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A Study of the Relationship of Performance in Certain Generally Accepted Tests of Physical Fitness to Circulatory - Respiratory Capacity of Normal College Men.

Walter L. Russell
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A STUDY OF THE RELATIONSHIP OF PERFORMANCE IN CERTAIN GENERALLY
ACCEPTED TESTS OF PHYSICAL FITNESS TO CIRCULATORY-
RESPIRATORY CAPACITY OF NORMAL COLLEGE MEN

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Health and Physical Education

by

Walter L. Russell
A. B., Berry College, 1942
M. S., University of Tennessee, 1948
August, 1952
MANUSCRIPT THESSES

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ABSTRACT

There are various and numerous tests of physical fitness. Perhaps the three types of fitness tests most generally in use today are those based on strength indexes, cardiovascular responses, and motor performance.

There seems little hope of reconciliation between these three generally accepted types of fitness. Each type of fitness has its advocates along with substantial evidence to postulate their test as a measure of physical fitness. The contributions of each type to the total picture of fitness is not known. Indeed, the definitions of fitness are sometimes vague and quite contradictory. In the final analysis, the contribution of each variable to the total picture will probably depend upon the definition one chooses for fitness.

In order to establish the relationship existing between circulatory-respiratory capacity and motor and strength fitness, this study was undertaken. Scores obtained from twenty-three normal young college men during all-out performances involving the measurement of exercise metabolism, strength, and motor performance were statistically analyzed to determine the extent of relationship which existed between these measures.

As a result of this analysis the following conclusions are drawn concerning the findings of this study.

1. Oxygen intake (liters/kilogram) is the most important metabolic indicator of all-out circulatory-respiratory capacity.
(2) Sitting metabolism is not related to exercise metabolism or all-out exercise performance. The physiologic differences between normal young men are most apparent when under the stress of exercise.

(3) Oxygen debt capacity (liters/kilogram) is not substantially related to motor performance, motor fitness, strength, or strength fitness. Apparently, oxygen debt capacity is not related to physical fitness.

(4) Oxygen intake capacity (liters/kilogram) is highly related to performance in those motor tests involving a large number of repetitions during vigorous all-out exercise. The larger the number of repetitions, the higher the relationship. Included in this category are the all-out exercises of the step-test, squat-jumps, and sit-ups.

(5) Circulatory-respiratory capacity is not related to strength or strength fitness.

(6) Circulatory-respiratory capacity is related to motor fitness to the degree that the testing device utilized includes performance tests which are related to oxygen intake ability.

The all-out step test at forty steps per minute on a seventeen-inch stool is recommended as the best practical screening device for the prediction of all-out circulatory-respiratory capacity. However, a short and easily administered predictive battery containing the performance tests of squat-jumps and sit-ups is recommended for use with large groups. The multiple regression equation in standard form is:

\[
\text{Oxygen intake (liters/kilogram)} = 0.592 \times \text{Squat-jumps (all-out)} + 0.338 \times \text{Sit-ups (all-out)}. 
\]
The Illinois Physical Fitness Test with its available norms and standard scores is probably just as satisfactory for the same purpose.

The Navy Physical Fitness Test is highly recommended as a versatile indicator of three aspects of fitness: namely, motor fitness, strength fitness, and circulatory-respiratory capacity. It is suggested as a mediatory test of all-around fitness.
CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS USED

I. INTRODUCTION

There are numerous tests of physical fitness based on data derived from cardio-respiratory indexes, nutritional status, physique and body build, medical ratings, motor performance, body mechanics, strength, and other factors. The field of physical fitness is broad, comprehensive, and often times is apt to appear confusing and even contradictory. To avoid this pitfall it is sometimes best to separate these tests into different categories according to the type of data upon which their rating is based. Thus, it is common procedure to refer to motor fitness, strength fitness, cardiovascular fitness, etc., all being different aspects of the more generalized expression of physical fitness.

The exact contribution of each of these different tests to the total picture of fitness is not completely known. In the final analysis, the contribution of each variable will probably depend upon the definition one chooses for fitness. Nevertheless, these tests are being used throughout the nation. Perhaps the three types most commonly utilized are those of motor, strength, and cardiovascular fitness.

Motor Fitness. A majority of the motor fitness tests which are being employed today for the testing of physical fitness have been
"pulled out" of large empirically selected batteries that contained from fifteen to thirty or more motor performance items. The Army Air Force, Navy, Indiana, and Illinois motor fitness batteries are typical examples of such a procedure. In each of the above cases the smaller, and finally accepted battery, correlated highly with the original criterion battery and thus was accepted as a test of physical fitness. However, it has not been shown just exactly what the criterion batteries measure.1

**Strength Fitness.** On the other hand, various strength tests have been advocated as the true measure of physical fitness. But physiology has shown that physical exertion overtaxes the circulatory mechanism long before it exhausts the skeletal musculature; and that, while it is not easy to overwork the muscles, the heart may be overworked. The convalescent from infectious disease may be limited in his exercise, not by what his muscles can do, but by the strength of his heart. Hence, the general opinion of many of the leading physiologists is that strength tests do not permit us to draw satisfactory conclusions regarding the efficiency of the entire body.2

**Cardiovascular Fitness.** The search for a true measure of physical fitness led to the formulation of various physiological tests which were designed to establish fitness of the circulatory and respiratory


systems through measures of heart size, heart output, pulse rate, blood pressure, breath holding, vital capacity, and lung ventilation. Many of the tests, such as The Barringer Test, The Schneider Test, The Tuttle Pulse-Ratio Test, and the McCurdy-Larson Test involved the measurement of pulse rate and/or blood pressure before and after moderate exercise. Others, such as The McCloy Test and The Barach Index, involved the measurement of pulse rate and/or blood pressure during rest. However, in a carefully conducted experiment, Sambolin found that the correlation between various cardiovascular tests is very low. A correlation of .68 was obtained between McCloy's and Schneider's tests. The other correlations were below .29.

