolevskiy, p. 119.

[73]M. Waquero, R. Limon, and A. Limon (1947), quoted in Karpman and Kukolevskiy, p. 119.

[74]T. K. Cureton and E. E. Phillips, "Physiological Fitness Changes in Middle-Aged Men Attributable to Equal Eight-Week Periods of Training, Non-Training and Re-Training," *Journal of Sports Medicine*, IV (1964),

[75]T. K. Cureton, "Effects of Longitudinal Physical Training on the Amplitude of the Highest Precordial T-Wave of the ECG," *Medicina Sportiva*, XII (1958), pp. 259-281.

[76]T. K. Cureton, *Physical Fitness of Champion Athletes* (Illinois, 1951), p. 142.

[77]H. Kraus and W. Raab, *Hypokinetic Disease* (Springfield, 1961), p. 68.

[78]Cureton, Physical Fitness of Champion Athletes, p. 226.

[79]Karpman and Kukolevskiy, pp. 3-6.

[80]Ibid., p. 4.

[81]S. P. Letunov and R. Ye. Motylyanskaya (1951), quoted in Karpman and Kukolevskiy, p. 6.

[82]Karpman and Kukolevskiy, p. 6.

[83]J. H. McCurdy, "Adolescent Changes in Heart Rate and Blood Pressure," American Physical Education Review, XV (1910), p. 421.

[84]P. M. Dawson, "Effect of Physical Training and Practice on the Pulse Rate and Blood Pressure During Activity and During Rest, With a Note on Certain Acute Infections and on the Distress Resulting From Exercise," American Journal of Physiology, XL (1917), p. 443.

[85]F. S. Cotton, "The Relation of Athletic Status to the Pulse Rate, in Men and Women," Journal of Physiology, LXXVI (1932), pp. 39-51.

[86]A. D. I. Costill, "The Relationship Between Selected Physiological Variables and Distance Running Performance," Journal of Sports Medicine, Vol. 5 (June, 1965), pp. 76-81.

[87]Bloomfield and Sigerseth, p. 79.

[88]A. W. Taylor, "A Physiological Analysis of the Effects of Two Training Programs," Journal of Sports Medicine, XI (1971), pp. 252-256.

[89]Kraus and Raab, pp. 68-74.

[90]T. K. Cureton, Physical Fitness Appraisal and Guidance (Illinois, 1951), p. 199.

[91]Kraus and Raab, p. 69.

[92]F. H. Epstein and R. D. Eckhoff, "Epidemiology of High Blood Pressure--Geographic Distributions and Etiological Factors," The Epidemiology of Hypertension, ed. J. Stamler and R. Stamler (New York, 1967), pp. 155-166.

[93]B. Kaminer and W. P. Lutz, "Blood Pressure in Bushmen of the Kalahari Desert," Circulation, XXII (1960), pp. 289-295.

[94]A. S. Truswell et al., "Blood Pressures of !Kung Bushmen in Northern Botswana," American Heart Journal, XXCIV (1972), pp. 5-12.

[95]Kaminer and Lutz, p. 293.

[96]H. J. Montoye et al., "Habitual Physical Activity and Blood Pressure," Medicine and Science in Sports, IV (1972), pp. 175-181.

[97]H. Mellerowicz, "Vergleichende Untersuchungen über das Oekonomieprinzip in Arbeit und Leistung des trainierten Kreislaufs und seine Bedeutung für die rehabilitative Medizin," Archiv für Kreislaufforschung, XXIV (1956), pp. 70-176.

[98]H. L. Taylor, "Occupational Factors in the Study of Coronary Heart Disease and Physical Activity," Canadian Medical Association Journal, XCVI (1956), pp. 825-831.

[99]B. S. Brown et al., "Physiological and Hematological Changes Among Basketball Players During Preseason," Research Quarterly, XL (1974), pp. 257-262.

[100]V. A. Buccola and W. J. Stone, "Effects of Jogging and Cycling Programs on Physiological and Personality Variables in Aged Men," Research Quarterly, XLVI (1975), pp. 134-139.

[101]F. Kasch, cited in K. H. Cooper, Aerobics (New York, 1968), p. 131.

[102]E. D. Michael, Jr. and A. J. Gallon, "Pulse Wave and Pressure Changes Occurring During a Physical Training Program," Research Quarterly, XXXI (1959), pp. 43-60.

[103]"Pulse pressure," Taber's Cyclopedic Medical Dictionary, 12th ed.

[104]Cureton, Physical Fitness Appraisal and Guidance, p. 204.

[105]J. H. Barach et al., "Physiological and Pathological Effects of Severe Exertion," American Physical Education Review, XVI (1911), pp. 262, 325.

[106]Cureton, Physical Fitness Appraisal and Guidance, p. 205.

[107]John Bloomfield and Peter O. Sigerseth, "Anatomical and Physiological Differences between Sprint and Middle Distance Swimmers at the University Level," Journal of Sports Medicine, V (1965), pp. 76-81.

[108]W. Hollmann, Der Arbeits- und Trainingseinfluss auf Kreislauf und Atmung (Darmstadt, 1959), quoted in Kraus and Raab, p. 68.

[109]T. K. Cureton and L. F. Sterling, "Factor Analysis of Cardiovascular Test Variables," The Journal of Sports Medicine and Physical Fitness, IV (1964), pp. 1-24.

[110]E. C. Schneider, "A Cardiovascular Rating as a Measure of Physical Fatigue and Efficiency," Journal of the American Medical Association, LII (1920), p. 1507.

[111]H. Montoye, "Inter-Relation of Maximum Pulse Rate During Moderate Exercise, Recovery Pulse Rate, and Post-Exercise Blood Lactate," Research Quarterly, XXIV (1953), pp. 453-458.

[112]B. Karpovich, Physiology of Muscular Activity (Philadelphia, 1965), pp. 163-178.

[113]V. T. Scott, "The Application of Certain Physical Efficiency Tests," Journal of the American Medical Association, LXXVI (1921), p. 705.

[114]Cureton, Physical Fitness of Champion Athletes, p. 263.

[115]Cureton, Physical Fitness Appraisal and Guidance, p. 334.

[116]John Hutchinson, Transactions of the Royal Medico-Society of London (1846), p. 137, quoted in Cureton, Physical Fitness Appraisal and Guidance, p. 334.

[117]Cureton, Physical Fitness Appraisal and Guidance, p. 336.

[118]B. Gordon, S. A. Levine, and A. Wilmaers, "Observations on a Group of Marathon Runners," Archive of Internal Medicine, XXXIII (1924), pp. 425-434.

[119]F. Newman, B. F. Smelley, and M. L. Thomson, "A Comparison Between Body Size and Lung Function of Swimmers and Normal School Children," Journal of Physiology, CLVI (1961), pp. 9-10.

[120]Bloomfield and Sigerseth, p. 79.

[121]Jack H. Wilmore et al., "Physiological Alterations Resulting from a 10-Week Program of Jogging," Medicine and Science in Sports, II (1970), pp. 7-14.

[122]C. R. Carey, K. E. Schaeffer, and H. J. Alvis, "Effects of Skin Diving on Lung Volumes," Journal of Applied Physiology, VIII (1955), pp. 519-523.

[123]T. Sessa and D. Vallario, Medicina dello Sport, II (Roma, 1964), reviewed in Journal of Sports Medicine, V (1965), p. 43.

[124]Donald K. Mathews and Edward L. Fox, The Physiological Basis of Physical Education and Athletics (Philadelphia, 1971), p. 133.

[125]E. Berglund et al., "Spirometric Studies in Normal Subjects. I. Forced Expirograms in Subjects between 7 and 70 Years of Age," Acta Med. Scandinavica, XXXVIII (1963), pp. 173, 185.

[126]F. Durusoy and H. Özgönül, "Lung Function Studies on Former Athletes Who Are Now Football Referees," Journal of Sports Medicine, II (1971), pp. 139-145.

[127]G. Grimby and B. Saltin, "Physiological Analysis of Physically Well-Trained Middle-Aged and Old Athletes," Acta Med. Scandinavica, XLIII (1966), pp. 179, 513.

[128]Durusoy and Özgönül, p. 144.

[129]Jerry A. Dempsey, "Anthropometrical Observations on Obese and Nonobese Young Men Undergoing a Program of Vigorous Physical Exercise," Research Quarterly, XXXV (1964), pp. 275-287.

[130]A. Keys, "Body Composition and Its Change with Age and Diet," Weight Control (Colloquium Presentation, Ames, Iowa, 1955), quoted in Dempsey, p. 275.

[131]R. A. Boileau et al., "Body Composition Changes in Obese and Lean Men during Physical Conditioning," Medicine and Science in Sports, III (1971), pp. 183-189.

[132]C. W. Thompson, E. R. Buskirk, and R. F. Goldman, "Changes in Body Fat Estimated from Skinfold Measures of College Basketball and Hockey Players during a Season," Research Quarterly, XXVII (1956), pp. 418-430.

[133]B. E. Welch et al., "Relationship of Maximal Oxygen Consumption to Various Components of Body Composition," Journal of Applied Physiology, XII (1958), pp. 395-398.

[134]Ibid., p. 398.

[135]A. T. Miller and C. S. Blyth, "Influences of Body Type and Body Fat Content on the Metabolic Cost of Work," Journal of Applied Physiology, VIII (1955), pp. 139-141.

[136]Jerry A. Dempsey, "Relationship between Obesity and Treadmill Performance in Sedentary and Active Young Men," Research Quarterly, XXXV (1964), p. 295.

CHAPTER III

METHODS AND PROCEDURES

This chapter deals with the methods and procedures employed to obtain the data on the parameters of the left ventricular cardiac dynamic cycle and fitness variables as well as with selected studies supporting the use of these methods.

Subjects

Records on 100 subjects were obtained and evaluated. However, only 41 of the records were used and the rest deleted because the parameters of the cardiac cycles could not be accurately measured. All subjects were volunteers in an annual physical fitness evaluation program which was expanded in 1974 to include measurements for the establishment of the left ventricular time components. The subjects were for the most part regular participants in physical activities, consisting mainly of jogging, swimming, and raquetball at the university physical education center.

Research Equipment

The following equipment was utilized in the data collection:

1. Birtcher Electrocardiograph. A machine which records the electrical impulses emanating from the heart and measurable on the surface of the body. (Model No. 335, Medical Specialty Company, Fort Worth, Texas.)

The main purpose of this machine was to provide a recording from which the various measurements of the electrocardiogram were taken.

2. Physiograph. An apparatus which records physiological functions (e.g., blood pressure, electrocardiogram, phonocardiogram, carotid pulse wave) which can be picked up as mechanical movements or electrical impulses (Figure 8). (Type PMP-4A-Six channels, Narco Bio-System, Houston, Texas.)

3. Transmitter and Electrodes (bi-polar). Minutarized equipment which can be easily attached with adhesive to the skin of the body and can be comfortably worn during most exercises. The electrodes pick up the changing electrical potential of the heart at the body surface, and the transmitter relays these impulses by radio waves to a receiver.

4. Heart Sound Microphone. A device which picks up the mechanical vibrations of the heart sound and converts the signal into an electrical impulse which is then fed into a preamplifier. (Part No. 705-0016, Narco Bio-System, Houston, Texas.)

5. Preamplifier. An additional electronics circuit which amplifies the weak signal from the heart sound microphone to the required level of the physiograph amplifier. (Narco Bio-System, Houston, Texas.)

6. Radio Receiver. An FM receiver which is used with the telemetric equipment. It picks up heart signals from the wireless transmitter and feeds the signal by cable to the physiograph amplifier. (Model F.M.-1100; Narco Bio-System, Houston, Texas.)

7. Strain Gage Pressure Transducer. A device which measures changes in flow of a fluid but is also responsive to changes in air pressure. It is connected directly to a plastic funnel (largest diameter 1 cm, see Figure 9). A small hole was drilled into the funnel so that

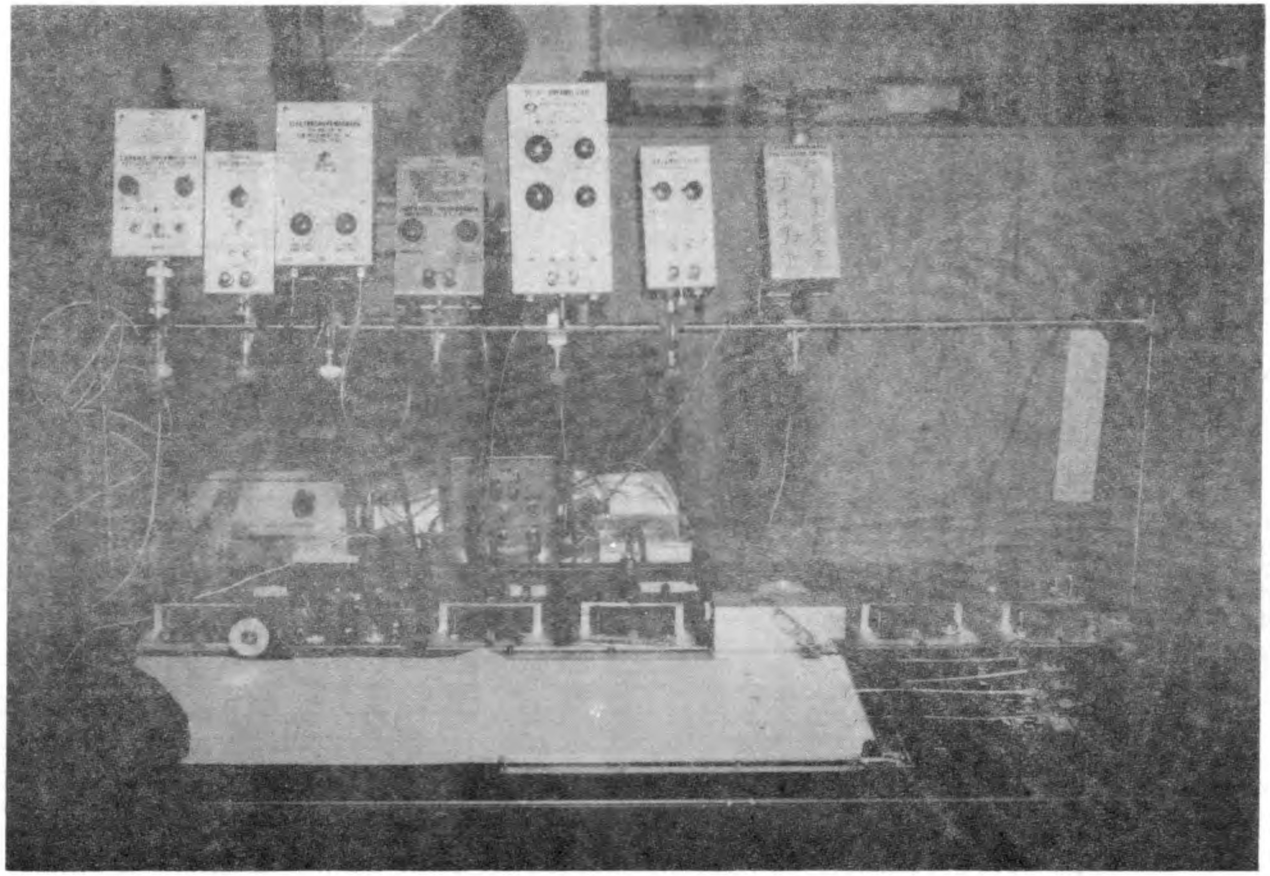


Figure 8. Six Channel Physiograph

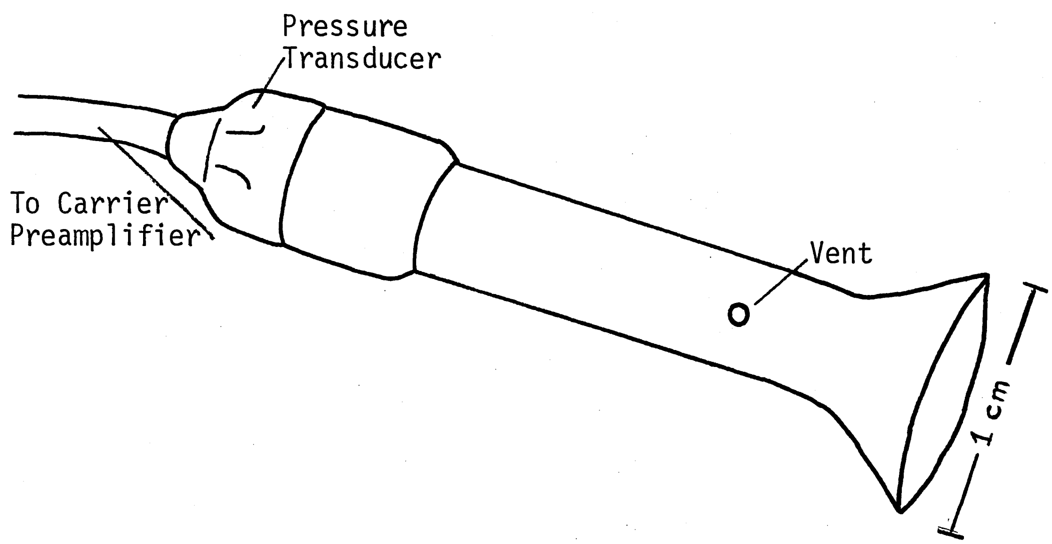


Figure 9. Recording Device for the Indirect Carotid Pulse Wave. The Air Pressure Changes Produced in the Funnel by the Pulsating Blood in the Carotid Artery are Changed by the Strain Gage Pressure Transducer Into Small Electrical Pulses Which are Fed Into a Carrier Preamplifier of the Physiograph

the air pressure could be equalized when the device was placed over the carotid artery. It provided most satisfactory recordings of the indirect carotid pulse wave. (Part No. 700-1010, Narco Bio-System, Houston, Texas.)

8. Occluding Cuff. A pneumatic cuff which contains a microphone for automatic recordings of blood pressures on a physiograph. (Part No. 712-0016, Narco Bio-System, Houston, Texas.)

9. Quinton Motorized Treadmill. A machine which has a moving belt which can be made to run at various speeds and inclinations for desired work loads. (Model 642; Speed Range 1.5-25 mph; Elevation [percent grade] 0-4.0; Seattle, Washington.)

10. Lange Skinfold Caliper. An instrument which is used to measure the thickness of skinfolds to estimate percent of body fat. (Part No. 3,008,329, Cambridge Scientific Industries, Inc., Cambridge, Maryland.)

11. Large Two-Way Breathing Valve. A device which enables the subjects to take in atmospheric air and then to expire the air into a Tissot Tank for measurement. (Model Triple "J" Valve; Warren E. Collins, Inc., Boston, Mass.)

12. Tissot Tank. A large stainless steel tank which is used for collecting and measuring the volume of expired air. (Capacity, 120 liters [0-720 mm], Serial No. 1440; Warren E. Collins, Inc., Boston, Mass.)

13. Collins 9 Liter Respirometer. An apparatus which consists of a tank, various valves, and an automatic recording system and which is used to measure various respiratory functions. (Serial No. 2555; Warren E. Collins, Inc., Boston, Mass.)

14. Barometer, Stopwatch, Weight Scale, Yard Stick. These instruments were used for the various tests described below when their obvious functions were part of any method used for data collection.