Circulatory-Respiratory Capacity. Another aspect of physiological testing which has captured the imagination and interest of physiologists the world over for the past two centuries is that of oxygen metabolism during exercise. It has repeatedly been demonstrated that the ability of the human machine to do strenuous work involving the large muscle groups depends in main upon its efficiency in the utilization of oxygen. Energy expenditure as measured by oxygen consumption during strenuous exercise has demonstrated a remarkable ability to differentiate between champions and normal men. Training also highly

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affects the capacity for oxygen consumption during work. And, it has been demonstrated that the best known way of determining the circulatory-respiratory capacity of the human machine is to determine the metabolic measurements during all-out work. There are those, such as Karpovich and Cureton who postulate that such a measure is a gross index of physical fitness in that it reflects the functions of most of the organs, tissues, and systems of the body to adjust to the increased demands of exercise.

The Advantages of Motor Fitness Testing. Even though physiologists have recognized the value and importance of measuring circulatory-respiratory capacity by means of oxygen metabolism during work, such a technique has received little consideration in the field of physical education as a device for the evaluation of physical fitness. The apparatus is too expensive and the testing procedures are too time consuming to be utilized in the normal routine of everyday testing.

On the other hand, motor performance tests do not require any equipment other than that ordinarily required for the conduct of a comprehensive program of physical education. They are easily administered to large groups and are not too time consuming to be employed in

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6 T. E. Cureton, Physical Fitness of Champion Athletes, p. 347.

7 P. V. Karpovich, “Metabolism and Energy Used in Exercise,” Research Quarterly (12:431, 1941).

the routine testing program. It is evident from the standpoint of practicality that the motor fitness tests have some very definite advantages.

**Importance of the Problem.** It is postulated that the relationship of circulatory-respiratory capacity to motor performance and motor fitness should be definitely established if the basic principles underlying motor performance are to be understood and the ultimate realization of a standardized, generally accepted technique of measuring physical fitness is to be fulfilled. Indeed, it is quite possible that circulatory-respiratory capacity and performance in a wide range of motor activities involving the major muscle groups are both measures of physical fitness. The major difference would appear to be in the approach being made, not in final results. It would seem probable that conditioning is the result of performance, and the best measure of fitness is that which measures both items. The thesis involved here is that these two items of all-around performance and all-out capacity both measure in the same direction and are predictive of each other.

As Cureton\(^9\) says,

> Some few professional workers will want to study for themselves the reliability and the validity of the physical fitness test. Such basic data are valuable because the work is rapidly developing and unquestionably there is much light to be thrown on the meaning of particular tests, how they cluster and duplicate each other and their predictive value for estimating various criteria.

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And later he\textsuperscript{10} adds,

The net contribution of cardiovascular condition to motor performance must be studied more specifically.

II. THE PROBLEM

Statement of the Problem. It was the purpose of this study (1) to investigate the relationship among various indexes of circulatory-respiratory capacity and performance in several individual motor activities; (2) to establish the relationship between circulatory-respiratory capacity and certain generally accepted tests or batteries of physical fitness; and (3) to determine the best battery of motor performance tests which can be utilized to predict circulatory-respiratory capacity.

III. LIMITATIONS OF THE STUDY

The Test of Circulatory-Respiratory Capacity. The measurement of circulatory-respiratory capacity in this study has been limited to the metabolic responses of normal college men during all-out exercise to exhaustion. As it will be pointed out later, such responses are indicative of the total circulatory-respiratory systems\textapos; capacity to provide energy for work, and reflect the efficiency and capacity of the lungs, heart, blood, muscles, and the body as a whole. It was not considered necessary to record such items as blood pressure, pulse rate, lung ventilation, etc. The overall capacity and efficiency of such indexes will appear in the metabolic measures.

The Subjects for Experimentation. This study was also limited

\textsuperscript{10}T. K. Cureton, \textit{Physical Fitness of Champion Athletes}, p. 83.
to an analysis of the responses of normal college men selected at random from the regular undergraduate physical education activity courses at Louisiana State University. As the routine testing program of a college or university is designed to evaluate the fitness of such men, it was deemed feasible that this study should be limited to this group. All subsequent data should be interpreted with regard to this selection of subjects.

Normal college men may be interpreted as indicating those men physically able to participate in the regular physical education activity classes of Louisiana State University. Normal indicates that they are free of any disease and are not physically handicapped.

It should also be pointed out that due to the nature of the study there is an obvious limitation to the number of subjects which can be employed for experimentation. This investigation is limited to the responses of twenty-three normal young college men selected at random from the physical education activity classes of Louisiana State University.

The Physical Fitness Tests Investigated. The physical fitness batteries selected for study were limited to the Army Air Force, Indiana, Illinois, and Navy Motor Fitness Tests and the McCloy Strength Test. This selection was based on the consideration of such factors as limitations in finances, the need for typical tests which are generally accepted as measures of physical fitness, and the obvious requirement of short time lapses between testing intervals.

The four motor fitness batteries contain eight different motor performance tests. This enabled a study of the different
batteries and also an analysis of the various individual motor performance items. However, it is not maintained that these batteries are the best measures of physical fitness. The only assertion is that they are typical batteries and typical tests, generally used to measure motor performance.
CHAPTER II

REVIEW OF THE LITERATURE

I. THE ROLE OF OXYGEN IN MUSCLE CONTRACTION

The exact processes involved in the mechanism of muscular contraction are still a theoretical and controversial issue. An hypothesis confirmed by the work of A. V. Hill\(^1\) and Meyerhof\(^2\) and later modified by Lundgaard,\(^3\) Lohmann,\(^4\) and Sacks\(^5\) is aptly summarized by Winton and Bayliss.\(^6\) The energy for muscle contraction is said to have two main sources or systems. (1) Anaerobic, in which the

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breakdown of adenosinestriphosphoric acid is postulated to be the immediate source of energy. The adenylic acid thus released is quickly re-phosphorylated, the necessary energy and phosphate being supplied by the breakdown of creatinephosphate. The creatine thus liberated is re-phosphorylated, the necessary energy and phosphate coming from the "lactacid" reaction, and resulting in the appearance of lactic acid. (2) Aerobic, in which the oxidation of foodstuffs (including lactic acid) provides the energy needed to resynthesize glycogen from the accumulated lactic acid.

This theory of energy for muscular contraction is further discussed by Reidman who states,

Muscles have available two closely related and interdependent stores of energy. Under certain conditions, the chemical sources of energy (the anaerobic systems) are the chief source for quick and immediate energy release. The continued use of this source, however, depends upon oxidative energy release. Without intensive concurrent oxidation, the quality of energy released by ATP and by phosphocreatine, though high cannot account for the enormous energy released in prolonged vigorous exercise. The quick turnover of energy from these chemical sources depends upon their continuous resynthesis by means of energy from another of the chemical systems or from oxidation. Assuming no oxidation at all, the energy stores are very low indeed.

......Whatever the immediate source of energy for contraction, the ultimate source is the oxidation of food, which is the fuel for the whole organism as well as for the muscle.

Morehouse and Wiggers further substantiate that the ultimate source

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of energy is the oxidation of energy rich compounds.

It seems quite apparent, then, that a measurement of oxygen consumption would reflect the amount of energy liberated when the foodstuffs are converted to fuel for use by the body. Studies by Dill,\textsuperscript{10} Gemmill,\textsuperscript{11} and Carpenter\textsuperscript{12} concerning heat production and the respiratory quotient (carbon dioxide produced divided by the oxygen consumed) have shown that the caloric value of one liter of oxygen varies according to the type of foodstuff being oxidized. Carbohydrates yield 5.0 Calories for one liter of oxygen, fats 4.7, and proteins 4.5 Calories. The respiratory quotient is the factor which determines the caloric value for each liter of oxygen consumed and this varies according to the type of foodstuff being oxidized.

Carpenter\textsuperscript{13} reached the conclusion that light work produces no change in the respiratory quotient, indicating that the same mixture of foodstuffs is burned as during rest. With heavier work, however, the respiratory quotient tends to rise at first and then, as the work is continued, to fall, indicating that heavy work increases the utilization of carbohydrate until the reserve supply begins to run low, when the metabolism of fat becomes accentuated.


\textsuperscript{13}T. M. Carpenter, \textit{loc. cit.}
Douglas and Priestly\textsuperscript{1} however, maintain that the Calories liberated per liter of oxygen absorbed only vary from 4.69 and 5.05 as the respiratory quotient changes from 0.7 to 1.0. When the oxygen absorption alone is measured it is usual to assume a respiratory quotient of 0.82 when the Calories liberated per liter of oxygen absorbed are 4.825. Moderate variations from this figure will not cause any serious error in the calculated Caloric output during rest.

Morehouse\textsuperscript{15} says,

At rest it may be assumed that the fuel is equivalent to a mixed diet containing a certain proportion of carbohydrates, fats, and proteins with an overall Caloric value of 4.825 Calories per liter. During exercise it is assumed that the fuel is predominantly carbohydrate and the caloric value of a liter of oxygen may be taken as 5.0 Calories.

Hill\textsuperscript{16} further substantiates the position that oxygen consumption is the important indicator of the amount of energy liberated by stating,

There are various ways in which it is possible to measure the energy liberated by a man....However, the only generally practical method is that involving a measurement of the oxygen consumed by the subject. A measure of the carbon dioxide by itself is of little value, although some physiologists are continually trying to prove that it is: partly because the energy per liter of carbon dioxide is much less constant than the energy per liter of oxygen, but chiefly because the body is a vast reservoir of carbon dioxide and many liters of


\textsuperscript{15}E. E. Morehouse and A. T. Miller, \textit{op. cit.}, p. 53.

it may be driven out by deep breathing, or by exercise involving the liberation of acid in the muscles, which certainly was not formed by oxidation during the interval considered. The carbon dioxide, in conjunction with the oxygen, is under certain circumstances a useful indicator of the degree of ventilation of the lungs and of the acid being produced by the muscles. Oxygen, however, the body cannot store to any considerable extent. It would be difficult to change the amount of oxygen present in the body and blood at any moment by more than a fraction of a liter. And since the energy per liter of oxygen is approximately constant, the oxygen used is a valuable indicator of the energy liberated.

In this connection it is interesting to note that in an experiment comparing the amount of oxygen consumed and the amount of carbon dioxide exhaled during exercise, Collins\textsuperscript{17} discovered that data on oxygen consumption were more significant than carbon dioxide in differentiating between individuals. Thus, it appears that a measurement of oxygen consumed during exercise is a valid and important indicator of the amount of energy expended.

II. OXYGEN CONSUMPTION DURING EXERCISE

It has already been shown that oxygen consumption is a measure of energy liberation, since for every liter of oxygen consumed approximately five Calories are liberated. Reidman\textsuperscript{18} states that the average healthy man takes in during rest, about 250 milliliters of oxygen per minute, liberating 1.25 Calories. Over a period of twenty-four hours this amounts to about 1,800 Calories, which is roughly the basal level of metabolism.


\textsuperscript{18}S. R. Reidman, op. cit., p. 90.
The body does not store oxygen, as it does water or food. It takes it in as it is needed. In normal individuals the rate of oxygen consumption increases in proportion to the work accomplished. When the work is not too heavy the increased oxygen intake suffices for energy expenditure, i.e., a steady state is reached. In severe exercise, an oxygen debt is incurred which is repaid through greater oxygen consumption after cessation of exercise.

Hill, 19 Henderson, 20 and Robinson 21 found that in the case of the trained athlete measured oxygen consumption approaching, and in excess of, five liters per minute has been recorded during strenuous exercise, whether in the form of running, rowing, or riding a bicycle ergometer, and this high rate of consumption has been maintained for a considerable time. This represents an increase of about twentyfold above that of basal metabolism.

It is possible to engage in exercise of such intensity that the oxygen requirement for the exercise exceeds the oxygen intake. In continuous exercise lasting more than a few minutes, however, the intake must be adequate to meet the oxygen requirement. When this condition exists, the subject is said to be in a steady state. The


steady state is defined by Best and Taylor\textsuperscript{22} as being that condition during exercise when the anaerobic and aerobic processes are balanced.

Hill and Lupton\textsuperscript{23} found that when a resting subject begins to exercise the steady state is not achieved immediately. The circulatory and respiratory adjustments which make possible a greater oxygen intake come into play gradually and in heavy work (within the intensity of a steady state for the individual concerned) several minutes may be required for the intake to reach the steady state level. During this preliminary period, a small oxygen debt is incurred which is repaid during the brief recovery period which follows the exercise.