Selected Variables of Physical Fitness

The series of tests was administered Mondays through Fridays between 9:00 A.M. and 3:00 P.M. in the 23°C temperature-controlled physiological work laboratory in the Colvin Physical Education Center at Oklahoma State University. The subjects were notified at least 24 hours ahead of the testing date and were requested to avoid heavy meals as well as strenuous activities on the test day.[1] They were also advised not to eat at all for at least two hours preceding the tests.

The data for the selected variables were obtained by the methods and testing procedures discussed below.

T Wave Amplitude and Rest/Work Ratio

These variables were taken from the recording made with the Birtcher electrocardiograph machine.

The subject was requested to lie down and rest before the electrodes were coated with electrode-paste and then attached for the standard three-lead recording to the right arm, the left arm, the left leg, and the right leg. This arrangement was coded as follows:

Lead I - a connection between the right arm and the left arm;

Lead II - a connection between the right arm and the left leg; and

Lead III - a connection between the left arm and the left leg.

The fourth electrode to the right leg provided a connection to ground.

The T wave amplitudes and the rest/work ratios were measured with vernier calipers in accordance with the method described by Cureton,[2] who averaged the measurements for the amplitudes taken from the lead which showed the highest deflection--generally Lead II in this study. Investigating the chance variations of the T wave amplitudes in single leads, the University of Illinois Physical Fitness Research Laboratory supported the use of the averaged amplitudes with high reliability coefficients. For Lead II, for example, they reported a reliability coefficient of 0.849 for their T wave amplitude measurements.[3] Therefore, the data obtained in this study can be considered reliable, although it is well known that the T wave amplitudes can vary considerably not only among individuals but also between leads of a single subject.[4, 5]

As mentioned above, the data for the rest/work ratio were taken from the same EKG recording. Rest, the numerator of this quotient, is simply the resting period of one cardiac cycle which extends from the end of the T wave to the end of the QRS complex. The denominator, on the other hand, is the average work time of the heart; that is, the contraction of the ventricles also called mechanical systole. It is represented by the ST segment of the cardiac cycle (see Figure 1).

Variables Recorded With the Physiograph

The physiograph machine was employed to record the resting as well as the post-exercise left ventricular time components discussed in detail on pages 10-13, the maximum oxygen uptake, the resting heart rate, resting blood pressure, resting pulse pressure, and the various indexes for the Schneider Index Test.

Parameters of the Cardiac Dynamic Cycle. The resting left ventricular time components were obtained from the simultaneous recording of the indirect carotid pulse wave, the electrocardiogram, and the phonocardiogram. The systolic time intervals were measured with a needlepoint caliper according to the analysis of the intervals discussed on pages 10 to 13 and graphically presented in Figure 4.

After the electrodes of the Birtcher electrocardiograph machine were removed, the subject remained in the supine position, and the most advantageous placement for the heart sound microphone was determined by the highest deflections obtained for the S_1 and S_2 sounds. Then the microphone was attached with a rubber strap and connected to the amplifier of the physiograph (Figure 8). After the skin was cleaned with specially impregnated towelettes (Medi Pak, Alcohol Prep), the telemetry transmitter and bipolar electrodes were attached with adhesive paper (Figure 10). For better conduction, the electrodes were coated with electrodepaste, and some horn layer of the skin was removed by vigorous rubbing with paper towels. The transmitter was attached in any convenient position, while one electrode was placed two inches below and two inches to the left (lateral side) of the left nipple, and the other electrode was placed over the middle of the sternum. The receiver was then tuned to the appropriate frequency to receive the transmitted signal. The paper speed was set to 5 cm/sec on the physiograph.

It proved to be advantageous to allow the researcher handling the carotid pulse wave pickup to see the recording in progress, so he could adjust the pressure on the artery to obtain the best wave form.

The procedure was essentially repeated after the maximum oxygen uptake test to obtain the post-exercise left ventricular time intervals.

Figure 10. The Bipolar Electrodes and the Telemetry Transmitter are Attached to the Subject and Connected to Each Other. The Cardiac Microphone is Held in Place by a Rubber Strap. The Carotid Pulse Wave Pickup is Pressed by the Researcher Against the Carotid Artery. The Microphone of the Blood Pressure Cuff as Well as the Air Hose are Connected to a Preamplifier and Pneumatic Pump, Respectively.

The subject had to lie down immediately after the treadmill exercise and the parameters were recorded for at least ten consecutive measurements at one-minute intervals. The first recording was taken at one minute after exercise; however, only the one and five-minute data were evaluated.

Maximum Oxygen Uptake. The treadmill test for the maximum oxygen uptake was actually the last one to be given because the high physical stress of the treadmill walk would have invalidated many of the other variables which had still to be recorded.

The maximum oxygen uptake was predicted by using the treadmill exercise protocol designed by Balke and Ware.[6] After receiving instructions about boarding the moving treadmill, the subjects walked at 3.4 mph at level grade, i.e., at 0% of incline until he achieved a steady gait without holding onto the rails. The incline was then raised 2% (for every distance of 200 ft, the subjects walked up 2 ft) and at each minute thereafter 1% until the heart rate reached 180 beats per minute. At that point the subjects should have reached their maximum aerobic capacity according to the Balke protocol. The treadmill time in minutes--equals also per cent of incline--is then converted on a nomogram to maximum oxygen uptake in ml/kg/min (see Appendix A).

The limiting factor of maximal work is the maximum oxygen consumption, a synonymous term for oxygen uptake or intake (max VO_2). This cardiovascular endurance factor is also called aerobic (with air, however, referring to oxygen) capacity, which many exercise physiologists consider to be the best indicator of cardiovascular fitness.[7, 8, 9]

The oxygen uptake is usually expressed in liters per minute (l/min) or in milliliters per kilogram per minute (ml/kg/min). These measuring units would indicate the amount of oxygen which an individual has to use per minute per kilogram of his body weight to be able to continue his work at the same level for extended periods of time. At the moment when the work load increases to the point where the body's oxygen consumption exceeds the quantity which the combined respiratory and cardiovascular system can transport to the muscles, the work is performed anaerobically (without air) and the ensuring oxygen debt would incapacitate the individual rapidly if he could drive himself to continue to work at that level for more than a minute.

The theoretical limit of maximal oxygen uptake was calculated by Hill[10] to be 5.5 liters per minute. This particular unit of measurement is also used to assess the working capacity of individuals. A number of studies have, however, since reported that this unit of measurement has only a very low correlation to physical fitness.[11, 12] Knuttgen,[13] among others, has shown that there exists a high correlation between aerobic capacity and body size (either weight or height) which could give an unrealistically high uptake for even less conditioned but large individuals.

The treadmill test was selected for this study because it is submaximal, reasonably valid, and efficient.

A submaximal fitness test is, of course, most advantageous for the evaluation of individuals whose condition has frequently yet to be determined. It assures the safety of the subject to a high degree because he is taken gradually to the limit of his aerobic capacity. In cases where subjects complained of considerable physical discomfort, the test was promptly terminated and the maximum possible treadmill time was estimated. The test was also prematurely terminated when the EKG indicated ST depressions or strong arrhythmias as well as with older individuals whose heart rate peaked below 180 beats per minute.

In terms of efficiency, the standard Balke test is, no doubt, a compromise. There are numerous other tests available which are either less time-consuming, but less accurate in their max VO_2 assessment, or are more accurate but time-consuming and difficult to administer. Newton,[14] for example, compared the accuracy of the max VO_2 assessment of the:

1. Cureton Test, which is an "all-out run" on a motor-driven treadmill at 10 mph on a grade of 8.6% with gas analysis of expired air samples.

2. Bicycle Ergometer Test, which is an exercise where the load is adjusted to exhaust the subject within five minutes. Samples of expired air are also analyzed.

3. Treadmill Run Test, which is an exercise where the speed and grade are adjusted to exhaust the subject within three to five minutes. Expired air samples are also analyzed.

4. Standard Balke Test, which is the same test used in this study.

The results indicated the superiority of the Balke and the standard treadmill run test; both showed the highest maximal oxygen consumption.

The Cureton test was considered too short in duration because the initial lag in oxygen intake (at the start an individual performs aerobically) does not enter into the calculation of the oxygen consumption.

The bicycle test, on the other hand, is suitable mainly for individuals with well-developed leg strength. Most subjects are not able to obtain their maximal oxygen uptake before their leg muscles are fatigued to exhaustion.

The Balke test and the treadmill run test were considered to incorporate more realistic work rates and sufficient time to allow the individual to reach his maximal uptake. The Balke test was also cited for its constant moderate speed and increasing grade which allowed a light starting load suitable for old and/or unfit subjects.

The possibility for a highly accurate assessment of the max VO_2 intake has been the center of considerable debate.

Froelicher and Thompson,[15] for example, tested 80 subjects with comparable physical parameters and activity habits. Using the Balke test, they reported a correlation coefficient of +0.87 when regressing max VO_2 against the duration of the exercise. (This duration is converted to oxygen uptake from a nomogram.)

In another study, Froelicher and Thompson[16] observed that the duration of exercise can increase with the number of times an individual is treadmill tested without an increase in max VO_2. Similar findings about test learning were reported by McHenry et al.[17]

Froelicher and Lancaster[18] tested over 1000 normal males in a comparison of the Balke and the Bruce protocol of estimating max VO_2. They concluded that maximal performance time by these protocols can only grossly predict maximal oxygen consumption. However, it should be pointed out that these conclusions were drawn in respect to the use of these protocols as the most appropriate tool for assessing max VO_2 for clinical purposes. An $r = 0.87$ can in most cases be considered a valid estimator of max VO_2 in cardiovascular fitness testing.

The validity of using the 180 heart rate response to measure aerobic capacity was tested among others by Nagle and Bedecki.[19] Testing by the

Balke protocol, they reported an $r = 0.85$ upon which they concluded that the heart rate of 180 serves as a valid cut-off point in estimating max VO_2.

The difference in opinion about the validity of the Balke protocol is based, as previously mentioned, on the use of the maximum oxygen consumption estimate. Nagle and Bedecki, for example, considered the estimate in the light of physical fitness and concluded that it is a valid indicator of physical endurance or cardiovascular fitness. There exists a wealth of studies--a selection was discussed in Chapter II--which came to the same conclusion.

Resting Heart Rate. The pulse frequency or so-called heart rate was taken with the subject in the reclining position. Because of the various psychological stress factors--unfamiliar surroundings, anxiety because of the testing situation, etc.--the rate was usually at first quite elevated.[20] It was, however, possible to have the subjects relax so that their heart rates generally decreased and stabilized. The measurements were taken thereafter from the telemetric EKG which was recorded continuously throughout all cardiovascular tests. The data can be considered sufficiently reliable according to a study by Sime et al.[21] on the reproducibility of heart rate at rest.

Resting Blood and Pulse Pressure. The procedural problems of obtaining reliable blood pressure readings paralleled those already discussed in the description of the heart rate recordings. However, the initial resting or relaxation period after the arrival of the subject usually stabilized not only the heart rate, but concomitantly in most cases also the blood pressure readings which were taken at regular intervals for five or more measurements (Figure 11).

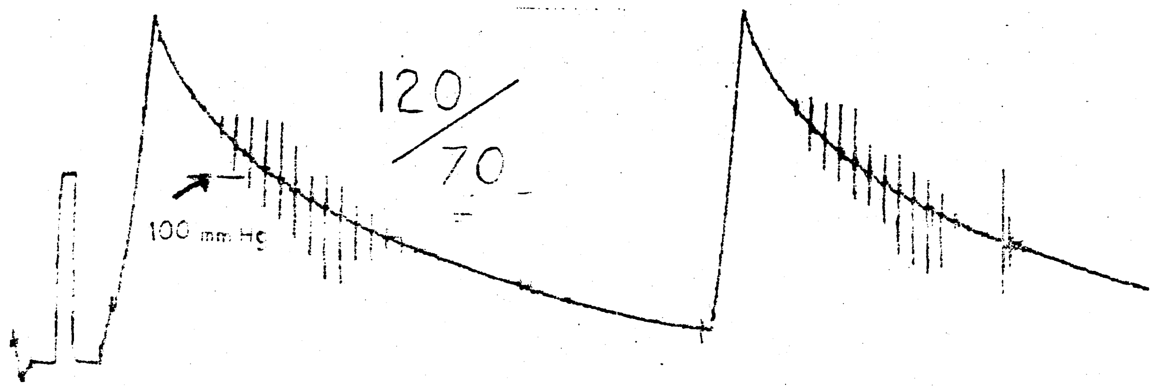


Figure 11. Blood Pressure Recorded Automatically With the Pneumatic Cuff. The Base Line was Calibrated for 100 mm of Hg and Each Square is Therefore 20 mm of Hg

The pneumatic blood pressure cuff which was operated automatically or semi-automatically according to the convenience of the operator was fastened over the right brachial artery of the subject.

The recorded data of the diastolic and systolic pressures were used in the computer program to calculate the difference between them which was recorded as the resting pulse pressure.

<u>Schneider Index Test</u>. After the resting heart rate and blood pressure readings had been recorded, the same data were also used for the Schneider Index Test which, as a guide to an evaluation of fitness, employed the following factors:

1. Lying pulse rate,
2. Lying systolic pressure,
3. Standing pulse rate,

4. Standing systolic pressure,

5. Pulse rate return to standing rate after exercise (5 step-ups onto a 17-inch chair in 15 seconds),

6. Pulse rate immediately after exercise and every 30 seconds thereafter until return of standing pulse rate.

These scores or their differences were then evaluated on a standardized rating scale and converted to an arbitrary number (see Appendix B). The evaluation of this number was based on the following fitness scale:

12 - 22 functionally fit,
9 - 11 average,
0 - 8 functionally unfit,
-1 - -8 chronic fatigue.

Thus, with lying heart rate and blood pressure already established, the subject's standing blood pressure and heart rate were recorded after both had sufficiently stabilized.

The cuff was then removed, and following the Schneider protocol, the subject stepped five times in approximately 15 seconds onto a 17-inch high chair so that the tester could obtain a recording of the heart rate immediately after exercise as well as every 30 seconds thereafter until the standing resting rate was reached again. The heart rate was either read off the physiograph recording of the EKG or counted for 15 seconds by listening to the heart sound over the receiver's speaker.

Respiratory Indicators of Fitness

With all of the resting cardiovascular data recorded, the subjects were tested for vital capacity (VC), timed vital capacity, also called forced vital capacity (FVC_1), and maximum breathing capacity (MBC) as shown in Figure 12.

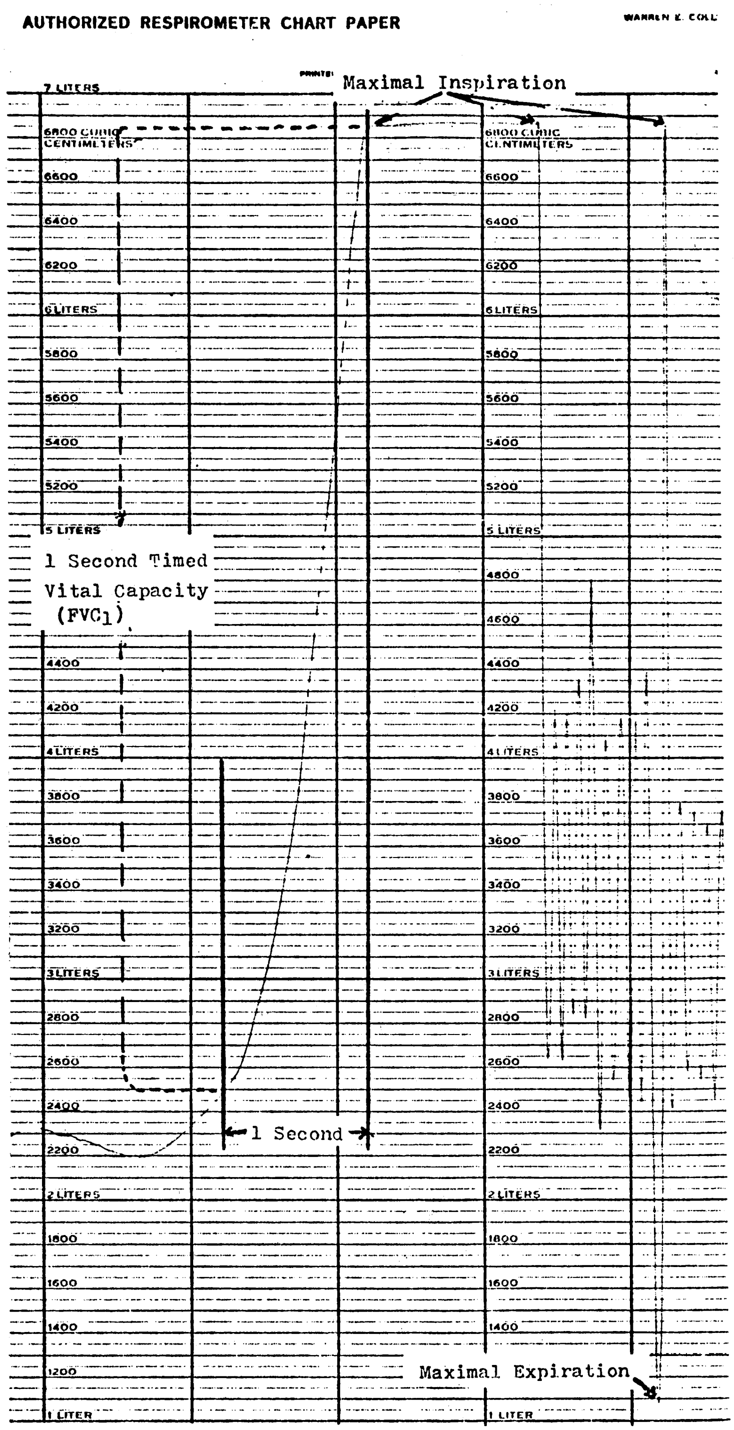


Figure 12. Normal Spirogram During VC and FVC_1 Maneuver

Vital Capacity. The maximum air that can be expired after the largest possible inspiration is called vital capacity. The test for this variable was conducted on the Collins 9 liter respirometer (Figure 13) with closed circuit and the subjects in the sitting position. Each individual was allowed sufficient time to acclimatize to the slightly increased resistance of breathing through the respirometer before they were instructed to inhale and then exhale as deeply as possible in one continuous effort. The result was graphically recorded on the kymograph (see Figure 12) in cubic centimeters or liters. After the correction for BTPS (body temperature and pressure) it should, according to Karpovich,[22] fall between 1400 cc and 6500 cc.

Because vital capacity per se varies like the oxygen uptake previously discussed according to the physiological variable of an individual, the VC should be related to body size, weight, age, or body surface area.[23, 24] The difference in per cent between the measured and predicted VC was therefore included as a fitness variable.

The predicted vital capacity was established by the cross reference of height in cm and age on a nomogram developed by Baldwin.[25]

Forced Vital Capacity. The maximum air that can be expired forcefully and as rapidly as possible is called forced vital capacity. According to Ricci[26] it is a more reliable index of ventilatory capacity than the VC obtained by the method described in the preceding paragraph because the timing used for the FVC establishes a common time basis, thus making comparisons valid. In this study the time interval was one second, which commonly is indicated by subscript and is written FVC_1.

The test immediately followed the VC measurement and was conducted by just changing the kymograph speed from slow to medium. The subjects

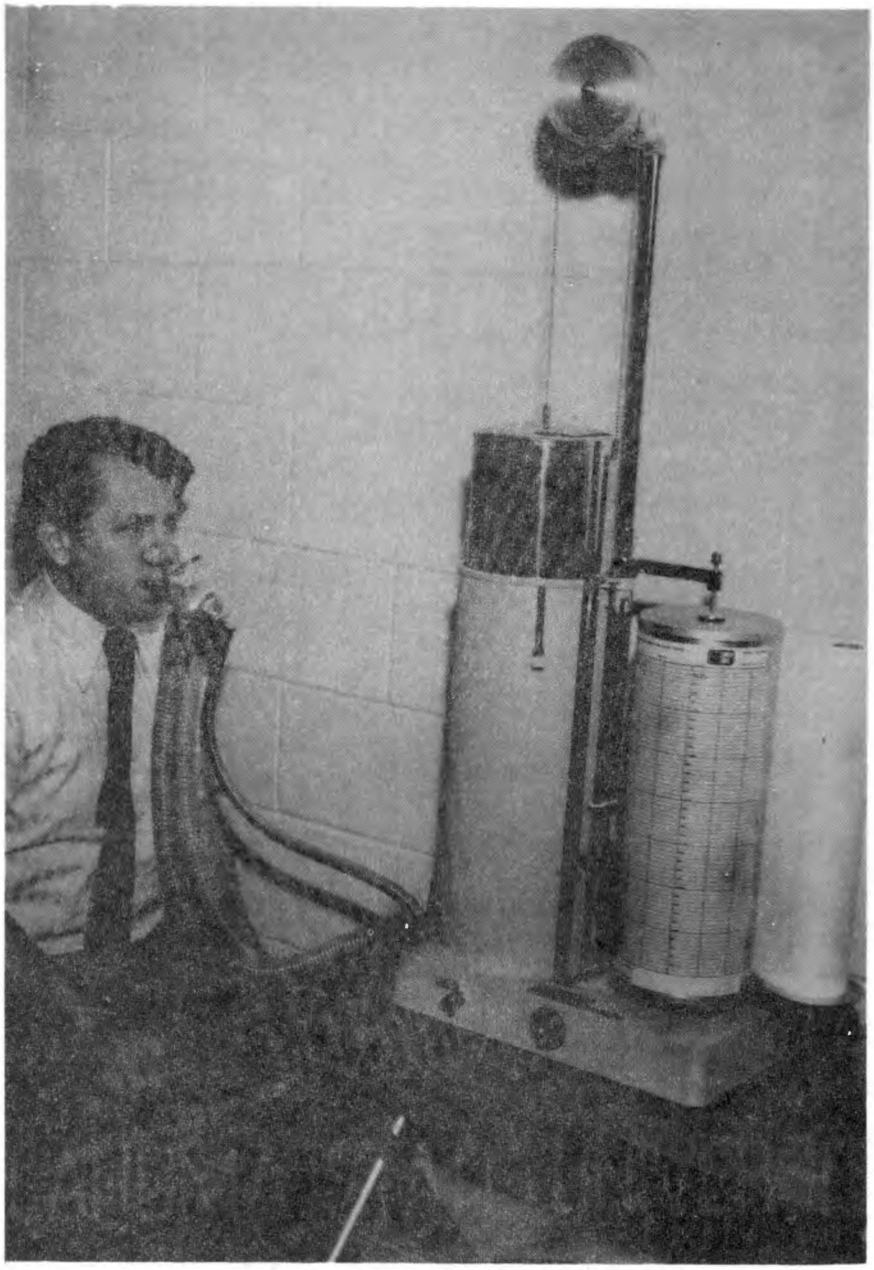


Figure 13. Collins 9 Liter Respirometer

were instructed to inhale as deeply as possible, hold their breath, and on the command "go," to exhale as forcefully and as rapidly as possible. The difference between the level of expiration after one second and complete expiration is expressed as per cent of the complete expiration (Figure 12). In this case the raw data required no adjustment for BTPS nor adjustment for any physiological variable. A score of 80 per cent was considered normal for young individuals.[27]

Maximum Breathing Capacity. The maximum volume of air that can be moved in and out of the lungs is called the maximum breathing capacity.[28] The test was conducted on the Tissot Tank (Figure 14) with the subjects in the standing position. Each individual received careful instructions to find the best compromise between breathing rate and depth to force as much air as possible into the tank within 15 seconds. Because the subjects experienced occasionally light dizziness from hyperventilation, they were limited to two trials with enough time to recuperate between the trials.

The vertical kymograph tracing in centimeters of the best test was multiplied by a constant bell factor to convert the distance of the tracing to liters. This 15-second volume was again multiplied by four to obtain liters per minute and then corrected for BTPS. As with the vital capacity the MBC was also expressed in relation to age and body surface area and converted to per cent of the population norm.[29]

The predicted MBC was established by cross reference of height in cm and age on a nomogram, also developed by Baldwin et al.[30]

Weight Residual. Taking the average of all equivalent weights in an analysis of body build by anthropometric fractionation of body weight will result in an estimate of the preferred body weight (see Appendix D).

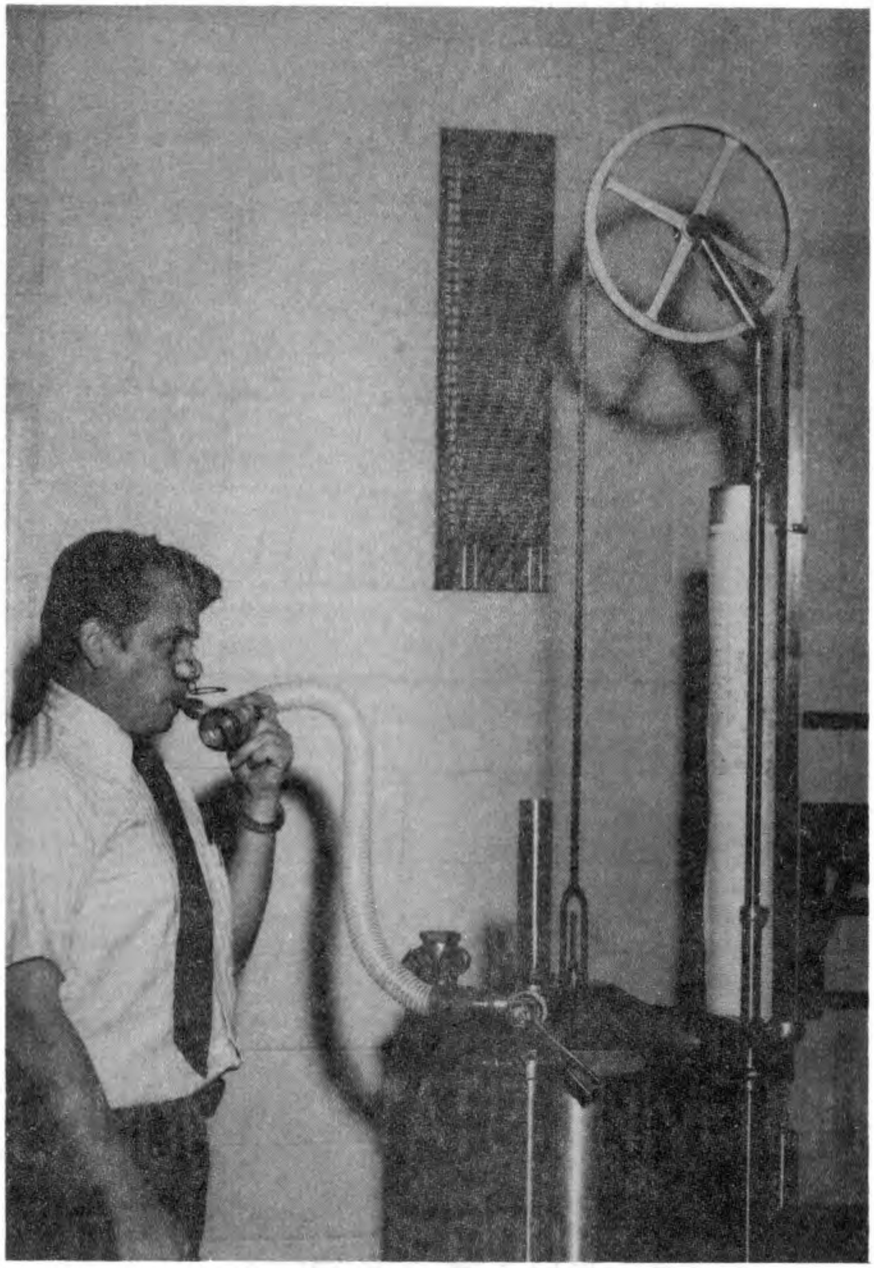


Figure 14. Tissot Tank

The actual weight recorded above or below the estimate is the weight residual.

Knowing the per cent body fat is, no doubt, the most meaningful information in regard to a person's ideal weight assessment. Probably the most precise method for such an evaluation of body composition--fat versus lean body mass--is the method developed by Behnke[31] in 1942 where the subject's body density is measured according to Archimedes' principle. A major problem with this underwater weighing method, however, is the necessity to correct for lung volume and other air space as well as the possible traumatic effect on nonswimmers of being submerged under water or on claustrophobes of being confined in a small place.

The so-called skinfold measurement protocol developed by Brozek and Keys[32] can, on the other hand, arrive at a body composition estimate within $\pm$ 7 to 8 per cent of the above method without those shortcomings. However, Consolazio[33] emphasized here some special problems which are characteristic of the skinfold protocol. Differences between observers measuring the same subject were reported to be as large as 50 per cent. Another problem listed is the phenomenon that the skinfold thickness may increase as much as 15 per cent because of simple dehydration usually occurring in the afternoons.

To circumvent the problems described, Behnke[34] developed the anthropometric method which was adopted for this study. He based the quantitative evaluation of body build on the fact that the correlation between body weight and anthropometric circumferences is equal to 0.98 or better.

By taking the sum of 11 circumferences of various body segments--for the limbs, the average of the right and left members--and dividing it by a constant, he arrived at a geometric dimension. This factor predicted then the weight in kg when it was squared and multiplied times the subject's height in dm ($D^2 \times H = kg$). The standard error of the method is $\pm$ 2 to 3 per cent.

The same procedure can be used for every one of the 11 body segments. The constant is, of course, different for every segment. This calculation indicates, for example, that an 80 kg subject might have the shoulder of a 90 kg man and so on.

Age. The effect of age on various physiological functions and general as well as specific fitness evaluations has been discussed in the review of literature and in some of the preceding paragraphs on methodology.

Because of the demonstrated influence of age on the cardiovascular, respiratory, and muscular system, age was included as a general fitness classification.[35] Age was expressed in years as determined on the day of testing.

Grouping of Subjects

Exercisers and Nonexercisers

Based on personal interviews about regular physical exercise habits, the subjects were classified as physically active or sedentary. The evaluation was based on Cooper's[36] point system where a point is the equivalent of 7 ml/kg/min of oxygen intake.

Individuals whose exercises were estimated to earn at least 10 points per week on the so-called aerobic point scale[37] were classified as exercisers if the activity or activities could be considered to take place on a regular basis. All of the remaining subjects were placed into the nonexercise group.

Cooper's Fitness Categories

The well-publicized fitness categories developed by K. Cooper[38] were based on the following age-adjusted oxygen consumption scale in ml/kg/min (Table VIII):

TABLE VIII

FITNESS CATEGORIES

	Age	Under 30	30-39	40-49	50+
I.	Very poor	25.0	25.0	25.0	--
II.	Poor	25.0-33.7	25.0-30.1	25.0-26.4	25.0
III.	Fair	33.8-42.5	30.2-39.1	26.5-35.4	25.0-33.7
IV.	Good	42.6-51.5	39.2-48.0	35.5-45.0	33.8-43.0
V.	Excellent	51.6+	48.1+	45.1+	43.1+

The maximum oxygen consumption of each subject was determined according to the previously described Balke treadmill protocol.

Grouping and Analysis of Data

The raw data of the left ventricular time components were grouped as follows:

1. TP, ICP, EML, EP, EP/HR, EP/ICP, and TP/EP (at rest);

2. TP, ICP, EML, EP, EP/HR, EP/ICP, and TP/EP (one minute after exercise);

3. TP, ICP, EML, EP, EP/HR, EP/ICP, and TP/EP (five minutes after exercise);

4. TP, ICP, EML, EP, EP/HR, EP/ICP, and TP/EP (changes from rest to one minute after exercise);

5. TP, ICP, EML, EP, EP/HR, EP/ICP, and TP/EP (changes from rest to five minutes after exercise).

These data were analyzed through statistical computations with the following variables:

a. Fitness levels according to Cooper's aerobic scale:

   1. Very poor
   2. Poor
   3. Fair
   4. Good
   5. Excellent

b. Age: 0-30, 31-40, 41-50, 51+

c. Fitness groups: exercisers, nonexercisers

d. General fitness measures:

   1. Maximum oxygen uptake
   2. Vital capacity
   3. Forced vital capacity
   4. Systolic blood pressure
   5. Diastolic blood pressure
   6. Pulse pressure
   7. Schneider Index
   8. Heart rate (resting)
   9. Rest/Work ratio
   10. T wave amplitude
   11. Weight residual

e. The sum of the per cent deviation from the norm of:

   1. Vital capacity
   2. Maximum breathing capacity
   3. Maximum oxygen uptake.

The directions for the computer analysis were:

1. Have three classification variables

   a. Fitness level
   b. Age
   c. Exercisers/Nonexercisers

      (1) Run an Analysis of Variance (one way) on variables 1 through 7 (all 35 parameters of the cardiac cycle) using these classification variables.

      (2) Compute correlation coefficients between variables 1 through 7 (all 35 parameters of the cardiac cycle) and variables d and e (all 11 fitness variables).

A significance level of 0.05 or less was considered necessary for any one test or combination of tests to be accepted as a significant correlation for predicting cardiovascular fitness, or providing a basis for further investigations.

FOOTNOTES

[1]E. Simonson et al., "The Effects of Meals on the Electrocardiogram in Normal Subjects," American Heart Journal, XXXV (1964), p. 202.

[2]T. K. Cureton, Physical Fitness of Champion Athletes (Urbana, Ill., 1951), pp. 137-140.

[3]L. H. Sigler, The Electrocardiogram, Its Interpretation and Clinical Application (New York and London, 1957), p. 41.

[4]E. Simonson, J. Brozek and A. Keys, "Variability of the ECG in Normal Young Men," American Heart Journal, XXXVIII (1949), pp. 407-423.

[5]Cureton, p. 139.

[6]B. Balke and R. W. Ware, "An Experimental Study of Physical Fitness of Air Force Personnel, U. S. Armed Forces Medical Journal, X (1959), p. 675.

[7]J. Newton, "Assessment of Maximal Oxygen Intake," Medicine and Science in Sports, III (1963), pp. 164-169.

[8]H. Mitchel, B. J. Sproule, and C. B. Chapman, "The Physiological Meaning of the Maximal Oxygen Intake Test," Journal of Clinical Investigation, XXXIV (1958), p. 538.

[9]J. H. Wilmore, "Maximal Oxygen Intake and Its Relationship to Endurance Capacity on a Bicycle Ergometer," Research Quarterly, XL (1969), pp. 203-210.

[10]A. V. Hill, Muscular Activity (Baltimore, 1926), p. 115.

[11]J. T. Kearney and W. C. Byrnes, "Relationship Between Running Performance and Predicted Maximum Oxygen Uptake Among Divergent Ability Groups," Research Quarterly, XLV (1974), pp. 9-15.

[12]H. G. Knuttgen, "Physical Working Capacity and Physical Performance," Medicine and Science in Sports, I (1969), pp. 1-8.

[13]Knuttgen, p. 6.

[14]Newton, pp. 164-169.

[15]V. F. Froelicher et al., "A Comparison of the Balke and Bruce Protocols," submitted for publication, cited in their letter to the editor, American Heart Journal, XXCVIII (1974), p. 534.

[16]V. F. Froelicher and M. C. Lancaster, "The Prediction of Maximal Oxygen Consumption from a Continuous Exercise Treadmill Protocol," American Heart Journal, XXCVII (1974), pp. 445-450.

[17]P. L. McHenry et al., "Cardiac Arrhythmias Observed During Maximal Treadmill Exercise Testing in Clinically Normal Men," American Journal of Cardiology, XXIX (1972), p. 331.

[18]V. F. Froelicher et al., "A Comparison of the Reproducibility and Physiological Response to Three Maximal Treadmill Protocols," Chest, LXV (1974), p. 512.

[19]F. Nagle and T. Bedecki, "Use of the 180 Heart Rate Response as a Measure of Circulorespiratory Capacity," Research Quarterly, XXXIV (1963), pp. 361-369.

[20]L. Brouha, "Physiological Reactions of Men and Women During Muscular Activity and Recovery in Various Environments," Journal of Applied Physiology, XVI (1961), p. 133.

[21]W. E. Sime et al., "Reproducibility of Heart Rate at Rest and in Response to Submaximal Treadmill and Bicycle Ergometer Test in Middle-Aged Men," Medicine and Science in Sports, IV (1972), pp. 14-17.

[22]P. V. Karpovich, Physiology of Muscular Activity (Philadelphia, 1971), p. 151.

[23]B. Ricci, Physiological Basis of Human Performance (Philadelphia, 1967), p. 128.

[24]D. K. Mathews and E. I. Fox, The Physiological Basis of Physical Education and Athletics (Philadelphia, 1971), p. 133.

[25]E. DeF. Baldwin, A. Cournard, and D. W. Richards, Jr., "Pulmonary Insufficiency 1, Physiologic Classification, Clinical Methods of Analysis, Standard Values in Normal Subjects," Medicine, XXVII (1948), p. 243.

[26]Ricci, p. 128.

[27]J. Crofton and A. Douglas, *Respiratory Diseases* (Oxford and Edinburgh, 1969), p. 41.

[28]Frank Consolazio, Robert Johnson, and Louis Pecora, *Physiological Measurements of Metabolic Functions in Man* (New York, 1963), p. 225.

[29]Ibid.

[30]Baldwin, Cournard and Richards, p. 243.

[31]A. R. Behnke, B. G. Feen, and W. C. Wilham, "Specific Gravity of Healthy Men. Body Weight-Volume as an Index of Obesity," *Journal American Medical Association*, CXVIII (1942), pp. 495-498.

[32]J. Brozek and A. Keys, "The Evaluation of Leanness-Fatness in Man: Norms and Interrelationships," *British Journal of Nutrition*, V (1951), pp. 194-206.

[33]Consolazio, p. 303.

[34]A. R. Behnke, "Anthropometric Fractionation of Body Weight," *Journal of Physiology*, XVI (1961), pp. 949-954.

[35]T. K. Cureton, *The Physiological Effects of Exercise Programs on Adults* (Springfield, 1969).

[36]K. Cooper, *Aerobics* (New York, 1968), p. 49.