When the exercise is of such intensity that the oxygen requirement cannot be furnished by the oxygen taken in during exercise then the energy requirements of the exercise over and above the maximum steady state level possible for the individual concerned must be provided for entirely by anaerobic chemical processes. When the body can no longer withstand the accumulations of anaerobic decomposition then activity is forced to a halt and these waste products are removed during the period of recovery. This period of recovery during which the body is throwing off or reconverting these anaerobic decompositions to their natural state has been aptly described by Hill\textsuperscript{24} as the "oxygen debt." Perhaps the largest debt ever contracted was that of 13.6 liters


\textsuperscript{24}A. V. Hill, \textit{Muscular Movement in Man: The Factors Governing Speed and Recovery from Fatigue}, p. 18.
which Hill recorded for a well trained athlete.

According to Best and Taylor\textsuperscript{25} the oxygen debt is determined by measuring the oxygen used during the period of recovery, i.e., from the termination of the exercise to the time that the oxygen consumption has returned to normal, and subtracting from it the quantity of oxygen used during a corresponding resting period. This results in a measurement which is commonly referred to as "net oxygen debt."

Schneider and Karpovich\textsuperscript{26} state that it is also standard procedure to state oxygen intake during the exercise in net terms, i.e., in terms of intake over and above that of the resting level.

Thus the total cost of the exercise is said to consist of the net intake during exercise plus the net debt during recovery. This is also sometimes referred to as the excess oxygen cost.

III. THE RELATIONSHIP BETWEEN OXYGEN CONSUMPTION AND INTENSITY OF EXERCISE

Benedict and Cathcart\textsuperscript{27} found that a linear relationship existed between the amount of oxygen consumed and the work done by a subject pedalling on a stationary bicycle at different rates and with different loads. With a constant load, oxygen consumption increased as the rate of pedalling increased. As the load was increased there was a proportionate increase in the amount of oxygen consumed. Later

\textsuperscript{25}C. H. Best and H. B. Taylor, \textit{loc. cit.}

\textsuperscript{26}E. C. Schneider and P. V. Karpovich, \textit{Physiology of Muscular Activity} (Philadelphia: W. B. Saunders, 1948), pp. 48-49.

\textsuperscript{27}F. G. Benedict and E. P. Cathcart, \textit{Muscular Work} (Carnegie Institute of Washington, Publication No. 187, 1913), p. 27.
experiments by Benedict and Murchhauser, and Benedict and Parmenter further established that the oxygen consumption increased as the rate of walking or the rate of climbing stairs was increased. However, it was also established that there was an optimum rate of walking for the most economical expenditure of energy per meter traveled. Speeds above or below the optimum increase the use of oxygen or Calories expended per unit of distance traveled. Lupton also verified that as the rate of climbing stairs was increased the amount of oxygen increased also. But he also established that there was an optimum rate or speed at which the expenditure of energy per amount of work was the most efficient.

An experiment by Sargent revealed there is not an optimum rate of running. Upon measuring the oxygen consumption of subjects running at various speeds he found that the energy cost of the exercise varied as the rate of the speed. This seems quite plausible for in running


even at low speeds, the subject is usually exceeding the optimal rate of walking.

A recent experiment by Cureton\(^2\) has established a very definite relationship between intensity of exercise expressed as the rate of energy consumption and duration of exercise. Taking a single subject and determining energy expenditure during various exercises such as running on a treadmill at various rates, stepping up and down, rowing, running in place, and the Burpee push-up test, it was found that regardless of whether the exercise was continued until exhaustion or merely for a standardized time, the relationship between oxygen consumption and duration of the exercise could be expressed as a function of the equation \( Y = 16.01 e^{-0.088X} \) where \( Y \) is the duration of the exercise in minutes and \( X \) is the energy expenditure in liters of oxygen per minute. A similar speed versus duration curve was obtained for a group of men running at various speeds on the treadmill.

IV. THE RELATIONSHIP OF OXYGEN METABOLISM TO CIRCULATORY-RESPIRATORY ADJUSTMENTS DURING EXERCISE

Oxygen Intake and Blood Flow. After extensive experiments conducted on fifty-one normal individuals, Grollman\(^3\) concluded that the cardiac output per minute (HWV) at rest paralleled the oxygen intake per minute and increased proportionately in moderate and severe exercises involving from 1,200 to 1,680 kilogram-meters of work per minute. Brown

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and Pearson\textsuperscript{34} also demonstrated a good relationship between cardiac output and oxygen consumption. For each 10 per cent increase in oxygen consumption there was an average increase of 7.07 per cent in cardiac output. Courmand\textsuperscript{35} verified this relationship in an experiment conducted on twenty-four subjects.

Bock and his co-workers\textsuperscript{36} have also demonstrated that the blood flow during moderate exercise is proportional to the amount of oxygen consumed during exercise. They also point out that pulse rate and oxygen consumption during exercise are similarly related.

These studies seem to firmly establish that oxygen intake and blood flow during moderate exercise are proportional. However, data concerning this relationship during violent or all-out work is not complete. Cureton\textsuperscript{37} concludes that a very close estimate of the cardiac output for well trained men (champions) during all-out work may be computed from the amount of oxygen consumed during exercise. However, for untrained men, or men with wide variations in capacity and condition, it can only be considered an approximation. He presents the following formulas for the conversion of oxygen intake into minute


\textsuperscript{37} T. K. Cureton, Physical Fitness of Champion Athletes, pp. 356-59.
volume of blood flow.$^{38}$

Resting MV = resting oxygen consumption (L./min.)$
\cdot 06$

Exercise MV = exercise oxygen consumption (L./min.)$
\cdot 123$

Mill$^{39}$ found that a similar linear relationship existed between total ventilation of the lungs and the rate of oxygen intake during exercise of a moderate nature. The rate of oxygen consumption and total ventilation varies almost directly with the amount of work performed, so long as a steady state can be maintained; but when exhaustion approaches at the end of a short period of strenuous exercise, there is an increase in ventilation out of proportion to the amount of oxygen consumed.

During exercise there are many adjustments of the circulatory and respiratory systems to the increased demand for oxygen. Turner$^{40}$ sums up these adjustments by stating,

In the responses of the circulatory mechanism to exercise we see the cooperation of many parts, conspicuously in increased return of the blood to the heart because of the suction of augmented respiration and the message of the exercise itself with accompanying increase in force and rate of the heart. A dilation of arterioles in the active regions combines helpfully with enough constriction elsewhere so that systolic pressure is high, diastolic not low, with a consequence wide pulse pressure suggesting a large output from the heart per beat. There is in the active regions the opening of large

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$^{38}$Ibid., p. 294.


numbers of capillaries previously closed as well as the
dilation of all, so that the needy tissues may be flooded
with blood.

The accurate grading of all these responses to the
amount of exercise has been checked by comparative studies
of the use of oxygen. The parallel changes are most
impressive in their accuracy of adjustment.

Schneider and Karpovich\textsuperscript{41} and Reidman\textsuperscript{42} agree that the important
factors determining the rate of oxygen consumption during exercise are
(1) lung ventilation, or the rate and depth of breathing, (2) the oxygen
capacity of the blood, or the hemoglobin content of the blood, (3) un­
loading of oxygen at the tissues, and (4) cardiac output or the amount
of blood circulated during exercise. It is concluded that, in the final
analysis, the quantity of circulating blood will determine the amount
of oxygen supplied to the muscles during exercise.

**Oxygen Debt and Lactic Acid.** Hill and Lupton\textsuperscript{43} established a
positive relationship between blood lactate concentration and the
amount of oxygen consumed during recovery or the oxygen debt. Later
work by Owles\textsuperscript{44} and Margaria, Edwards and Dill\textsuperscript{45} demonstrated that

\textsuperscript{41}E. C. Schneider and P. V. Karpovich, \textit{op. cit.}, pp. 42-43.

\textsuperscript{42}R. Reidman, \textit{op. cit.}, pp. 92-99.

\textsuperscript{43}A. V. Hill and N. Lupton, "Muscular Exercise, Lactic Acid, and

\textsuperscript{44}W. H. Owles, "Alternations in the Lactic Acid Content of the

\textsuperscript{45}R. Margaria, N. T. Edwards, and D. B. Dill, "The Possible
Mechanism of Contracting and Paying the Oxygen Debt and the Role of Lactic
blood lactate is increased by severe, but not by moderate exercise. They concluded that in moderate exercises the oxygen debt may reach three or four liters with no evidence of lactic acid accumulation, and that a considerable portion is repaid very rapidly after the cessation of exercise, while the remainder of the debt may require several hours for repayment. They also asserted that the true oxygen debt consisted of two fractions: (1) the "lactacid" debt which is not related to the accumulation of lactic acid and is repayed within a few minutes after exercise ceases, and (2) the "lactacid" debt which is proportional to the amount of lactic acid concentration, and may require an hour or more for repayment.

Sacks and Flock maintain that the lactate which appears in the blood is associated with anaerobic metabolism in the muscles. And this occurs not only in severe exercise, but in the beginning stages of moderate exercise before circulatory and respiratory adjustments have been made.

Winton and Bayliss conclude that at least a substantial fraction of man's ability to undergo short periods of very energetic work and thus to contract an oxygen debt can be accounted for by the reserves.

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of creatine phosphate in the muscles and by the amount of lactic acid accumulation which the body as a whole can tolerate. Robinson and Harmon\(^{49}\) found that poorly trained runners cannot tolerate very much lactate because of poor circulation and fast exhaustion of the buffering reserves. Only the "toughest" athletes can deplete the blood pH and the alkaline buffers such as hemoglobin, sodium bicarbonate, potassium, and other alkaline salts, to very low levels. Cureton\(^{50}\) found that oxygen debt was highly related with breath holding as measured by the Flarimeter Breath Holding Test. He suggests that oxygen debt and the ability to buffer large quantities of lactic acid is highly related to high tolerance for carbon dioxide tension in the blood, will power, high levels of hemoglobin and red corpuscles, as well as alkaline reserves.

**Oxygen Debt and Recovery From Exercise.** Hill\(^{51}\) has demonstrated that recovery from moderate exercise is about 65 per cent complete in ten minutes, 82 per cent in twenty minutes, 88 per cent in thirty minutes, 94 per cent in forty minutes, 97 per cent in fifty minutes, 99 per cent in sixty minutes, and almost complete in seventy minutes. Recovery was determined by the return of oxygen metabolism to the resting state. However, Margaria, Edwards, and Hill\(^{52}\) found that after

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severe work most of the recovery (measured in terms of lactic acid concentration) was accomplished after a few minutes, but that usually 15 to 80 minutes were necessary for the respiration, pulse rate, and blood pressure to return to normal. Lythgoe and Pereira\textsuperscript{53} studied the relationship of the pulse rate and the oxygen intake after strenuous exercise. They found that the heart rate and the oxygen consumption fell abruptly when the exercise ceased, but that the fall in oxygen intake was considerably more rapid than that of the heart rate. It is believed that the output of the heart per beat is diminished by the stoppage of the bodily movements which normally play a large part in the venous return of blood to the heart. It was also discovered that recovery from strenuous exercise measured in terms of oxygen metabolism was a little more than eighty per cent complete in two and a half minutes.

V. THE EFFECTS OF TRAINING ON OXYGEN METABOLISM

\textit{Basal Metabolism and the Effects of Training.} The exact effects of training and conditioning on the basal metabolism are not clearly known. Reports from various investigators throughout the past century have resulted in conflicting conclusions. Schneider and Foster\textsuperscript{54} reported that during training the basal metabolism of athletes tends to drop,


whereas in normal non-athletes it may rise, fall, or remain steady. However, Morehouse after an investigation including twenty athletes in and out of training came to the conclusion that although the basal metabolism was two per cent higher in training, the difference was not significant and basal metabolism was not altered by training. The most recent experiments on basal metabolism were conducted by Cureton at the University of Illinois. It was demonstrated that training increased the basal metabolism of normal young women except in the case of obese individuals. He also found that champion athletes maintain a higher basal metabolism rate than normal young men by about eighteen per cent. However, there was no significant difference between the champions and physical education majors or college varsity athletes. An earlier experiment by Benedict and Smith seems to agree with the results of Cureton's experiments. They found that when compared with non-athletes of approximately the same body build and weight the athlete invariably had a higher basal metabolism. They conclude that the trained or conditioned man has greatly more active protoplasmic tissue and thus typically shows a higher metabolic rate per gram of body weight and per square meter of body surface.