[37]K. Cooper, *The New Aerobics* (New York, 1972), pp. 172-185.

[38]Cooper, *The New Aerobics*, p. 28.

CHAPTER IV

RESULTS AND DISCUSSION

This study investigated the relationship of the left ventricular systolic time intervals and some of their ratios to maximum oxygen consumption and indexes of general fitness. The parameters of the cardiac dynamic cycle, the selected variables, as well as their validity as fitness indexes have been discussed in the preceding chapters. This discussion will be mainly concerned with the interpretation of the results obtained from the correlations between the parameters and fitness variables and the analysis of variance of the parameters and three classification variables--Cooper's fitness levels, age, and exercise versus nonexercise.

Means of the Parameters and Variables

A comparison of the systolic time interval means in this study with the averages of healthy normals reported by various authors--all of which were discussed in the preceding chapters on the pages indicated--shows that they were well within the given ranges or in excellent agreement (Table IX).

Such an agreement among the means should, to a point, strengthen the validity of the data reported in this study. Similarly, the shortening of the time intervals initiated by exercise that were reported in previous research studies (Table X) indicated the same ranges as those measured in this investigation (Table XI).

TABLE IX

MEANS OF SYSTOLIC TIME INTERVALS OF NORMAL INDIVIDUALS

Investigators	TP	EP	EML	ICP
Wohlert (1975)	100	293	59	41
Blumberger (1942)	50-100	200-310		
Holldack (1951)	87	290	51	37
Emmrich, Klepzig, Reindell (1956)			31-67	16-67
same	90-106			
Raab (1960)	81-101			
Hyman (1964)			58-80	
Shkhavatsabaya (1964)	82-114			31-49
same			50-65	
Lang (1965)	86	274	56	31
Ahmed (1972)	107	284		

TABLE X

DECREASE OF SYSTOLIC TIME INTERVALS AS A RESULT OF EXERCISE
(Resting Intervals = 100%)

	1 min.-1½ min. Post-Exercise				5 min. Post-Exercise			
% Level	EML	ICP	EP	TP	EML	ICP	EP	TP
Wohlert	88	54	73	68	90	78	91	85
Frank and Cureton	92	60	88	75	98	77	95	80

Source: Don Franks and T. K. Cureton, Jr., "Orthogonal Factors of Cardiac Intervals and Their Response to Stress," Research Quarterly, XXXIX (1967), p. 526.

The slightly larger decreases seen in the intervals of this study seem to be a result of the greater exercise load. The subjects in this investigation were taken to their maximum aerobic capacity (HR = 180 bpm) while Frank and Cureton used only a moderate ergometer ride (average high HR = 138 bpm). The assumption above is supported by data about the effect of strenuous exercise. Sutton et al.,[1] reported for the EML a decrease from 56 msec to 48 msec, Sloniger[2] 45 msec to 36 msec after an all-out ergometer ride, and Hyman[3] 58 msec to 42 msec.

The means of the fitness variables given in Table XII indicate that the sample of 41 subjects used in this study was representative of the one hundred faculty and administrators tested annually for physical fitness.

In view of the max VO_2 uptake average, the conclusion can be made that subjects of this study were physically quite fit. The 39.46 ml/kg/min of O_2 uptake would place the average subject (mean age 40 years) into Cooper's good fitness level. The fitness level variable actually shows a mean of 3.76, which is just below the good category (level 4).

The respiratory variables indicate the same good fitness status; however, the norms were taken from the prediction tables developed by Baldwin (Appendix C)[4] which are considerably less stringent than the predicted normal values according to Kory et al.[5] Taking the latter as the norm, the average mean of the VC and MBC percent would lie approximately at 100 percent.

All other means support a good fitness assessment for the subjects of this study; the exception could be the weight residual which is above the norm.

Variance

The standard deviations of the systolic time intervals presented in Table XI seem to indicate a high variance for the EML, ICP, and the ratios. In comparison with Lang's data, the SD's are indeed larger; however, the number and magnitude of the maximum and minimum values indicated, according to the discussion of the means above, a somewhat homogeneous group with only a few extremely low scores mainly responsible for the large variance. A cursory check run on the resting EML showed that by dropping just the lowest two scores, the SD was reduced by nearly 40 percent. Such variance would be equal to or better than the SD's reported in a survey of literature by Frank and Cureton.[6] They listed

TABLE XI

MEANS AND DEVIATIONS OF SYSTOLIC TIME INTERVALS

Parameters	Mean (msec)	SD*
1. TP rest	100.073	17.438 (10.76)
2. TP 1 min post-ex.	68.317	14.595
3. TP 5 min post-ex.	85.463	16.576
4. EML rest	59.073	13.436 (9.90)
5. EML 1 min post-ex.	46.220	13.112
6. EML 5 min post-ex.	52.512	15.691
7. ICP rest	41.000	18.211 (10.65)
8. ICP 1 min post-ex.	22.098	9.919
9. ICP 5 min post-ex.	32.951	15.532
10. EP rest	293.585	21.110 (28.63)
11. EP 1 min post-ex.	215.634	23.744
12. EP 5 min post-ex.	267.854	21.643
13. EP/ICP rest	8.874	5.003
14. EP/ICP 1 min post-ex.	11.434	4.634
15. EP/ICP 5 min post-ex.	10.129	5.821
16. EP/HR rest	4.620	0.948
17. EP/HR 1 min post-ex.	3.394	0.764
18. EP/HR 5 min post-ex.	4.217	0.883
19. TP/EP rest	0.343	0.068
20. TP/EP 1 min post-ex.	0.321	0.080
21. TP/EP 5 min post-ex.	0.322	0.073

*The SD's in parentheses are from E. Lang given in Table IV.

TABLE XII

MEANS AND STANDARD DEVIATIONS OF FITNESS VARIABLES

Variables	Mean*		SD
1. Max VO_2 uptake (ml/kg/min)	39.46	(38.89)	5.21
2. Cooper's fitness level (level I = very poor to level V = excellent)	3.76		0.70
3. Vital capacity (cm^3)	4958.44	(46500.00)	816.34
4. VC per cent (100% = ave. normal)	118.64		17.28
5. MBC per cent (100% = ave. normal)	123.93	(121)	24.95
6. FEV_1 (Per cent air expired in 1 second)	82.44	(77.50)	7.86
7. Systolic BP (mm/Hg)	124.90	(122)	11.62
8. Diastolic BP (mm/Hg)	73.81	(74)	10.05
9. Pulse pressure (mm/Hg)	51.10	(48)	11.29
10. Schneider Index	13.02	(12.80)	3.62
11. Heart rate (bpm)	65.71	(64.65)	11.26
12. T Wave Amplitude (mm)	3.01	(3.02)	1.27
13. Weight residual (lb)	9.37	(9.63)	6.69

*The means in parentheses were collected in 1974 during physical fitness assessments of 100 volunteer faculty members and administrators at Oklahoma State University.

for the EML 10, 7, 11, 10, and 12 msec (13.4 msec this study) and for the ICP 6, 12, and 19 msec (18.2 msec this study).

Correlations

The level of significance for a correlation to be accepted as significant was set at 0.05 or better. However, the 0.1 level was also indicated in order not to lose the data since such correlations between parameters and some established fitness variable could possibly be used for general fitness screening or be considered cause for further investigations.

The Systolic Time Intervals and Ratios at Rest

The summary of the significant correlations which are presented in Table XIV establishes a clear trend in favor of the ratios for using the parameters of the cardiac dynamic cycle in the assessment of cardiovascular fitness (Table XIII).

The TP, the sum of EML and ICP, shows three significant correlations which are identical to those of the ICP. Since the EML indicates no significant correlations for the same variables, it has to be assumed that the ICP accounts for the relationship to the maximum oxygen uptake, Cooper's fitness levels, and weight residual. The ICP, therefore, could be considered a usuable discriminator between physically conditioned and unconditioned individuals. Practical support comes from the data in Table V, page 36, showing longer TP and ICP for trained subjects. Theoretical support comes from the fact that the ICP is more closely correlated to measures of contractility (see page 45), and the prolonged resting TP or ICP is, according to the discussion on page 19, an

TABLE XIII

SUMMARY OF SIGNIFICANCE OF CORRELATIONS BETWEEN SYSTOLIC TIME INTERVALS (REST) AND FITNESS VARIABLES*

Variables	Parameters TP	EML	ICP	EP	EP/HR	EP/ICP	EP/TP
Maximum VO_2	.067	-	.067	-	.036	-	.084
Cooper levels	.015	-	.015	.034	.027	.035	.037
Maximum VO_2 %	-	-	-	-	.043	-	-
Exercise/Nonexercise	-	-	-	.039	.012	-	-
Heart rate	-	-	-	.001	.001	-	.031
T wave	-	-	-	-	.046	-	-
Rest/Work ratio	-	-	-	.001	.001	-	.077
Schneider	-	-	-	.001	.001	-	.027
Systolic BP	-	.055	-	-	.050	-	-
Pulse pressure	-	.044	-	-	-	-	-
VC	-	-	-	-	.079	-	-
MBC %	-	.073	-	-	-	-	.069
FEV_1	-	-	-	.073	-	-	-
Age	-	-	-	.012	.074	.080	-
Weight residual	.035	-	.035	-	-	-	-

*Values expressed as significant levels.

TABLE XIV

SIGNIFICANCE LEVELS OF CORRELATIONS BETWEEN VENTRICULAR SYSTOLIC TIME INTERVALS (REST) AND FITNESS VARIABLES*

Variables	TP	EML	ICP	Rest EP	EP/HR	EP/ICP	EP/TP
Maximum VO_2	.067[a]	.563	.067[a]	.159	.036[b]	.586	.084[a]
Cooper levels	.015[b]	.153	.015[b]	.034[b]	.027[b]	.035[b]	.037[b]
Maximum VO_2 %	.509	.596	.509	.183	.043[b]	.630	.729
Exercise/Nonexercise	.623	.531	.623	.039[b]	.012[b]	.514	.213
Heart rate	.641	.893	.641	.001[d]	.001[d]	.577	.031[b]
T wave	.591	.540	.591	.124	.046[b]	.230	.599
Rest/Work ratio	.630	.615	.630	.001[d]	.001[d]	.247	.077[a]
Schneider	.587	.910	.587	.001[d]	.001[d]	.203	.027[b]
Systolic BP	.531	.055[a]	.531	.128	.049[b]	.847	.914
Diastolic BP	.714	.967	.714	.661	.673	.543	.940
Pulse pressure	.675	.044[b]	.675	.501	.107	.608	.858
VC	.884	.673	.884	.231	.079[a]	.277	.283
VC %	.945	.154	.945	.214	.161	.527	.104
MBC %	.742	.073[a]	.742	.503	.654	.539	.069[a]
FEV_1	.513	.662	.513	.073[a]	.140	.020	.507
Age	.664	.704	.664	.012[b]	.074[a]	.080[a]	.651
Weight residual	.035[b]	.165	.035[b]	.707	.822	.538	.573

*Values significant [a]at 0.1; [b]at 0.05; [c]at 0.01; [d]at 0.001.

expression of reinforced activities of the sympathetic-inhibitor mechanism and cholinergic influence found in athletes.

The EP, contrary to the TP and ICP, has a linear negative correlation to heart rate. This fact should reduce the significance of the EP's contribution to the correlations with the fitness variables because the correlations between heart rate and the other fitness variables is even higher (Table XV) and the relationships between the EP and the variables are, therefore, most likely due to heart rate. It should further be noted that the EP shows no significant correlation with max VO_2; and with Cooper's levels, the EP has a significance of only 0.034 which is less than that between Cooper and heart rate.

Of all the ratios, the EP/HR seems to be the best indicator of cardiovascular fitness. The EP/TP, on the other hand, indicated more significant correlations than the EP/ICP ratio. For some unexplained reason, the EP/TP had also a higher significant correlation to heart rate than the EP/ICP. This aspect might warrant some further investigation.

While all three ratios are indicators of myocardial contractility (see page 65) and would in this respect support a conclusion pronouncing these ratios as excellent indicators of cardiovascular fitness, it cannot be overlooked that heart rate might again be the decisive factor responsible for the significant correlations. Yet, a comparison of the resting data (Table XIII) with the post-exercise data (Tables XVI through XIX) offers strong evidence for the fact that heart rate alone is not responsible for the correlations established between the ratios and the variables.

TABLE XV

CORRELATION MATRIX FOR FITNESS VARIABLES (LEVELS OF SIGNIFICANCE)

Fitness Variables	Variable Number 1	2	3	4	5	6	7	8	9	10
1. Maximum VO_2										
2. Cooper levels	.001									
3. Exercise/Nonexercise	.001	.001								
4. Heart rate	.005	.007	.002							
5. Schneider	.002	.001	.001	.001						
6. VC	.137	.963	.676	.052	.311					
7. VC %	.067	.281	.520	.153	.309	.001				
8. MBC %	.157	.752	.535	.537	.669	.003	.003			
9. FEV_1	.246	.543	.099	.181	.286	.104	.066	.004		
10. Age	.534	.117	.668	.189	.539	.008	.242	.094	.002	
11. Weight Residual	.002	.006	.073	.595	.874	.764	.935	.021	.570	.931

TABLE XVI

SUMMARY OF SIGNIFICANCE OF CORRELATIONS BETWEEN SYSTOLIC TIME INTERVALS (ONE MINUTE POST-EXERCISE) AND FITNESS VARIABLES*

Variables	Parameters TP	EML	ICP	EP	EP/HR	EP/ICP	EP/TP
Maximum VO_2	.084	-	-	-	.028	.073	.029
Cooper levels	-	-	-	.069	.026	.089	.035
Maximum VO_2 %	.073	.004	-	.095	.026	-	.018
Exercise/Nonexercise	-	-	-	.097	.012	.053	-
Heart rate	-	-	-	.002	.001	-	.060
Rest/Work ratio	-	-	-	.071	.001	-	-
Schneider	-	-	-	.015	.001	-	-
Systolic BP	-	.081	-	-	-	-	-
Pulse pressure	.062	-	-	-	-	-	-
MBC %	.056	-	-	-	-	-	.090
Age	-	-	-	.052	.084	-	.099
Weight residual	-	-	.035	-	-	-	-

*Values expressed as significant levels.

TABLE XVII

SIGNIFICANCE OF CORRELATIONS BETWEEN VENTRICULAR SYSTOLIC TIME INTERVALS (ONE MINUTE POST-EXERCISE) AND FITNESS VARIABLES*

	Parameters						
Variables	TP	EML	ICP	EP	EP/HR	EP/ICP	EP/TP
Maximum VO_2	.084[a]	.592	.163	.141	.028[b]	.073[a]	.029[b]
Cooper levels	.154	.596	.171	.069[a]	.026[b]	.089[a]	.035[b]
Maximum VO_2 %	.073[a]	.004[c]	.256	.095[a]	.026[b]	.994	.018[b]
Exercise/Nonexercise	.605	.962	.179	.097[a]	.012[b]	.053[a]	.161
Heart rate	.642	.254	.572	.002[c]	.001[d]	.548	.060[a]
T wave	.742	.972	.604	.568	.105	.905	.923
Rest/Work ratio	.742	.646	.267	.071[a]	.001[d]	.721	.541
Schneider	.713	.582	.192	.015[b]	.001[d]	.968	.578
Systole BP	.114	.081[a]	.973	.857	.198	.718	.271
Diastole BP	.801	.503	.201	.685	.877	.171	.971
Pulse pressure	.062[a]	.251	.243	.593	.142	.587	.243
VC	.504	.152	.596	.852	.172	.703	.515
VC %	.266	.126	.725	.722	.246	.574	.262
MBC %	.056[a]	.154	.612	.739	.608	.616	.090[a]
FEV_1	.317	.567	.509	.636	.308	.522	.525
Age	.588	.673	.936	.052[a]	.084[a]	.739	.099[a]
Weight residual	.252	.165	.035[b]	.707	.822	.538	.573

*Values significant: [a]at 0.1; [b]at 0.05; [c]at 0.01; [d]at 0.001.

TABLE XVIII

SUMMARY OF SIGNIFICANCE OF CORRELATIONS BETWEEN SYSTOLIC TIME INTERVALS (FIVE MINUTE POST-EXERCISE) AND FITNESS VARIABLES*

Variables	TP	EML	ICP	Parameters EP	EP/HR	EP/ICP	EP/TP
Maximum VO_2	-	-	-	.005	.009	-	.016
Cooper levels	.076	-	-	.007	.014	-	.006
Maximum VO_2 %	.095	-	-	.050	.028	-	.027
Exercise/Nonexercise	-	-	-	.003	.003	-	.048
Heart rate	.057	-	-	.001	.001	-	.001
T wave	-	-	.097	-	-	-	-
Rest/Work ratio	-	-	-	.012	.001	-	.050
Schneider	-	-	-	.001	.001	.100	.005
Systolic BP	-	.075	-	-	.063	-	-
Pulse pressure	-	.009	.081	-	-	-	-
VC	-	-	-	-	.086	-	-
Age	-	-	-	-	-	-	.047

*Values expressed as significant levels.

TABLE XIX

SIGNIFICANCE OF CORRELATIONS BETWEEN VENTRICULAR SYSTOLIC TIME INTERVALS (FIVE MINUTE POST-EXERCISE) AND FITNESS VARIABLES*

Variables	Five Minute Post-Exercise						
	TP	EML	ICP	EP	EP/HR	EP/ICP	EP/TP
Maximum VO_2	.184	.708	.308	.005[c]	.009[c]	.544	.016[b]
Cooper levels	.076[a]	.532	.227	.007[c]	.014[b]	.227	.006[c]
Maximum VO_2 %	.095[a]	.138	.786	.050[b]	.028[b]	.809	.027[b]
Exercise/Nonexercise	.593	.791	.536	.003[c]	.003[c]	.558	.048[b]
Heart rate	.057[a]	.538	.218	.001[d]	.001[d]	.741	.001[d]
T wave	.569	.323	.097[a]	.683	.144	.271	.659
Rest/Work ratio	.622	.959	.319	.012[b]	.001[d]	.746	.050[b]
Schneider	.232	.673	.557	.001[d]	.001[d]	.100[a]	.005[c]
Systole BP	.541	.075[a]	.657	.175	.063[a]	.191	.583
Diastole BP	.990	.565	.575	.575	.710	.279	.749
Pulse Pressure	.550	.009[c]	.081[a]	.518	.120	.715	.735
VC	.538	.966	.543	.595	.086[a]	.573	.676
VC %	.654	.552	.697	.504	.191	.680	.284
MBC %	.610	.593	.770	.741	.584	.920	.599
FEV_1	.727	.953	.671	.736	.320	.922	.693
Age	.121	.156	.829	.113	.155	.958	.047[b]
Weight residual	.888	.147	.105	.226	.574	.531	.555

*Values significant [a]at 0.1; [b]at 0.05; [c]at 0.01; [d]at 0.001.

The Systolic Time Intervals and Ratios at One Minute and Five Minute Post-Exercise

Since the ratios improved their power of discrimination between the trained and untrained individuals after exercise (see page 63), it could be expected that an improvement in the level of significance would be found. If the correlation between heart rate and the other variables remains constant or even decreases as indicated in Tables XVI through XIX (see also Appendix E), it can be considered evidence that time intervals or ratios contributed to the significance of the relationships between the fitness variables and the ventricular systolic time intervals.

A study of Tables XIII and XVI reveals that the correlation between heart rate and the parameters of the cardiac cycle did remain constant or decreased. The most dramatic demonstration comes from the EP/TP ratio; the correlation between this ratio and heart rate decreased from rest to one minute post-exercise from $r = 0.33$, $P < 0.03$ to $r = 0.29$, $P < 0.06$ while the correlation between the ratio and the fitness variables (max VO_2 from $r = 0.27$, $P < 0.08$ to $r = 0.034$, $P < 0.03$) improved significantly. Using regression equations to correct for heart rate, Whitsett and Naughton[7] confirmed the above conclusions by demonstrating that the correlation between the EP/HR and fitness status was also caused by the parameters of the cardiac dynamic cycle.

The five minute post-exercise data (Tables XVIII and XIX) show--with the exception of the TP, EML, and ICP--higher significant relationships to the variables than the resting or one minute post-exercise values.

The EP/HR and the EP/TP ratios measured at five minutes post-exercise increased their significance of correlation with most of the cardiovascular fitness variables. However, one has to exercise caution to declare these values superior to the one minute post-exercise correlations because the significance of the heart rate increased correspondingly. One other factor for the increased significance might be greater accuracy in measurement. Since the one minute post-exercise data were recorded immediately after what was for some individuals very strenuous exercise, some records produced were less well defined and therefore more difficult to read. For the five minute recording, on the other hand, the subjects had recuperated sufficiently to allow normal recordings.

Whitsett and Naughton[8] regarded the response of the TP to exercise as a combination of influences created by physical work. This expenditure of energy should cause increased adrenergic activity (see also page 18) and increased stroke volume.

For their parametric values of the cardiac cycle that is related to EP, the two authors consider the response to exercise to be a function of an increased rate of myocardial fiber shortening for active subjects, while sedentary individuals would be characterized by a decreased rate.

The Change From Rest to One and Five Minutes Post-Exercise for the Systolic Time Intervals

The data representing the differences between the resting and post-exercise parameters indicate sharply reduced correlations to the fitness variables (Appendix E).

According to these findings, it is apparent that these parameters show no promise to be of value in cardiovascular fitness assessment, nor do they seem to warrant any further investigation.

Analysis of Variance

Cooper's Fitness Classification

According to the ANOVA, the systolic time intervals were, with the exception of the EP/TP ratio, not able to distinguish between the individual fitness levels. The ratio could distinguish only between levels 3 (fair) and 4 (good). The computer print-out indicated numerous other significant differences; however, a closer analysis revealed that these differences existed invariably between levels 2 (poor) and 3 (fair). Since level 2 contained only one subject, the significance had to be rejected.

Also, of all the fitness variables, only max VO_2 (all levels), Schneider (levels 4 and 5), and weight residual (levels 3 and 4) indicated significant differences.

One possible explanation, especially in view of the significant correlation between oxygen uptake and EP/HR, is the unequal distribution of subjects, since the ANOVA assumes an even distribution over all categories.

Exercise and Nonexercise Groups

The conclusions drawn above in regard to the lack of significant discriminators between Cooper's levels of fitness are supported by the data about the exercise groups (Table XXI). While the distribution was not even (N_1 = 28, N_2 = 13), it exhibited not such an extreme distribution. This might explain why the EP/HR, which correlated so highly with many cardiovascular variables, could differentiate between the exercise and nonexercise groups. Likewise, the max VO_2 uptake, which is one of the highly correlating variables, could also discriminate between the two groups.

TABLE XX

ANOVA OF THE MAX VO_2 UPTAKE BETWEEN EXERCISERS AND NONEXERCISERS*

	Max VO_2 Uptake: Prob > F = .0004		
Group	Exerciser		Nonexerciser
Max VO_2 Mean	41.39	(6.10)	35.29
LSD		3.68_b	

*The number in parenthesis denotes the difference between the means of the exerciser and nonexerciser groups.

b = LSD at .01.

On the other hand, the significant difference between the EP (rest) and the Schneider Index of the two groups is more than likely--as with the correlations--due to the influence of the heart rate.

TABLE XXI

ANOVA OF PARAMETERS OF THE CARDIAC DYNAMIC CYCLE BETWEEN EXERCISERS AND NONEXERCISERS*

EP (Rest) : Prob > F = 0.0386

Group	Exerciser		Nonexerciser
EP Mean	283.77	(14.37)	298.14
LSD		12.64[a]	

EP/HR (Rest) : Prob > F = 0.0119

Group	Exerciser		Nonexerciser
EP/HR Mean	4.09	(0.78)	4.87
LSD		0.74[b]	

EP/HR (5 Min Post-Exercise) : Prob > F = 0.0032

Group	Exerciser		Nonexerciser
EP/HR Mean	3.64	(0.85)	4.49
LSD		0.66[b]	

EP/HR (1 Min Post-Exercise) : Prob > F = 0.0120

Group	Exerciser		Nonexerciser
EP/HR Mean	2.97	(0.62)	3.59
LSD		0.60[b]	

*The number in parentheses denotes the difference between the means of the exerciser and nonexerciser groups.

a = LSD at .05.

b = LSD at .01.

Age

The significant difference between the heart rates of the age groups detected by the ANOVA conflicts with the findings of Motylyanskaya (Table XXII) and Karpovich.[9]

TABLE XXII

CHANGE OF HEART RATE OF ATHLETES WITH AGE

Age	19-20	21-25	26-30	31-35	36-40	41-45	46-50
HR	62.1	58.1	58.6	55.6	58.2	58.5	61.1

Source: R. Ye. Motylyanskaya, _Sports and Age_ (Moscow, 1956), quoted in V. L. Karpman and G. M. Kukolevskiy ed., _The Heart and Sports. Essays on Cardiology in Sports_, tr. National Aeronautics and Space Administration (Washington, D.C., 1971), p. 4.

Karpovich[10] reported similar heart rates for average Americans. The high rates recorded at birth (130 bpm) gradually decrease to typical adult values until they begin to rise slightly with old age.

Therefore, an assumption that some factor other than age contributed to any of the discriminative power of the EP/HR (Table XXIII) is supported by the fact that the age responsive VC and FEV_1 of the groups indicated a significant difference only between the 41-50 and 51+ groups (Tables XIII, XVI and XVIII).

TABLE XXIII

ANOVA OF PARAMETERS OF THE CARDIAC DYNAMIC CYCLE BETWEEN AGE GROUPS*

EP (Rest) : Prob > F = 0.0007

Age	0-30		31-40		41-50		51+
EP Mean	260	(26)	286	(24)	310	(19)	291
LSD		21[b]		21[b]		15.7[a]	

EP/HR (Rest) : Prob > F = 0.0034

Age	0-30		31-40		41-50		51+
EP/HR Mean	4.00	(.25)	4.25	(.13)	5.38	(.97)	4.41
LSD		.74		.74		.74[a]	

EP/HR (1 Min Post-Ex.) : Prob > F = 0.008

Age	0-30		31-40		41-50		51+
EP/HR Mean	3.36	(.31)	3.05	(.90)	3.95	(.59)	3.36
LSD		.61		.82[b]		.61	

EP/HR (1 Min Post-Ex.) : Prob > F = .0096

Age	0-30		31-40		41-50		51+
EP/HR Mean	4.05	(.18)	3.87	(1.00)	4.87	(.84)	4.03
LSD		.71		.96[b]		.71[a]	

*The number in parentheses denotes the difference between the means of the age groups.

a = LSD at .05.

b = LSD at .01.

The conclusion might therefore be drawn that the age group may differ in fitness, and the significant difference between the EP/HR and heart rate of the groups is due not only to age but to cardiovascular conditioning as well.

Summary of Results

The means of the parameters of the cardiac dynamic cycle and the fitness variables agreed with those reported in previous publications.

The analysis of variance revealed no significant differences for Cooper's fitness classification. However, max VO_2 uptake and the EP/HR ratio could differentiate between the exercise and nonexercise groups.

The ANOVA also indicated that EP (rest), all EP/HR ratios, and heart rate could discriminate between the age levels.

Of the resting parameters, the ratios proved related to cardiovascular variables but not to respiratory ones.

The post-exercise intervals and ratios indicated approximately the same relationships as above to the variables; however, the correlations and significance were increased in most cases.

While these relationships were highly significant, the correlations were generally below 0.6 which is too low for the parameters to have sufficient predictive power for cardiovascular fitness assessment. Yet, the employment of some of the parameters of the cardiac cycle for fitness screening or their use in conjunction with other tests for fitness assessment must still be considered valuable. Furthermore, fitness evaluation by the five minute post-exercise ratio EP/HR would not necessitate a recording of the EKG and phonocardiogram, as required for the other parameters, but only one of the carotid pulse wave and heart rate.

This aspect would make the fitness test quite efficient in respect to time required for data evaluation and accuracy in measurement.

The EP/HR recorded at five minutes after exercise also produced the most significant correlations of all parameters and ratios, particularly with cardiovascular variables. This left ventricular systolic time interval ratio may be considered a suitable fitness index for use in fitness screening. Other studies indicate that this measure discriminates between different levels of cardiovascular fitness. Changes in this ratio discovered through serial testing could be useful in detection or possibly prediction of cardiovascular disease.

FOOTNOTES

[1]G. C. Sutton et al., "Measurement of Mechanical and Electrical Events of the Cardiac Cycle: I. Effect of Tachycardia, Pre-Anesthetic Medication and Di-Ethyl Ether Anesthesia," American Journal of Medical Science, CCXXXII (1956), pp. 648-653.

[2]E. L. Sloniger, "Relationship of Stress Indicators to Pre-Ejection Cardiac Intervals," (unpub. doctoral dissertation, University of Illinois, 1966), quoted in Frank and Cureton, p. 526.

[3]A. S. Hyman, "The Q-First Heart Sound Interval in Ahtletes at Rest and After Exercise," Journal of Sports Medicine and Physical Fitness, IV (1964), pp. 199-203.

[4]E. deF. Baldwin, A. Cournand, and W. R. Dickinson, Jr., "Pulmonary Insufficiency. I. Physiological Classification, Clinical Methods of Analysis, Standard Values in Normal Subjects," Medicine, XXVII (1948, pp. 243-278.

[5]R. C. Kory et al., "The Veterans Administration-Army Cooperative Study of Pulmonary Function," American Journal of Medicine, XXX (1961), pp. 243-258.

[6]Don Franks and T. K. Cureton, Jr., "Orthogonal Factors of Cardiac Intervals and Their Response to Stress," Research Quarterly, XXXIX (1967), p. 526.

[7]Thomas L. Whitsett and John Naughton, "The Effect of Exercise on Systolic Time Intervals in Sedentary and Active Individuals and Rehabilitated Patients with Heart Disease," The American Journal of Cardiology, XXVII (1971), pp. 352-358.

[8]Whitsett and Naughton, p. 357.

[9]P. V. Karpovich, Physiology of Muscular Activity (Philadelphia, 1971), p. 199.

[10]Karpovich, p. 199.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

From an analysis of the results obtained on the 41 subjects in this study, the following conclusions were made in regard to the research objectives that were investigated:

(1) The resting parameters TP, EML, ICP, EP, EP/ICP, and EP/TP indicated no significant or only moderate correlations to fitness variables and had no discriminative powers between fit and unfit individuals. It was concluded that these resting time intervals and the ratios EP/ICP as well as EP/TP are not suitable indexes for cardiovascular fitness.

(2) The resting ratio EP/HR was significantly correlated to max VO_2 uptake as well as cardiovascular and respiratory (VC) variables. The correlation, however, was too low to have satisfactory predictive power for fitness assessments. The ANOVA revealed a significant difference between the resting ratios of the exercise and nonexercise groups. It was concluded that the resting ratio EP/HR provides a rough index of cardiovascular fitness which might be useful for group fitness classification.

(3) The 1 minute post-exercise parameters TP, EML, ICP, EP, and EP/ICP showed no or only moderately significant correlations to the fitness variables. These parametric values also indicated no discriminative powers between various levels of cardiovascular or respiratory

fitness. It was concluded that these parameters are not suitable indexes for cardiovascular fitness.

(4) The correlations between the 1 minute post-exercise ratios and the fitness variables increased above those obtained at rest. The ANOVA, however, revealed significant differences only between the EP/HR of the exercise and nonexercise groups. It was concluded that the EP/TP ratio warrants further investigation in view of its significant correlations to the fitness variables. This investigation could not determine the cause for the ratio's lack of discriminative power in regard to fitness states. The 1 minute post-exercise EP/HR ratio offers an index of fitness that is superior to the resting one.

(5) The 5 minute post-exercise parameters were similar to the 1 minute measurements. Yet, the correlations, while highly significant, were still too low to be considered to have good predictive power for cardiovascular fitness. The EP/HR and EP/TP had the highest significant correlations with the fitness variables of all intervals tested in this study. The EP/HR, however, was still superior in its relationships with the fitness variables, indicating, for example, an $r = 0.40$, $P < 0.009$ for max VO_2 uptake, $r = 0.38$, $P < 0.014$ for Cooper's fitness levels, $r = 0.39$, $P < 0.012$ for exercise/nonexercise groups, $r = 0.60$, $P < 0.001$ for the Schneider Index. It was also the only ratio the ANOVA indicated as a discriminator between exercise and nonexercise groups. It was concluded that the EP/HR ratio measured five minutes after exercise is the parameter of the cardiac dynamic cycle that offers the greatest potential as an index of cardiovascular fitness.

(6) The parametric values calculated to indicate the change from rest to one and five minutes after exercise revealed no significant

correlations or discriminating power between levels of fitness. It was, therefore, concluded that these calculated differences are of no value in cardiovascular fitness assessment.

Recommendations

Various phases of the cardiac cycle have shown significant correlations or strong trends (0.10 level of significance) to cardiovascular and respiratory fitness variables as well as to the weight residual. On the basis of these findings the following recommendations are made:

(1) Classification norms should be established for the use of the EP/HR ratio in general cardiovascular fitness assessment.

(2) The EP/HR ratio should be employed in longitudinal studies to investigate its possible use for early detection or prediction of heart disease.

(3) The EP/TP ratio's relationship to fitness variables should be investigated to further substantiate its validity for possible use in fitness assessment.

(4) Further studies attempting to relate systolic time intervals to cardiovascular fitness should seek an even distribution of subjects across fitness levels reading into the lower fitness categories.

BIBLIOGRAPHY

Ahmed, S. Sultan et al. "Systolic Time Intervals as Measures of the Contractile State of the Left Ventricular Myocardium in Man." Circulation, Vol. 46 (1972), pp. 559-571.

Andreoli, Kathleen et al. Comprehensive Cardiac Care. 2nd ed. St. Louis: C. V. Mosby, Inc., 1971.

Armstrong, T. G., B. S. Lewis, and M. S. Gotsman. "Systolic Time Intervals in Constrictive Pericarditis and Severe Primary Myocardial Disease." American Heart Journal, Vol. 85 (1973), pp. 6-12.

Aronow, W., A. Bowyer, and M. Kaplan. "External Isovolumic Contraction Times and Left Ventricular Ejection Time/External Isovolumic Contraction Time Ratios at Rest and After Exercise in Coronary Heart Disease." Circulation, Vol. 48 (1971), pp. 59-67.

Astrand, P. O. and K. Randahl. Textbook of Work Physiology. New York: McGraw-Hill Book Company, 1970.

Baldwin, E. DeF., A Cournard, and D. W. Richards, Jr. "Pulmonary Insufficiency, I, Physiologic Classifications, Clinical Methods of Analysis, Standard Values in Normal Subjects." Medicine, Vol. 27 (1948), p. 243.

Balke, Bruno. "The Effect of Physical Exercise on the Metabolic Potential a Crucial Measure of Physical Fitness." Exercise and Fitness. Urbana: University of Illinois Press, 1960.

Balke, Bruno and R. W. Ware. "An Experimental Study of Physical Fitness in Air Force Personnel." U. S. Armed Forces Medical Journal, Vol. 10 (1959), p. 675.

Barach, J. H. et al. "Physiological and Pathological Effects of Severe Exertion." American Physical Education Review, Vol. 16 (1911), pp. 262-325.

Behnke, A. R. "Anthropometric Fractionation of Body Weight." Journal of Physiology, Vol. 16 (1961), pp. 949-954.

Behnke, A. R., B. G. Feen, and W. C. Wilham. "Specific Gravity of Healthy Men. Body Weight--Volume as an Index of Obesity." Journal of the American Medical Association, Vol. 118 (1942), pp. 495-498.

Berglund, E. et al. "Spirometric Studies in Normal Subjects, I. Forced Spirograms in Subjects Between 7 and 70 Years of age." Acta med. Scand., Vol. 38 (1963), pp. 173-185.

Bloomfield, John and Peter O. Sigerseth. "Anatomical and Physiological Differences Between Sprint and Middle Distance Swimmers at the University Level." Journal of Sports Medicine, Vol. 5 (1965), pp. 75-81.

Blumberger, Karljosef. "Die Untersuchung der Dynamik des Herzens beim Menschen. Ihre Anwendung als Herzleistungsprüfung." Ergebnisse der Inneren Medizin und Kinderheilklinik, Vol. 42 (1942), p. 424.

Blumberger, Karljosef and S. Meiners. "Studies of Cardiac Dynamics." Cardiology: An Encyclopedia of the Cardiovascular System, Vol. 2, ed. A. Luisada. New York: McGraw-Hill Book Company, 1959.

Blumberger, Karljosef and S. Effert. Quoted by Emmrich, Klepzig, and Reindell in "Zur Frage der klinischen Bedeutung einer Unterteilung der Anspannungszeit des linken Ventrikels in Umformungszeit und Druckanstiegszeit." Archiv für Kreislaufforschung, Vol. 24, pp. 177-204.

Boileau, R. A. et al. "Body Composition Changes in Obese and Lean Men During Physical Conditioning." Medicine and Science in Sports, Vol. 3 (1972), pp. 183-189.

Brouha, L. "Physiological Reactions of Men and Women During Muscular Activity and Recovery in Various Environments." Journal of Applied Physiology, Vol. 16 (1961), p. 133.

Brown, B. S. et al. "Physiological and Hematological Changes Among Basketball Players During Preseason." Research Quarterly, Vol. 40 (1974), pp. 257-262.

Brozek, J. and A. Keys. "The Evaluation of Leanness-Fatness in Man: Norms and Interrelationships." British Journal of Nutrition, Vol. 5 (1951), pp. 194-206.

Buccola, V. A. and W. J. Stone. "Effects of Jogging and Cycling Programs on Physiological and Personality Variables in Aged Men." Research Quarterly, Vol. 46 (1975), pp. 134-139.

Buskirk, E. and H. L. Taylor. Journal of Applied Physiology, Vol. 11 (1957), p. 72. Quoted in A. Ryan and F. Allman, Jr., eds. in Sports Medicine. New York: Academic Press, 1974.

Butschenko, L. A. Elektrokardiografiya v Sportivnoy Meditsine (Leningrad, 1963). Quoted in Karpman and Kulolevskiy in The Heart and Sports. Essays on Cardiology in Sports. Washington, D.C.: National Aeronautics and Space Administration, 1971.