56 T. K. Cureton, Physical Fitness of Champion Athletes, pp. 287-301.

The Effects of Training on Exercise Metabolism and Related Physiologic Measures. The physiological difference between champion runners and healthy non-athletes during exercise were tested by Robinson, Edwards, and Dill. They found that in performing moderate work for the same duration the trained man exhibited lower oxygen consumption, slower pulse rate during work, lower blood lactate during work and faster return of heart rate to normal after exercise. On performing the same type of exhausting work in which a steady state could not be maintained, the trained man demonstrated longer duration of effort before exhaustion, higher oxygen consumption, slower maximal heart rate, higher blood lactate and faster return of heart rate to normal. The most significant differences were found to be those measurements which were determined during exhausting work.

Morehouse sums up the effects of training on oxygen metabolism by stating,

(1) the oxygen metabolism for a given task is diminished as a result of more efficient use of the muscles and elimination of extraneous movements, and of greater mechanical efficiency of the muscles themselves.

(2) the maximal oxygen intake is increased through improved capacity of the heart to pump blood, and through circulatory and respiratory adjustments.

(3) the maximal oxygen debt which can be incurred is increased probably due to an increase in the amount of buffer alkali available for neutralizing lactic acid.

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59. E. Morehouse and A. T. Miller, op. cit., p. 76.
Robinson and Harmon concluded that on a standardized moderate exercise the lactate levels of trained runners are relatively lower, because their circulation is better and the blood buffering is better, and there is more efficient conversion of lactic acid to glycogen in the presence of relatively greater amounts of oxygen. However, on strenuous exercise to the point of exhaustion this relationship is reversed, as the lactate levels go very high only at the top of the run and the trained men are able to tolerate higher levels of blood lactate before they are forced to give up. Part of this ability is attributed to will power, and part of it is tolerance to high levels of blood lactate resulting from training. A low lactate level at the end of exhausting work indicates that the subject did the work easily or that his neuromuscular condition and will power were so poorly trained that he had to give up before running very long. Poorly trained runners cannot tolerate very much lactate because of poor circulation and fast exhaustion of the buffering reserves.

Robinson found that during training for middle distance running nine previously untrained college men constantly improved in running ability and in time performance. These same men exhibited a gradual increase in oxygen consumption during an all-out treadmill run. The same was true of blood lactic acid. Blood sugar content, and basal alveolar carbon dioxide tension and alkaline reserve were unaffected.

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60 S. Robinson and P. M. Harmon, loc. cit.

by training. But during work, the increased ability of the men to
tolerate larger quantities of blood lactate was accompanied by cor-
responding decreases in alveolar carbon dioxide tension during work
and in alkaline reserve of the blood immediately after work.

It is indicated that training increases the bodies tolerance
for lactic acid with a resulting increase of the stores of alkaline
reserve. Conversely, the trained man should have larger stores of
alkali. Davis and Brewer\textsuperscript{62} observed that dogs subjected to regular
exercise increased their alkali reserve. Full and Huxheimer\textsuperscript{63}
demonstrated that trained athletes had higher alkali reserves than
normal men. However, Robinson, Edwards, and Dill\textsuperscript{64} reported that a
group of five well trained athletes exhibited only normal reserves
of alkali.

The ability to accumulate a large oxygen debt cannot be said
to depend completely upon the buffering capacity of alkali reserves
or tolerance to high levels of lactic acid. Apparently, there are
other factors, yet unidentified, which must be considered. It should
be pointed out that blood lactic measures during exercise are not

\textsuperscript{62}J. E. Davis and N. Brewer, "Effect of Training on Blood
Volume, Hemoglobin, Alkali Reserve, and Osmotic Resistance of

\textsuperscript{63}F. Full and H. Herxheimer, "Uber der Alkalireserve,"
\textit{Klinische Wochenschrift} (5:228, 1926), cited by E. C. Schneider,

\textsuperscript{64}S. Robinson, H. T. Edwards, and D. B. Dill, "New Records
completely reliable. Sacks, Sacks, and Shaw\textsuperscript{65} discovered that in human subjects the blood lactate from venous blood samples taken after exercise are invalid for indicating the total amounts of lactic in the body. Some lactate also spills over into the urine before the blood sample is taken.

Stewart and Watson\textsuperscript{66} found that training does not seem to alter the cardiac index, the work of the left ventricle, the circulation time or the A-V oxygen difference of resting subjects.

Schneider\textsuperscript{67} discovered that the basal heart rate of trained subjects is slower and a normal output per minute is maintained by a larger systolic discharge. During moderate work he found that the trained man had a lower stroke-volume. During exhaustive work the trained man exhibited a greater change in heart rate.

Cureton\textsuperscript{68} in an extensive study concerned with measuring the differences between champions and normal men during all-out exercise, found that the champions demonstrated significant superiority in their ability to maintain the exercise and in their ability to take in oxygen during exhaustive work. It was discovered that oxygen debt did not discriminate between champions and normal men, the exact

\begin{itemize}
\item \textsuperscript{68}T. E. Cureton, \textit{Physical Fitness of Champion Athletes}, pp. 315–54.
\end{itemize}
difference being zero. He further maintained that the major metabolic difference was in terms of intake oxygen during exercise. The debt accumulated was merely a reflection of the inability to take in oxygen as needed, and certain other factors not completely known. When intake oxygen was divided by the weight of the subject, the difference between champions and normal men increased. The champions also were found to have a larger heart size, more total oxygen, and a lower or more efficient utilization of oxygen consumption and oxygen debt.

He concludes,

There is no denying the evidence that the highly trained athletes use more total intake oxygen, that they use it at a faster rate than less highly trained athletes, and that they build up oxygen deficiency (equivalent to oxygen debt) at a slower rate in a standard exercise and at a lower average rate in the all-out exercise.

He further asserts,

The oxygen intake is the important measure and the oxygen debt depends upon it and is an indirect reflection of it. Large oxygen intake capacity is certainly very essential to endurance. It is one prime element in physical fitness for endurance running.

Cureton discounted the importance attributed to blood changes during exercise as valid indicators of levels of physical fitness. He maintains that there is no basis at this time to claim that these blood changes may be systematically used as valid fitness tests for individuals. Pulse waves, red blood count, white blood count,

69 Ibid., p. 329.

70 Ibid., p. 327.

71 Ibid., pp. 343-346.
respiratory quotients, pH levels, and lactic acid content of the blood were discounted at this stage of the research as being inconsistent indicators of fitness or ability to discriminate between champions and normal men.