Canadian Medical Association (1967). "Proceedings of the International Symposium on Physical Activity and Cardiovascular Health." Canadian Medical Association Journal, Vol. 96 (1967), pp. 695-917.

Carey, C. R., K. E. Schaeffer, and H. J. Alvis. "Effects of Skin Diving on Lung Volumes." Journal of Applied Physiology, Vol. 8 (1955), pp. 519-523.

Consolazio, Frank, Robert Johnson, and Louis Pecora. Physiological Measurements of Metabolic Functions in Man. New York: McGraw-Hill Book Company, 1963.

Cooper, Kenneth H. Aerobics. New York: Bantam Books, Inc., 1968.

Costill, David L. "The Relationship Between Selected Physiological Variables and Distance Performance." Medicine and Science in Sports, Vol. 7 (1967), pp. 61-66.

Costill, David L., H. Thomason, and E. Roberts. "Fractional Utilization of the Aerobic Capacity During Distance Running." Medicine and Science in Sports, Vol. 5 (1973), pp. 248-252.

Cotton, F. S. "The Relation of Athletic Status to the Pulse Rate in Men and Women." Journal of Physiology, Vol. 126 (1932), pp. 39-51.

Crofton, J. and A. Douglas. Respiratory Diseases. Oxford: Blackwell Scientific, 1969.

Csinady, von E. "Sportärztliche Untersuchungen, III. Mitteilung: vergleichende elektrokardiographische Untersuchungen an Sporttreibenden bei besonderer Berücksichtigung der EKG-Zeitwerte." Arbeitsphysiologie, Vol. 3 (1930), pp. 579-595.

Cureton, Thomas Kirk. The Physiological Effects of Exercise Programs on Adults. Springfield: Charles C. Thomas, 1969.

________. Physical Fitness of Champion Athletes. Springfield, Ill.: Charles C. Thomas, 1951.

________. Physical Fitness Appraisal and Guidance. Springfield, Ill.: Charles C. Thomas, 1951.

________. "Effects of Longitudinal Physical Training on the Amplitude of the Highest Precordial T-Wave of the EKG." Medicina Sportiva, Vol. 12 (1958), pp. 259-281.

Cureton, Thomas Kirk and E. E. Phillips. "Physiological Fitness Changes in Middle-Aged Men Attributable to Equal Eight-Week Periods of Training, Non-Training and Re-Training." Journal of Sports Medicine, Vol. 4 (1964), pp. 87-93.

Cureton, Thomas Kirk and L. F. Sterling. "Factor Analysis of Cardiovascular Test Variables." The Journal of Sports Medicine and Physical Fitness, Vol. 4 (1964), pp. 1-24.

Daniels, J. "Aerobic and Anaerobic Performance Characteristics of Champion Runners at Sea Level and Moderate Altitude." (Unpub. doctoral dissertation, University of Wisconsin, 1969.)

Dawson, P. M. "Effect of Physical Training and Practice on the Pulse Rate and Blood Pressure During Activity and During Rest, with a Note on Certain Acute Infections and on the Distress Resulting from Exercise." American Journal of Physiology, Vol. 90 (1917), p. 443.

Dempsey, Jerry A. "Anthropometrical Observations on Obese and Nonobese Young Men Undergoing a Program of Vigorous Physical Exercise." Research Quarterly, Vol. 35 (1964), pp. 275-287.

________. "Relationship Between Obesity and Treadmill Performance in Sedentary and Active Young Men." Research Quarterly, Vol. 35 (1964), p. 295.

Durusoy, F. and H. Özgönül. "Lung Function Studies on Former Athletes Who Are Now Football Referees." Journal of Sports Medicine, Vol. 2 (1971), pp. 139-145.

Emmrich, Johannes. "Zur Frage der klinischen Bedeutung einer Unterteilung der Anspannungszeit des linken Ventrikels in Umformungszeit und Druckanstiegszeit." (Unpub. doctoral dissertation, University of Freiburg, Germany, 1955.)

Emmrich, J., H. Klepzig, and H. Reindell. "Zur Frage der klinischen Bedeutung einer Unterteilung der Anspannungszeit des linken Ventrikels in Umformungszeit und Druckanstiegszeit." Archiv für Kreislaufforschung, Vol. 24 (1956), pp. 177-204.

Epstein, F. H. and R. D. Eckhoff. "Epidemiology of High Blood Pressure--Geographic Distributions and Etiological Factors." The Epidemiology of Hypertension. Ed. J. Stamler and R. Stamler. New York: Grune and Stratton, Inc., 1967.

Fardy, Paul S. "The Effects of Soccer Training and Detraining Upon Selected Cardiac and Metabolic Measures." Research Quarterly, Vol. 90 (1969), pp. 502-509.

________. "The Influence of Physical Activity on Selected Cardiac Cycle Time Components." Journal of Sports Medicine, Vol. 11 (1971), pp. 227-233.

Frank, O. Zeitschrift für Biologie, Vol. 37 (1899), pp. 483-529. Quoted in Karpman and Kukolevskiy, The Heart and Sports. Essays on Cardiology in Sports. Washington, D.C.: National Aeronautics and Space Administration, 1971.

Froelicher, V. F. et al. "A Comparison of the Balke and Bruce Protocols." Submitted for publication, cited in their letter to the editor. American Heart Journal, Vol. 88 (1974), p. 534.

Froelicher, V. F. and M. C. Lancaster. "The Prediction of Maximal Oxygen Consumption from a Continuous Exercise Treadmill Protocol." American Heart Journal, Vol. 87 (1974), pp. 445-450.

Froelicher, V. F. et al. "A Comparison of the Reproducibility and Physiolgoical Response to Three Maximal Treadmill Protocols." Chest, Vol. 65 (1974), p. 512.

Gordon, B., S. A. Levine, and A. Wilmaers. "Observations on a Group of Marathon Runners." Archive of Internal Medicine, Vol. 33 (1924),

Grimby, G. and B. Saltin. "Physiological Analysis of Physically Well-Trained Middle-Aged and Old Athletes." Acta Med. Scandinavica, Vol. 43 (1966), pp. 179-513.

Hamosh, Paul et al. "Systolic Interval and Left Ventricular Function in Acute Myocardial Infarction." Circulation, Vol. 45 (1972), pp. 375-380.

Hess, W. R. Deutsches Archiv für klinische Medizin, Vol. 132 (1920), p. 69. Quoted in K. Holldack, Deutsches Archiv für klinische Medizin, Vol. 198 (1951), pp. 71-90.

Hexheimer, H. Zeitschrift für klinische Medizin (1923), p. 484. Quoted in Zeitschrift für die gesamte Experimentelle Medizin, Vol. 60 (1928), pp. 490-501.

Hill, A. V. Muscular Activity. Baltimore: Williams and Wilkins Company, 1926.

Holldack, K. "Die Bedeutung der 'Umformungs- und Druckanstiegszeit' für die Herzdynamik." Deutsches Archiv für klinische Medizin, Vol. 198 (1951), pp. 71-90.

Hollman, V. Der Arbeits- und Trainingseinfluss auf Kreislauf und Atmung (Darmstadt, 1959). Quoted in Hypokinetic Disease. Springfield, Ill.: Charles C. Thomas, 1961, p. 68.

Hoogerwerf, S. "Elektrokardiographische Untersuchungen der Amsterdamer Olympiade Kämpfer." Arbeitsphysiologie, Vol. 2 (1929), pp. 61-76.

Hürthle, P. "Beiträge zur Hamodynamik." Archiv für die gesamte Physiologie, Vol. 46 (1891), pp. 29-104. Quoted in The Heart and Sports. Essays on Cardiology in Sports. Washington, D.C.: National Aeronautics and Space Administration, 1971, p. 20.

Hutchinson, John. Transactions of the Royal Medico Society of London (1846), p. 137. Quoted in Physical Fitness Appraisal and Guidance. Springfield, Ill.: Charles C. Thomas, 1951, p. 334.

Hyman, Albert S. "The Q-First Heart Sound Interval in Athletes at Rest and After Exercise." Journal of Sports Medicine and Physical Fitness, Vol. 4 (1964), pp. 199-203.

Johnson, R. E., L. Brouha, and R. C. Darling. "A Test of Physical Fitness for Strenuous Exertion." Review of Canadian Biology, Vol. 1 (1942), pp. 491-503.

Kaminer, R. and W. P. Lutz. "Blood Pressure in Bushmen of the Kalahari Desert." Circulation, Vol. 22 (1960), pp. 289-295.

Karpman, V. L. and G. M. Kukolevskiy, eds. The Heart and Sports. Essays on Cardiology in Sports. Washington, D. C.: National Aeronautics and Space Administration, 1971, pp. 220-221.

Karpovich, P. V. Physiology of Muscular Activity. Philadelphia: W. B. Saunders Company, 1965.

Kasch, F. Cited in Aerobics. New York: Bantam Books, 1968, p. 131.

Katz, L. N. Electrocardiography. 2nd ed. Philadelphia: W. B. Saunders Company, 1947.

Kearney, J. T. and W. C. Byrnes. "Relationship Between Running Performance and Predicted Maximum Oxygen Uptake Among Divergent Ability Groups." Research Quarterly, Vol. 45 (1974), pp. 9-15.

Keys, A. "Body Composition and Its Change with Age and Diet." Weight Control (Colloquium Presentation, Ames, Iowa, 1955). Quoted in "Anthropometrical Observations on Obese and Nonobese Young Men Undergoing a Program of Vigorous Physical Exercise." Research Quarterly, Vol. 35 (1964), pp. 275-287.

Knuttgen, H. G. "Physical Working Capacity and Physical Performance." Medicine and Science in Sports, Vol. 1 (1969), pp. 1-8.

Kory, R. C. et al. "The Veterans' Administration--Army Cooperative Study of Pulmonary Function." American Journal of Medicine, Vol. 30 (1961), pp. 243-258.

Kraus, F. and G. Nicolai. Das Elektrokardiogramm (Leipzig,1910). Quoted in Zeitschrift für die gesamte Experimentelle Medizin, Vol. 60 (1928), pp. 490-501.

Kraus, F. and W. Raab. Hypokinetic Disease. Springfield, Ill.: Charles C. Thomas, 1961.

Lang, E. "Einfluss der Pulsfrequenz auf die Kontraktionsphasen des Herzens." Zeitschrift für Kreislaufforschung, Vol. 54 (1965), pp. 479-487.

Letunov, S. P. and R. Ye. Motylyanskaya, 1951. Quoted in The Heart and Sports. Essays on Cardiology in Sports. Washington, D.C.: National Aeronautics and Space Administration, 1971, p. 6.

Maass, H. "Über ein Verfahren zur Messung der Anspannungszeit und Austreibungszeit beim Menschen." Zeitschrift für Kreislaufforschung, Vol. 38 (1949), p. 228.

Mathews, D. K. and E. I. Fox. The Physiological Basis of Physical Education and Athletics. Philadelphia: W. B. Saunders Company, 1971.

Mellerowicz, H. "Vergleichende Untersuchungen über das Oekonomieprinzip in Arbeit und Leistung des trainierten Kreislaufs und seine Bedeutung für die rehabilitative Medizin." Archiv für Kreislaufforschung, Vol. 24 (1956), pp. 70-176.

Messerle, N. "Die Veränderung im Elektrokardiogramm bei Körperarbeit." Zeitschrift für die gesamte Experimentelle Medizin, Vol. 60 (1928), pp. 490-501.

Michael, E. D., Jr. and A. J. Gallon. "Pulse Wave and Pressure Change Occurring During a Physical Training Program." Research Quarterly, Vol. 31 (1959), pp. 43-60.

Millahn, H. P. "Die Kontraktionsphasen des jugendlichen Herzens und ihre Beziehung zur Hämodynamik." Zeitschrift für Kreislaufforschung, Vol. 53 (1964), pp. 179-187.

Miller, A. T. and C. S. Blyth. "Influences of Body Type and Body Fat Content on the Metabolic Cost of Work." Journal of Applied Physiology, Vol. 8 (1955), pp. 139-141.

Mitchel, H., B. J. Sproule, and C. B. Chapman. "The Physiological Meaning of the Maximal Oxygen Intake Test." Journal of Clinical Investigation, Vol. 34 (1958), p. 538.

Molnar, S. "Relationship Between Cardiac Time Components, Maximal Oxygen Consumption and Endurance Performance." (Unpub. Ph.D. dissertation, University of Illinois, 1970.)

Montoye, Henry J. et al. "Systolic Preejection Period: Relation to Habitual Physical Activity." Medicine and Science in Sports, Vol. 4 (1972), p. 78.

________. "Habitual Physical Activity and Blood Pressure." Medicine and Science in Sports, Vol. 4 (1972), pp. 175-181.

________. "Inter-relation of Maximum Pulse Rate During Moderate Exercise, Recovery Pulse Rate, and Post-Exercise Blood Lactate." Research Quarterly, Vol. 24 (1953), pp. 453-458.

McCurdy, J. H. "Adolescent Changes in Heart Rate and Blood Pressure." American Physical Education Review, Vol. 15 (1910), p. 421.

McHenry, P. L. et al. "Cardiac Arrhythmias Observed During Maximal Treadmill Exercise Testing in Clinically Normal Men." American Journal of Cardiology, Vol. 24 (1972), p. 331.

Nagle, F. and T. Bedecki. "Use of the 180 Heart Rate Response as a Measure of Circulorespiratory Capacity." Research Quarterly, Vol. 34 (1963), pp. 361-369.

Nandi, Priya S. and David Spodick. "Determination of Systolic Intervals Utilizing the Carotid First Derivative." American Heart Journal, Vol. 84 (1973), p. 495.

Newman, F., B. F. Smelley, and M. L. Thomson. "A Comparison Between Body Size and Lung Function of Swimmers and Normal School Children." Journal of Physiology, Vol. 146 (1961), pp. 9-10.

Newton, J. "Assessment of Maximal Oxygen Intake." Medicine and Science in Sports, Vol. 3 (1963), pp. 164-169.

Parisi, Alfred F. et al. "The Short Cardiac Pre-ejection Period, an Index to Thyrotoxicosis." Circulation, Vol. 94 (1974), pp. 900-904.

Perloff, Joseph K. and Nathaniel Reichek, eds. "Value and Limitations of Systolic Time Intervals (Pre-ejection Period and Ejection Time) in Patients with Acute Myocardial Infarction." Circulation, Vol. 95 (1972), pp. 929-932.

Raab, W. "Exercise and Ischemic Heart Disease." Proceedings, Second National Conference on Cardiovascular Disease, Washington, D. C., 1964, pp. 356-357. Quoted in H. J. Montoye et al. "Systolic Pre-ejection Period: Relation to Habitual Physical Activity." Medicine and Science in Sports, Vol. 4 (1972), p. 77.

________. "Adrenergic-Cholinergic Control of Cardiac Metabolism and Function." Advances of Cardiology, Vol. 1 (1956), p. 65.

Raab, W. et al. "Cardiac Adrenergic Preponderance Due to Lack of Physical Exercise and Its Pathogenic Implications." American Journal of Cardiology, Vol. 5 (1960), p. 300.

Raab, W. and H. J. Krzywanek. "Cardiovascular Sympathetic Tone and Stress Response Related to Personality Patterns and Exercise Habits. A Potential Cardiac Risk and Screening Test." American Journal of Cardiology, Vol. 16 (1965), p. 42.

Reindell, H. and H. Klepzig. "Untersuchungen über die Anspannungs- und Austreibungszeit des Herzens bei Herzmuskelschädigung und bei veränderter Kreislaufregulation." Zeitschrift für Kreislaufforschung, Vol. 38 (1949), p. 146.

Ricci, Benjamin. Physiological Basis of Human Performance. Philadelphia: Lea and Febiger, 1967.

Robinson, C., A. Cagby, and G. Draper. Deutches Archiv für klinische Medizin, Vol. 100 (1910), p. 347. Quoted by J. Emmrich in "Zur Frage der klinischen Bedeutung einer Unterteilung der Anspannungszeit." Archiv für Kreislaufforschung, Vol. 24 (1956), pp. 177-204.

Saltin, B. et al. "Response to Exercise After Bed Rest and After Training." Circulation, Vol. 38 (1968), No. 5 (Supplement 7), pp. 48-50.

Schneider, E. C. "A Cardiovascular Rating as a Measure of Physical Fatigue and Efficiency." Journal of the American Medical Association, Vol. 52 (1920), p. 1507.

Schulz, Hanns. "Über die Bestimmungsmöglichkeit der Anspannungszeit des Herzens." Zeitschrift für Kreislaufforschung, Vol. 12 (1937), pp. 427-434.

Sessa, T. and D. Vallario. Medicina dello Sport, Vol. 2 (Roma, 1964), in Journal of Sports Medicine, Vol. 5 (1965), p. 43.

Shkhavatsabaya, Yu. K. "Investigation of the Length of Phases of the Cardiac Cycle During Muscular Exercise." Kardiologiva, Vol. 4 (1964), pp. 62-68.

Sigler, L. H. The Electrocardiogram, Its Interpretation and Clinical Application. New York: Green and Stratton, Inc., 1957.

Sime, W. E. et al. "Reproducibility of Heart Rate at Rest and in Response to Submaximal Treadmill and Bicycle Ergometer Test in Middle-Aged Men." Medicine and Science in Sports, Vol. 4 (1972), pp. 14-17.

Simonson, E. et al. "The Effects of Meals on the Electrocardiogram in Normal Subjects." American Heart Journal, Vol. 35 (1964), p. 202.

Slongiger, E. L. "Relationship of Stress Indicators to Pre-ejection Cardiac Intervals." (Unpub. doctoral dissertation, University of Illinois, 1966.)

Spodick, D. H., C. A. Dorr, and B. F. Calbrese. "Detection of Cardiac Abnormalities by Clinical Measurement of Left Ventricular Ejection Time." Journal of the American Medical Association, Vol. 206 (1969), pp. 239-242.

Spodick, D. H. and S. Kumar. "Left Ventricular Ejection Period: Results in Normal Young Men and Comparison of Methods of Calculation." American Heart Journal, Vol. 76 (1968), pp. 70-73.

Sutton, G. C. et al. "Measurement of Mechanical and Electrical Events of the Cardiac Cycle: I. Effect of Tachycardia, Pre-Anesthetic Medication and Di-Ethyl Ether Anesthesia." American Journal of Medical Science, Vol. 232 (1956), pp. 648-653.

Symposium on "The Catecholamines in Cardiovascular Pathology." University of Vermont, August 23-26, 1956. American Journal of Cardiology, Vol. 5 (1960), pp. 571-665.

Tavel, Morton E. Clinical Phonocardiocargraphy and External Pulse Recording. 2nd ed. Chicago: Year Book Medical Publisher, Inc., 1973.

Taylor, A. W. "A Physiological Analysis of the Effects of Two Training Programs." Journal of Sports Medicine, Vol. 11 (1971), pp. 252-256.

Taylor, H. L. "Occupational Factors in the Study of Coronary Heart Disease and Physical Activity." Canadian Medical Association Journal, Vol. 96 (1956), pp. 825-831.

Tharp, Gerald. "Cardiac Function Tests as Indexes of Fitness." Research Quarterly, Vol. 40 (1970), pp. 818-823.