Metheny, however, demonstrated that young women will develop higher levels of blood lactate than young men of the same age during a standardized exercise. It was also shown that men had higher red blood count, higher hemoglobin, and showed the strain of the treadmill run less in the white blood count and in the changes in lymphocytes associated with similar amounts of work. It was indicated that these differences may be considered as differences in fitness. However, she did not report the significance of these differences.

Margaria, Edwards, and Dill have shown that the blood lactate concentration is not proportional to the oxygen debt at low levels of exercise. Crescitelli and Taylor report that less fit individuals have a significantly greater lactic acid concentration during the entire period of standardized submaximal exercise. Experiments by Margaria and Edwards indicate that the lactic acid concentration is not directly related to the intensity of work until a critical


level of oxygen consumption is reached, which for a well trained indi-
vidual may be at a rather high level.

It seems rather apparent that the conflicting reports concerning
oxygen debt measures and the related physiological measures of lactic
acid concentration and buffering reserves indicate that at this stage
of the research a definite conclusion concerning their ability to dis-
tinguish between champions and normal men or to accurately define the
effects of training cannot be asserted. It appears that the most
significant differences are found in the responses during strenuous
exercise and these differences are reflected in the ability to take
in large quantities of oxygen. At least this is one measure which has
consistently demonstrated the ability to show the effects of training
and to differentiate between champions and normal men.

The Relationship of Improvement in Skill to Energy Metabolism.
Steinhauser76 has emphasized "perfection of movement" as the most pro-
minent and most specific result of training. Karpovich and Millman77
found that a poorly skilled swimmer used two to five times as much
energy as a skilled swimmer. They concluded that in an activity re-
quiring skill, training increases the efficiency of energy expenditure
as the skill is learned.

76 A. H. Steinhaus, "Chronic Effects of Exercise," *Physiological
Reviews* (13:140, 1933).

77 P. V. Karpovich and H. Millman, "Energy Expenditure in Swim-
Dill, Talbott, and Edwards\textsuperscript{78} studied the effects of a standardized treadmill run for twenty minutes upon twenty-three individuals with wide variations in running skill. The subjects were rated according to their skill in running and according to concentrations of blood lactate and oxygen consumption. Only a fair correlation was found between skill and lactic acid concentration, but a definite relation was established between economy of oxygen consumption and skill in running. They conclude that in moderate exercise the ratio between oxygen consumption per minute of work divided by the weight of the individual could be indicated as a "skill index."

Reidman\textsuperscript{79} believes that skill is closely related to endurance. She says,

Skill indirectly increases endurance. Learning to do the activity quickly means being able to repeat it more often and to last longer at the exercise. This is certainly true for running. Skill involves better body mechanics, fewer contractions, and fewer muscles used, thereby delaying fatigue and increasing endurance. The strength and power of the muscles make it possible to achieve more force with a smaller expenditure of energy. Clearly, then, strength and power contribute to skill, and the development of skill increases endurance for protracted activity.

This is corroborated by Cureton.\textsuperscript{80} Although he found that a major portion of the time of the all-out treadmill run could be accounted for in terms of intake oxygen, there was a certain portion of the run which


\textsuperscript{79}R. Reidman, \textit{op. cit.}, p. 140.

\textsuperscript{80}T. K. Cureton, \textit{Physical Fitness of Champion Athletes}, p. 341.
could not be accounted for in terms of aerobic or anaerobic oxygen.

He states,

The writers have a great respect for neuromuscular conditioning which enables a given intensity of exercise to be held on less and less oxygen supply. This must mean that better utilization of oxygen develops in the process of training, the nerve trunks develop, the motor brain cells become capable of more sustained output, and the neuromuscular junctions become more impervious to fatigue. It is also likely that specific muscles become strengthened and do their work more easily. It is certain that many minute adjustments occur to improve mechanical efficiency. Some of these factors certainly operate apart from oxygen supply.

Therefore, he concludes that in an all-out treadmill run the duration of effort as measured by total run time is a measure of neuromuscular and circulatory-respiratory capacity.

VI. METABOLIC MEASURES AS PREDICTORS OF PERFORMANCE

Various studies concerned with oxygen consumption during exhaustive endurance work have shown that performance is practically proportional to the amount of oxygen consumed during the exercise. Sargent\(^1\) and Hill\(^2\) demonstrated that the curves of running and swimming time plotted against the distances of various races paralleled the curve of oxygen requirement and the claim was made that the rate of total oxygen consumption determined the physiological basis of athletic records.


They pointed out that it was possible to predict the speed with which a good athlete could run a certain distance if they knew the maximum oxygen intake during exercise, the maximum oxygen debt possible, and the oxygen requirement per minute for various speeds. Later, Karpovich and LeMaistre83 demonstrated that the same accurate predictions could be made in regards to swimming performance if these three metabolic measures were known. Actually, their predictions were almost too good to be true.

Hill84 says,

Imagine an athlete with a maximum oxygen intake of 4 liters per minute capable of running until his maximum oxygen debt has been occurred for 15 liters. If he runs for fifteen minutes the total oxygen available during the exercise and in arrears is \(15 \times 4 + 15 = 75\) liters; an effort can be made requiring 5 liters of oxygen per minute.

Conversely, if this man runs at a speed requiring five liters of oxygen per minute, he would become exhausted at the end of fifteen minutes.

At first Cureton85 agreed with the analogies of Hill, Sargent, and Karpovich. In his book, Physical Fitness Appraisal and Guidance, he says,

The use of total or oxygen/minute consumption as a criterion of maximal exercise exertion has considerable physiological support. The world record curves

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for swimming and running various distances are shown to parallel the values for total oxygen consumption in parabolic curves concave upward when time or speed is plotted on the horizontal axis against oxygen consumption on the vertical axis.

Later, however, after rather extensive research involving metabolic measures of twenty champion athletes and eighteen normal men during all-out runs on an inclined treadmill, he reached a quite different conclusion. Cureton\textsuperscript{86} demonstrates that if the amount of total oxygen is divided by the rate of oxygen consumption (total oxygen divided by the time of the run) then the time of the run will be the quotient. It is also explained that if the oxygen debt is subtracted from total oxygen and the remainder is divided by the rate at which the remainder is used, then the time of the run is the quotient.