Thomas, Clayton L., ed. "Pulse Pressure." Taber's Cyclopedic Medical Dictionary. 12th ed. Philadelphia: F. A. Davis Company, 1970, p. 175.

Thompson, C. W., E. R. Buskirk, and R. F. Goldman. "Changes in Body Fat Estimated from Skinfold Measures of College Basketball and Hockey Players During a Season." Research Quarterly, Vol. 27 (1956), pp. 418-430.

Truswell, A. S. et al. "Blood Pressures of !Kung Bushmen in Northern Botswana." American Heart Journal, Vol. 84 (1972), pp. 5-12.

Tuttle, W. W. and H. M. Korns. "Electrocardiographic Observations on Athletes Before and After Season of Physical Training." American Heart Journal, Vol. 21 (1941), pp. 104-107.

"Latest Fight Against Heart Attacks." U. S. News and World Report, Vol. 126 (February 3, 1975), pp. 42-43.

Waquero, M., R. Limon, and A. Limon (1947). Quoted in The Heart and Sports. Essays on Cardiology in Sports. Eds. V. L. Karpman and G. M. Kukolevskiy. Washington, D. C.: National Aeronautics and Space Administration, 1971, p. 119.

Weissler, Arnold, Robert Peeler, and Walter Roehll. "Relationships Between Left Ventricular Ejection Time, Stroke Volume, and Heart Rate in Normal Individuals and Patients with Cardiovascular Disease." American Heart Journal, Vol. 62 (1961), pp. 367-378.

Welch, B. E. et al. "Relationship of Maximal Oxygen Consumption to Various Components of Body Compression." Journal of Applied Physiology, Vol. 12 (1958), pp. 395-398.

Whitsett, Thomas and John Naughton. "The Effect of Exercise on Systolic Time Intervals in Sedentary and Active Individuals and Rehabilitated Patients with Heart Disease." The American Journal of Cardiology, Vol. 27 (1971), pp. 352-358.

Wiggers, Carl J. "Studies on the Consecutive Phases of the Cardiac Cycle." American Journal of Physiology, Vol. 56 (1921), pp. 439-459.

Wiley, Jack. "Effects of 10 Weeks of Endurance Training on Left Ventricular Intervals." Journal of Sports Medicine, Vol. 11 (1971), pp. 104-111.

Wilmore, J. H. "Maximal Oxygen Intake and Its Relationship to Endurance Capacity on a Bicycle Ergometer." Research Quarterly, Vol. 40 (1969), pp. 203-210.

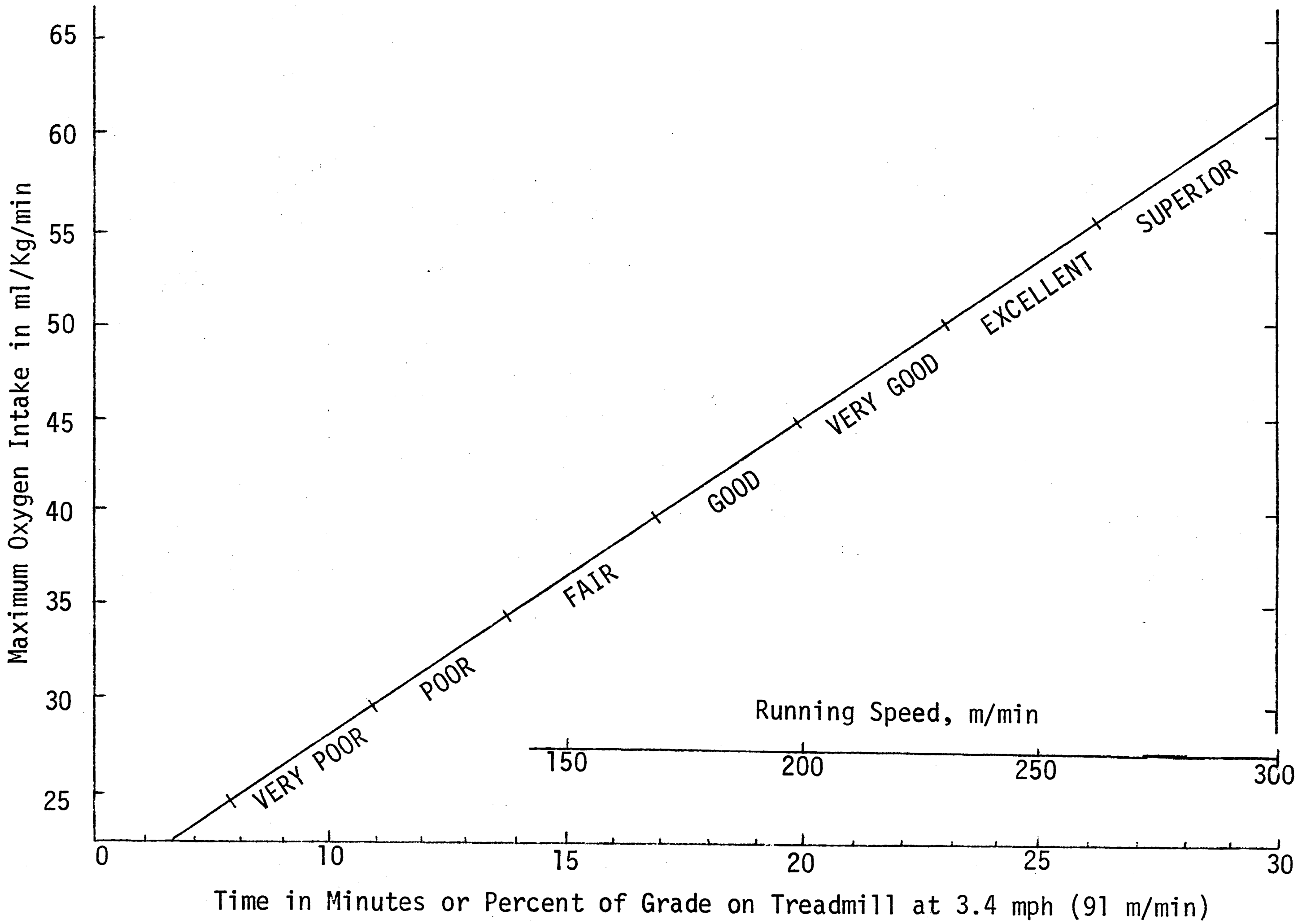
Wilmore, J. H. et al. "Physiological Alterations Resulting from a 10-Week Program of Jogging." Medicine and Science in Sports, Vol. 2 (1970), pp. 7-14.

Zalis, Edwin G. and Mary H. Conover. Understanding Electrocardiography. St. Louis: C. V. Mosby Company, 1972.

APPENDIX A

CONVERSION CHART FOR WALKING TIME

MAX VO_2 INTAKE


Maximum Oxygen Intake in ml/Kg/min
65
60
55
50
45
40
35
30
25
VERY POOR
POOR
FAIR
GOOD
VERY GOOD
EXCELLENT
SUPERIOR
Running Speed, m/min
150
200
250
300
0
10
15
20
25
30
Time in Minutes or Percent of Grade on Treadmill at 3.4 mph (91 m/min)

APPENDIX B

SCHNEIDER INDEX SCORING SHEET

SCHNEIDER INDEX

Name____Date_____________

Observations

Lying Position: Pulse Rate_______Systolic BP_______Diastolic BP___________

Standing Position: Pulse Rate_______Systolic BP_______Diastolic BP________

STEP EXERCISE (5 steps - chair 20" high): Pulse Rate Immediately After Exercise_____

Pulse Rate After Exercise: 30 sec._____ 60 sec._______90 sec._______120 sec._______

Scoring Table

A. Reclining Pulse Rate		B. Pulse Rate Increase on Standing				
Rate	Points	0-10	11-18	19-26	27-34	35-42
41-50	4	4	4	3	2	1
51-60	3	3	3	2	1	0
61-70	3	3	2	1	0	-1
71-80	2	3	2	0	-1	-2
81-90	1	2	1	-1	-2	-3
91-100	0	1	0	-2	-3	-3
101-110	-1	0	-1	-3	-3	-3

C. Standing Pulse Rate		D. Pulse Rate Change Immediately After Exercise				
Rate	Points	0-10	11-20	21-30	31-40	41-50
51-60	4	4	4	3	2	1
61-70	3	3	3	2	1	0
71-80	3	3	3	2	0	0
81-90	2	3	2	1	0	-1
91-100	1	2	1	0	-1	-2
101-110	1	1	0	-1	-2	-3
111-120	0	1	-1	-2	-3	-3
121-130	0	0	-2	-3	-3	-3
131-140	-1	0	-3	-3	-3	-3

E. Return of Pulse Rate to Standing Normal after Exercise		F. Standing Systolic B.P. Compared with Reclining Systolic B.P.	
Seconds	Points	Change in Millimeters	Points
0-30	3	Rise 30 and more	-2
31-60	2	Rise 21 to 30	-1
61-90	1	Rise 16 to 20	0
91-120	0	Rise 11 to 15	1
After 120 2-10 beats Above normal	-1	Rise of 6 to 10	2
		No rise greater than 5	3
		Fall of 6 to 10	2
After 120 11-30 Above normal	-2	Fall of 11 to 15	1
		Fall of 16 to 20	0
		Fall of 21 to 25	-1
		Fall of 26 and more	-2

APPENDIX C

RESPIRATORY CHARTS

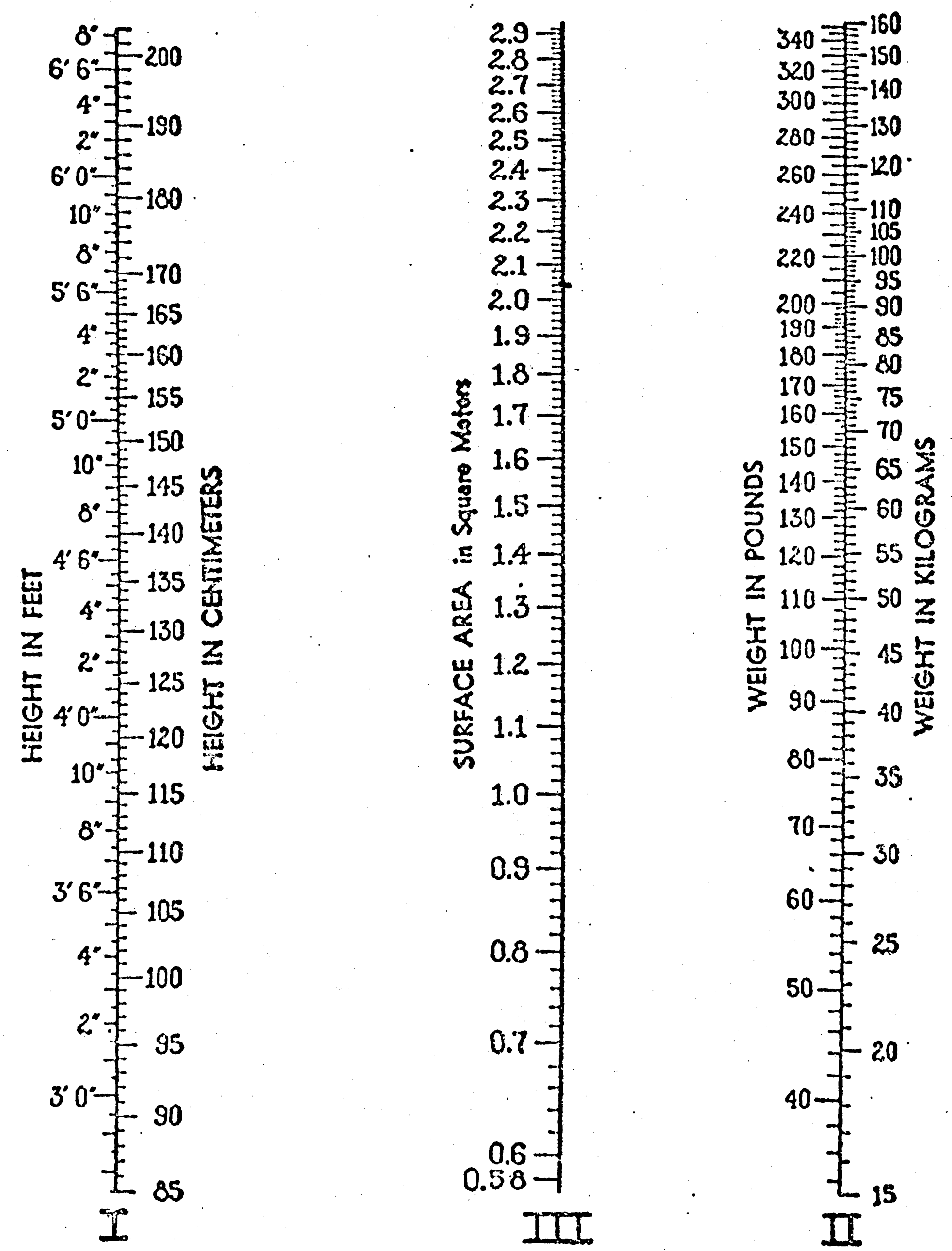
PREDICTED VITAL CAPACITY--MALES

HEIGHT IN CENTIMETERS

Age	146	148	150	152	154	156	158	160	162	164	166	168	170	172	174	176	178	180	182	184	186	188	190	192	194
16	3765	3820	3870	3920	3975	4025	4075	4130	4180	4230	4285	4335	4385	4440	4490	4540	4590	4645	4695	4745	4800	4850	4900	4955	5005
18	3740	3790	3840	3890	3940	3995	4045	4095	4145	4200	4250	4300	4350	4405	4455	4505	4555	4610	4660	4710	4760	4815	4865	4915	4965
20	3710	3760	3810	3860	3910	3960	4015	4065	4115	4165	4215	4265	4320	4370	4420	4470	4520	4570	4625	4675	4725	4775	4825	4875	4930
22	3680	3730	3780	3830	3880	3930	3980	4030	4080	4135	4185	4235	4285	4335	4385	4435	4485	4535	4585	4635	4685	4735	4790	4840	4890
24	3635	3685	3735	3785	3835	3885	3935	3985	4035	4085	4135	4185	4235	4285	4330	4380	4430	4480	4530	4580	4630	4680	4730	4780	4830
26	3605	3655	3705	3755	3805	3855	3905	3955	4000	4050	4100	4150	4200	4250	4300	4350	4395	4445	4495	4545	4595	4645	4695	4740	4790
28	3575	3625	3675	3725	3775	3820	3870	3920	3970	4020	4070	4115	4165	4215	4265	4310	4360	4410	4460	4510	4555	4605	4655	4705	4755
30	3550	3595	3645	3695	3740	3790	3840	3890	3935	3985	4035	4080	4130	4180	4230	4275	4325	4375	4425	4470	4520	4570	4615	4665	4715
32	3520	3565	3615	3665	3710	3760	3810	3855	3905	3950	4000	4050	4095	4145	4195	4240	4290	4340	4385	4435	4485	4530	4580	4625	4675
34	3475	3525	3570	3620	3665	3715	3760	3810	3855	3905	3950	4000	4045	4095	4140	4190	4225	4285	4330	4380	4425	4475	4520	4570	4615
36	3445	3495	3540	3585	3635	3680	3730	3775	3825	3870	3920	3965	4010	4060	4105	4155	4200	4250	4295	4340	4390	4435	4485	4530	4580
38	3415	3465	3510	3555	3605	3650	3695	3745	3790	3840	3885	3930	3980	4025	4070	4120	4165	4210	4260	4305	4350	4400	4445	4495	4540
40	3385	3435	3480	3525	3575	3620	3665	3710	3760	3805	3850	3900	3945	3990	4035	4085	4130	4175	4220	4270	4315	4360	4410	4455	4500
42	3360	3405	3450	3495	3540	3590	3635	3680	3725	3770	3820	3865	3910	3955	4000	4050	4095	4140	4185	4230	4280	4325	4370	4415	4460
44	3315	3360	3405	3450	3495	3540	3585	3630	3675	3725	3770	3815	3860	3905	3950	3995	4040	4085	4130	4175	4220	4270	4315	4360	4405
46	3285	3330	3375	3420	3465	3510	3555	3600	3645	3690	3735	3780	3825	3870	3915	3960	4005	4050	4095	4140	4185	4230	4275	4320	4365
48	3255	3300	3345	3390	3435	3480	3525	3570	3615	3655	3700	3745	3790	3835	3880	3925	3970	4015	4060	4105	4150	4190	4235	4280	4325
50	3210	3255	3300	3345	3390	3430	3475	3520	3565	3610	3650	3695	3740	3785	3830	3870	3915	3960	4005	4050	4090	4135	4180	4225	4270
52	3185	3225	3270	3315	3355	3400	3445	3490	3530	3575	3620	3660	3705	3750	3795	3835	3880	3925	3970	4010	4055	4100	4140	4185	4230
54	3155	3195	3240	3285	3325	3370	3415	3455	3500	3540	3585	3630	3670	3715	3760	3800	3845	3890	3930	3975	4020	4060	4105	4145	4190
56	3125	3165	3210	3255	3295	3340	3380	3425	3465	3510	3550	3595	3640	3680	3725	3765	3810	3850	3895	3940	3980	4025	4065	4110	4150
58	3080	3125	3165	3210	3250	3290	3335	3375	3420	3460	3500	3545	3585	3630	3670	3715	3755	3800	3840	3880	3925	3965	4010	4050	4095
60	3050	3095	3135	3175	3220	3260	3300	3345	3385	3430	3470	3500	3555	3595	3635	3680	3720	3760	3805	3845	3885	3930	3970	4015	4055
62	3020	3060	3110	3150	3190	3230	3270	3310	3350	3390	3440	3480	3520	3560	3600	3640	3680	3730	3770	3810	3850	3890	3930	3970	4020
64	2990	3030	3080	3120	3160	3200	3240	3280	3320	3360	3400	3440	3490	3530	3570	3610	3650	3690	3730	3770	3810	3850	3900	3940	3980
66	2950	2990	3030	3070	3110	3150	3190	3230	3270	3310	3350	3390	3430	3470	3510	3550	3600	3640	3680	3720	3760	3800	3840	3880	3920
68	2920	2960	3000	3040	3080	3120	3160	3200	3240	3280	3320	3360	3400	3440	3480	3520	3560	3600	3640	3680	3720	3760	3800	3840	3880
70	2890	2930	2970	3010	3050	3090	3130	3170	3210	3250	3290	3330	3370	3410	3450	3480	3520	3560	3600	3640	3680	3720	3760	3800	3840
72	2860	2900	2940	2980	3020	3060	3100	3140	3180	3210	3250	3290	3330	3370	3410	3450	3490	3530	3570	3610	3650	3680	3720	3760	3800
74	2820	2860	2900	2930	2970	3010	3050	3090	3130	3170	3200	3240	3280	3320	3360	3400	3440	3470	3510	3550	3590	3630	3670	3710	3740

DUBOIS BODY SURFACE CHART

(As prepared by Boothby and Sandiford
of the Mayo Clinic)



DIRECTIONS

To find body surface of a patient, locate the height in inches (or centimeters) on scale I and the weight in pounds (or kilograms) on Scale II and place a straight edge (ruler) between these two points which will intersect Scale III at the patient's surface area.

PREDICTED MAXIMAL BREATHING CAPACITY--MALES

BODY SURFACE AREA

Age	1.40	1.42	1.44	1.46	1.48	1.50	1.52	1.54	1.56	1.58	1.60	1.62	1.64	1.66	1.68	1.70	1.72	1.74	1.76	1.78	1.80	1.82	1.84	1.86	1.88	1.90	1.92	1.94	1.96	1.98	2.00	2.02	2.04	2.06	2.08	2.10
16	110	111	113	114	116	118	119	121	122	124	125	127	129	130	132	133	135	136	138	140	141	143	144	146	147	149	151	152	154	155	157	158	160	162	163	165
18	108	110	111	113	115	116	118	119	121	122	124	125	127	128	130	132	133	135	136	138	139	141	143	144	146	147	149	150	152	153	155	156	158	159	161	163
20	107	108	110	111	113	114	116	118	119	121	122	124	125	127	128	130	131	133	135	136	137	138	140	142	143	145	146	148	150	151	153	154	156	157	159	160
22	105	107	108	110	111	113	114	116	117	119	120	122	123	125	126	128	129	131	132	134	135	137	138	140	141	143	144	146	147	149	150	152	153	155	156	158
24	104	105	107	108	110	111	113	114	116	117	119	120	122	123	125	126	128	129	131	132	134	135	137	138	139	141	142	144	145	147	148	150	151	153	154	156
26	102	104	105	107	108	110	111	112	114	115	117	118	120	121	123	124	126	127	128	130	131	133	134	136	137	139	140	142	143	145	146	147	149	150	152	153
28	101	102	104	105	107	108	109	111	112	114	115	117	118	120	121	122	124	125	127	128	130	131	132	134	135	137	138	140	141	143	144	145	147	148	150	151
30	99	101	102	104	105	107	108	109	111	112	114	115	116	118	119	121	122	124	125	126	128	129	131	132	133	135	136	138	139	141	142	143	145	146	148	149
32	98	99	101	102	104	105	106	108	109	111	112	113	115	116	118	119	120	122	123	125	126	127	129	130	132	133	134	136	137	139	140	141	143	144	146	147
34	96	98	99	101	102	103	105	106	107	109	110	112	113	114	116	117	119	120	121	123	124	125	127	128	130	131	132	134	135	136	138	139	141	142	143	145
36	95	96	98	99	100	102	103	104	106	107	108	110	111	113	114	115	117	118	119	121	122	123	125	126	127	129	130	131	133	134	136	137	138	140	141	142
38	93	95	96	97	99	100	101	103	104	105	107	108	109	111	112	113	115	116	117	119	120	121	123	124	125	127	128	129	131	132	133	135	136	137	139	140
40	92	93	95	96	97	99	100	101	102	104	105	106	108	109	110	112	113	114	116	117	118	120	121	122	124	125	126	127	129	130	131	133	134	135	137	138
42	91	92	93	94	96	97	98	99	100	102	103	105	106	107	109	110	111	113	114	115	116	118	119	120	122	123	124	126	127	128	129	131	132	133	135	136
44	89	90	92	93	94	95	97	98	99	100	102	103	104	106	107	108	109	111	112	113	114	116	117	118	120	121	122	123	125	126	127	128	130	131	132	134
46	88	89	90	91	93	94	95	96	98	99	100	101	103	104	105	106	108	109	110	111	113	114	115	116	118	119	120	121	123	124	125	126	128	129	130	131
48	86	87	88	90	91	92	93	95	96	97	98	100	101	102	103	105	106	107	108	109	111	112	113	114	116	117	118	119	121	122	123	124	125	127	128	129
50	85	86	87	88	89	91	92	93	94	95	97	98	99	100	101	103	104	105	106	108	109	110	111	112	114	115	116	117	118	120	121	122	123	124	126	127
52	83	84	85	86	88	89	90	91	92	94	95	96	97	98	99	101	102	103	104	105	107	108	109	110	111	112	114	115	116	117	118	120	121	122	123	124
54	82	84	85	86	87	88	89	90	91	92	93	94	96	97	98	99	100	101	103	104	105	106	107	108	110	111	112	113	114	115	117	118	119	120	121	122
56	80	81	82	84	85	86	87	88	89	91	92	93	94	95	96	97	99	100	101	102	103	104	105	107	108	109	110	111	112	113	115	116	117	118	119	120
58	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	96	97	98	99	100	101	102	103	105	106	107	108	109	110	111	112	114	115	116	117	118
60	77	78	79	80	82	83	84	85	86	87	88	89	90	91	93	94	95	96	97	98	99	100	101	102	104	105	106	107	108	109	110	111	112	114	115	116
62	76	77	78	79	80	81	82	83	84	85	86	87	89	90	91	92	93	94	95	96	97	98	99	100	102	103	104	105	106	107	108	109	110	111	112	113
64	74	75	76	77	78	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	98	99	100	101	102	103	104	105	106	107	108	109	110	111
66	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	97	98	99	100	101	102	103	104	105	106	107	108	109
68	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	83	39	50	91	92	93	94	96	97	98	99	100	101	102	103	104	105	106	107
70	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105
72	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100	101	102	102
74	67	68	69	70	71	72	73	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	92	93	94	95	96	97	98	99	100
76	65	66	67	68	69	70	71	72	73	74	75	76	77	78	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	92	93	94	95	96	[illegible]	[illegible]

APPENDIX D

DATA SHEET FOR ESTIMATING WEIGHT RESIDUAL

ANALYSIS OF BODY BUILD

Data Collection for Analysis of Body Build by Method

Name________________ Wt._____ lbs._____ kg. Ht._____ in._____ dm.

(1) Body Segment	(2) Circumference			(3) Male k Value	(4) Female k Value	(5) d Value	(6) Equiv Wt (kg) $d^2 \times H$
	L.	R	Av.				
1 Shoulder				55.4	52.0		
2 Chest				45.9	44.5		
3 Abdomen				40.6	38.7		
4 Buttocks				46.7	50.8		
5 Thighs				27.4	30.1		
6 Biceps				15.4	14.4		
7 Forearm				13.4	13.0		
8 Wrist				8.2	8.2		
9 Knee				18.3	18.8		
10 Calf				17.9	18.4		
11 Ankle				10.8	11.1		
Σ							
M							

Predicted Wt. as Mean of Equiv. Wts. (col. 6) ________________

Predicted Wt. as $\frac{C}{K} = \frac{\text{Sum (col. 2)}}{300}$ ________________

APPENDIX E

CORRELATION CHARTS FOR CHANGE REST TO POST-EXERCISE VALUES

SIGNIFICANCE OF CORRELATIONS BETWEEN VENTRICULAR SYSTOLIC TIME INTERVALS (CHANGE REST TO ONE MINUTE POST-EXERCISE) AND FITNESS VARIABLES

	Change Rest to 1 Minute Post-Exercise						
Variables	TP	EML	ICP	EP	ETI	EP/ICP	EP/TP
Maximum VO_2	.889	.165	.289	.820	.501	.324	.591
Cooper levels	.869	.091[a]	.093[a]	.956	.608	.129	.777
Maximum VO_2 %	.180	.099[a]	.928	.636	.635	.919	.027[b]
Exercise/Nonexercise	.805	.619	.858	.864	.311	.157	.786
Heart rate	1.000	.293	.647	.288	.001[d]	.975	.965
T wave	.641	.583	.584	.579	.149	.775	.659
Rest/Work Ratio	.089[a]	.587	.116	.205	.006[c]	.195	.501
Schneider	.647	.583	.110	.312	.009[c]	.600	.584
Systole BP	.658	.855	.510	.226	.051[a]	.683	.583
Diastole BP	.637	.555	.277	.183	.235	.584	.981
Pulse pressure	.624	.519	.090[a]	.945	.626	.792	.586
Vital capacity	.978	.736	.744	.635	.172	.886	.835
Vital capacity %	.842	.957	.787	.548	.668	.892	.842
Maximum breathing cap. %	.900	.746	.878	.775	.598	.153	.899
FEV_1	.519	.739	.262	.264	.170	.160	.311
Age	.657	.249	.627	.775	.580	.172	.516
Weight residual	.911	.501	.528	.207	.621	.535	.728

[a]Significant at 0.1.

[b]Significant at 0.05.

[c]Significant at 0.01.

[d]Significant at 0.001.

SIGNIFICANCE OF CORRELATIONS BETWEEN VENTRICULAR SYSTOLIC TIME INTERVALS (CHANGE REST TO FIVE MINUTE POST-EXERCISE) AND FITNESS VARIABLES

	Change Rest to 5 Minute Post-Exercise						
Variables	TP	EML	ICP	EP	ETI	EP/ICP	EP/TP
Maximum VO_2	.992	.284	.665	.143	.649	.216	.591
Cooper levels	.818	.054[a]	.165	.541	.838	.672	.777
Maximum VO_2 %	.189	.539	.665	.507	.953	.878	.098[a]
Exercise/Nonexercise	.773	.583	.717	.307	.534	.082[a]	.786
Heart rate	.278	.631	.565	.925	.190	.226	.965
T wave	.123	.650	.017[b]	.248	.073[a]	.732	.659
Rest/Work ratio	.809	.696	.957	.637	.086[a]	.959	.501
Schneider	.781	.567	.860	.810	.556	.021[b]	.584
Systole BP	.964	.883	.852	.893	.526	.570	.583
Diastole BP	.780	.552	.739	.887	.814	.108	.981
Pulse pressure	.836	.589	.637	.988	.074[a]	.592	.586
Vital capacity	.934	.577	.579	.731	.664	.556	.835
Vital capacity %	.836	.554	.778	.590	.613	.870	.842
Maximum breathing cap. %	.656	.511	.557	.718	.609	.590	.899
FEV_1	.788	.557	.724	.131	.119	.056[a]	.311
Age	.310	.072[a]	.782	.620	.202	.956	.516
Weight residual	.542	.793	.520	.080[a]	.112	.608	.728

[a]Significant at 0.1 level.

[b]Significant at 0.05 level.

APPENDIX F

RAW DATA

PARAMETERS OF CARDIAC CYCLE

Subject	Age	Cooper Fitness Level	Exercise/ Non-Exercise	Resting			1 Min Post-Ex.			5 Min Post-Ex.		
				EML	ICP	EP	EML	ICP	EP	EML	ICP	EP
01	56	4	NE	60	56	324	54	18	262	60	36	300
02	31	4	NE	59	53	307	58	20	200	62	27	263
03	40	3	NE	80	25	305	39	13	220	43	14	270
04	41	4	NE	50	59	307	30	31	242	46	60	287
05	48	4	NE	60	47	283	53	20	190	60	40	260
06	46	3	E	40	20	320	25	16	204	30	40	260
07	31	4	E	56	26	284	40	26	192	46	20	243
08	38	3	NE	70	33	300	78	26	196	82	26	270
09	32	3	E	50	40	253	64	22	203	99	12	250
10	31	4	NE	50	30	280	40	10	220	60	30	270
11	46	3	E	40	96	324	38	50	250	40	40	290
12	42	3	NE	40	65	280	31	37	230	54	30	280
13	49	4	E	60	38	309	50	20	210	60	26	270

PARAMETERS OF CARDIAC CYCLE (Continued)

Subject	Age	Cooper Fitness Level	Exercise/ Non-Exercise	Resting			1 Min. Post-Ex.			5 Min Post-Ex.		
				EML	ICP	EP	EML	ICP	EP	EML	ICP	EP
14	45	5	NE	60	20	320	50	28	242	60	32	300
15	54	4	NE	73	10	300	70	21	213	66	27	233
16	34	4	E	70	20	300	60	16	224	60	30	280
17	40	4	NE	70	34	290	60	10	190	60	11	279
18	42	3	E	76	36	321	32	52	242	60	11	287
19	44	4	NE	46	40	322	53	20	193	47	40	244
20	36	4	NE	59	43	300	56	17	203	62	57	263
21	38	3	NE	50	43	291	37	22	218	50	20	263
22	44	4	NE	80	35	297	40	19	221	80	30	290
23	23	4	NE	58	75	280	43	20	240	47	35	284
24	22	3	E	70	33	240	60	25	195	70	23	243
25	53	4	NE	66	48	292	41	10	200	40	24	276
26	39	3	E	60	24	260	37	24	180	60	22	216
27	37	4	NE	81	40	290	61	11	229	71	27	280

PARAMETERS OF CARDIAC CYCLE (Continued)

Subject	Age	Cooper Fitness Level	Exercise/ Non-Exercise	Resting			1 Min Post-Ex.			5 Min Post-Ex.		
				EML	ICP	EP	EML	ICP	EP	EML	ICP	EP
28	48	4	NE	28	41	320	20	17	283	24	33	266
29	39	4	NE	59	25	310	38	36	191	57	27	266
30	51	5	NE	70	28	282	30	14	207	30	24	256
31	38	3	E	40	78	280	36	13	210	30	69	251
32	61	3	E	70	60	250	40	23	217	40	40	259
33	40	4	NE	61	60	300	41	44	256	40	34	276
34	46	5	NE	69	32	311	42	14	235	60	08	277
35	31	2	E	40	63	266	60	20	180	40	80	224
36	43	4	NE	30	45	318	59	22	220	31	67	300
37	33	5	NE	61	37	283	25	26	223	34	50	270
38	31	4	NE	68	25	275	50	10	200	40	23	277
39	38	4	NE	52	29	281	44	23	200	48	36	270
40	57	5	NE	70	15	300	53	20	230	44	25	275
41	33	3	E	70	48	282	57	20	180	60	29	220

FITNESS VARIABLES

Subj.	Max VO_2	Max VC	Max FEV_1	Systolic BP	Diastolic BP	Schneider	Heart Rate	Rest/ Work	T Wave	Wt. Res.	VC %	MBC %
01	38.5	3970	73	112	65	11	54	2.60	3.0	05	107	135
02	42.0	5912	82	115	70	16	54	2.10	4.5	05	136	129
03	35.0	5290	75	125	75	12	60	1.87	5.0	15	098	122
04	42.0	5643	81	120	70	15	66	1.62	4.5	00	134	132
05	43.5	5428	85	135	95	13	66	1.10	1.5	11	134	128
06	35.0	5643	83	118	65	12	54	2.50	2.0	18	139	156
07	43.0	5321	94	130	65	14	78	2.50	3.5	07	128	126
08	35.0	4250	78	110	65	15	66	2.60	3.0	15	094	078
09	35.0	4770	83	123	70	06	90	1.14	3.0	06	114	123
10	45.0	5982	86	150	85	15	66	1.66	4.0	08	138	118
11	33.5	4410	80	140	80	16	60	2.00	4.0	30	112	084
12	33.0	6021	79	130	85	17	52	2.37	3.0	16	143	124
13	40.0	4654	75	120	85	13	54	1.87	4.0	04	106	151

FITNESS VARIABLES (Continued)

Subj.	Max VO_2	VC	FEV_1	Systolic BP	Diastolic BP	Schneider	Heart Rate	Rest/ Work	T Wave	Wt. Res.	VC %	MBC %
14	50.0	5859	95	115	90	15	54	2.20	3.0	06	138	123
15	33.5	3360	59	140	90	15	72	1.80	1.5	11	094	075
16	42.0	4783	89	115	80	14	60	2.00	3.0	02	110	160
17	38.5	5213	84	118	58	14	60	1.75	3.5	06	120	135
18	35.0	5780	86	110	70	16	54	2.00	3.0	15	134	134
19	40.0	4138	86	118	70	17	54	2.30	5.5	13	105	130
20	45.0	4816	83	130	65	14	66	1.75	4.0	07	113	115
21	38.5	4864	96	130	75	14	66	1.39	3.5	09	111	121
22	38.5	3816	75	110	70	16	60	2.30	1.5	12	095	080
23	48.5	5052	87	130	70	12	56	1.88	4.0	03	110	156
24	38.5	4891	95	130	90	12	80	1.50	3.0	11	115	123
25	42.0	5267	77	125	80	12	66	1.50	2.5	10	136	119
26	33.5	5213	89	130	98	01	84	1.57	3.0	07	127	176
27	42.0	5540	99	110	70	13	66	1.87	4.0	00	140	157

FITNESS VARIABLES (Continued)

Subj.	Max VO_2	Max VC	Max FEV_1	Systolic BP	Diastolic BP	Schneider	Heart Rate	Rest/ Work	T Wave	Wt. Res.	VC %	MBC %
28	42.0	5160	83	140	80	15	56	1.66	2.5	01	127	151
29	43.0	6260	68	120	70	15	60	2.00	3.0	07	123	130
30	45.0	4235	82	132	70	14	72	1.75	1.8	10	139	113
31	33.5	5260	93	120	65	09	84	1.50	2.0	19	117	154
32	30.0	2658	80	130	75	07	84	1.64	2.5	09	062	058
33	38.5	5885	75	112	78	14	60	2.00	3.0	17	132	122
34	45.0	5300	82	118	65	13	66	2.11	3.0	11	130	118
35	28.0	4010	85	120	60	02	96	1.16	1.0	17	109	116
36	38.5	5375	80	135	70	17	60	1.87	1.5	19	131	130
37	48.0	4407	83	160	82	15	66	2.00	3.0	11	102	119
38	43.5	5210	80	110	60	14	54	2.10	2.0	06	118	092
39	40.0	3800	85	125	65	14	78	1.42	1.5	00	101	148
40	45.0	3870	72	118	60	16	60	1.63	3.0	05	107	114
41	31.8	6020	78	142	75	09	80	1.25	3.5	12	135	106

2

VITA

Harry S. Wohlert

Candidate for the Degree of

Doctor of Education

Thesis: THE ASSESSMENT OF CARDIOVASCULAR FITNESS THROUGH ANALYSIS OF THE LEFT VENTRICULAR TIME COMPONENTS

Major Field: Higher Education

Biographical:

Personal Data: Born in Berlin, Germany, February 21, 1935, the son of Mr. and Mrs. Stefan Wohlert.

Education: Graduated from Gerhart Hauptmann School, Wernigerode, Germany, in February, 1953; received Bachelor of Science degree in Psychology from Oklahoma State University, Stillwater, Oklahoma, in May, 1964; received Master of Arts degree in Germanic literature and linguistics from Oklahoma University, Norman, Oklahoma, in August, 1967; completed requirements for the Doctor of Education degree at Oklahoma State University in December, 1975.

Professional Experience: Managerial position in international business, Berlin, Germany, 1954-1956; electronics technician U.S. Air Force, 1957-1961; instructor in Germanic linguistics, Department of Foreign Languages, Oklahoma State University, 1963-1965; teaching assistant in Germanic linguistics, Department of Modern Languages, Oklahoma University, 1965-1967; Assistant Professor and Coordinator of Programs of Germanic Literature and Linguistics in the Department of Foreign Languages, Oklahoma State University, 1967 to present.

Professional Organizations: American Association for Health, Physical Education, and Recreation; Oklahoma Association of Health, Physical Education, and Recreation; American College of Sports Medicine; American Council on the Teaching of Foreign Languages; Modern Language Association of America; American Association of Teachers of German; Oklahoma Association of Teachers of German (Vice-President and President-Elect).