In reference to the thesis advanced by Hill and Sargent he\textsuperscript{37} writes,

The fallacy in the above calculations is that the same measures of oxygen debt and rate of oxygen intake are used to obtain the total oxygen value, including the length of the time of the run (for the rate of intake), hence the reversal of the calculations only bring us back to the measures available in the first place. The prediction is fallacious and cannot be done without knowing the time of the run. A real prediction would be to measure the cardiovascular responses without involving use of the time of the run in any way, i.e., predict the criterion from independent measures.


\textsuperscript{37}Ibid., p. 325.
It should be pointed out that Hill and Sargent used maximum oxygen intake and maximum oxygen debt in their calculations. On the other hand the metabolic measures of Cureton were derived during an all-out run which was regulated to obtain maximum debt and maximum intake. Thus it appears quite possible that the thesis of Hill and Sargent is subject to some revision.

Cureton88 also studied the relationship of various individual metabolic measures with performance on the all-out treadmill run. He found that the best correlations with run time and the oxygen measures were, in order of their best predictive value: (1) Gross oxygen intake divided by weight, \( r = .87 \), (2) Total oxygen (gross intake plus net debt), \( r = .81 \), (3) Gross oxygen intake, \( r = .75 \), (4) Rate of net oxygen debt divided by weight (net debt divided by time of run divided by weight) \( r = -.64 \), (5) Rate of net oxygen debt (net debt divided by time of run), \( r = -.60 \), and (6) Total oxygen rate (total oxygen divided by time of run), \( r = -.57 \). Rate of gross intake, net debt, and respiratory quotient all correlated lower than .34 with time of the run.

He found that a combination of gross intake divided by weight with net debt per minute divided by weight produced a high correlation of .97 with performance. He admits, however, that this is subject to some spuriousness due mainly to time of the run being included in the criterion and in the oxygen debt rate measure.

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88 Ibid., p. 336.
Cureton concludes

It seems very logical that an individual needs (1) large oxygen intake capacity and that he needs also (2) to be able to keep down the net oxygen debt or the rate of oxygen debt (allow it to build up at a slow rate for the whole time of the run). On logical grounds a very efficient runner with a large oxygen intake capacity is able to keep the oxygen deficiency from mounting very fast, even though at the very end of an all-out run he may push up a large oxygen debt by great exertion of will power. This should be verified in further experimentation. It has been hard to show that oxygen debt adds anything to the prediction which is not already provided by the oxygen intake.

...It is clear that oxygen debt is not related in a simple manner to all-out run time. Extraneous factors which interfere with the relationship are either (1) skill in running (not tensing up, proper balance, good stride, etc.), (2) will power, (3) physical build, especially leg strength. The use of the drop in pH or the oximeter test of arterial oxygen depletion during the all-out run may throw more light on the problem. At the present time the use of oxygen debt or blood lactate as tests of physical fitness cannot be fully recommended.

Karpovich maintains that it is a simple matter to demonstrate why a sprinter depends more upon his greater oxygen debt and a long distance man has to rely on his maximum oxygen intake during exercise. He says,

Suppose there are two swimmers, A and B, identical in all respects except for their oxygen intake and debt.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Maximum Oxygen Intake in Liters per minute</th>
<th>Maximum Oxygen Debt in Liters</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>4.5</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>3.0</td>
<td>16</td>
</tr>
</tbody>
</table>

89 Ibid., pp. 331-32.

During the first minute A will have 14.5 liters of oxygen and B 19 liters, therefore B will be able to move faster than A. Swimming a distance requiring ten minutes, A will have 55 liters of oxygen; whereas B will have only 46 liters and therefore B will be slower.

Although arrived at by different calculation both Cureton and Karpovich agree that oxygen intake is the main essential in endurance activities. In Cureton's experiments, run time varied from 1.13 minutes to 5.05 minutes. It seems quite logical to assume that all-out exercise, at least within these limits, can be asserted to be limited by endurance capacity which in main is dependent upon the ability to take in large quantities of oxygen during the exercise.

VII. THE THEORY OF OXYGEN METABOLISM AS A TEST OF FITNESS AND ITS RELATIONSHIP TO MOTOR PERFORMANCE

Cureton has said, "To separate organic condition from skill of performance is to understand the organic capacity of the individual and the conditioning requirement of the exercise."

Throughout the literature on metabolic experiments and studies related to cardiovascular measures of tolerance for exhaustive endurance work there is suggested a reoccurring thesis: "The most basic and fundamental problem confronting man during exercise is the securing of adequate amounts of oxygen for the task at hand." It appears that whatever factors may be related to ultimate failure of the machine, the ultimate deciding one is the capacity for utilization of oxygen.


In this respect, Dill, Edwards, and Talbott\textsuperscript{93} conclude.

There are probably types and conditions of activity in which the limits of exertion may be determined by the available supplies of fuel, by the facilities for removal of metabolic wastes or by the ability of the body to dissipate heat but in the majority of cases the weak link is the capacity for supplying oxygen to the contracting muscles.

Reidman\textsuperscript{94} maintains that the factors which limit human power in the course of performance are the nature of the muscles, the capacity for oxygen intake, and the rate of oxygen delivery to the tissues.

Brassfield\textsuperscript{95} corroborates this belief and further amplifies the relationship of oxygen intake with other cardiovascular factors. He states,

The circulation is usually looked upon as the important factor in the limitation of muscular exertion. The chief determining factor, therefore, in the oxygen intake is the rate of circulation of the blood. Some look upon the oxygen holding capacities of the blood as the last reserve the body has to draw upon. When the body encroaches on the lower third of this reserve the athlete comes to the end of his physical powers. Others say that the coronary blood supply to the heart may be the weak link in the chain of circulatory adjustments of muscular activity. Still others believe that voluntary effort is limited by failure of the functional capacity of the cardiorespiratory system as a whole and not by premature failure of any one member of the team. It is not of great importance whether we regard one member more than another as the cause of failure. The outstanding point is that there is failure in the delivery


\textsuperscript{94}\textsuperscript{S. R. Reidman, \textit{op. cit.}, p. 141.}

\textsuperscript{95}\textsuperscript{C. R. Brassfield, "Some Physiological Aspects of Physical Fitness," \textit{Research Quarterly} (14:111, 1943).}
of oxygen to the muscles because the capacity of one or more of the adaptive mechanisms is finally overtaxed.

In the final analysis, physical fitness appears to be limited by the cardio-respiratory system. On rare occasions the muscles may fail for lack of energy-yielding compounds. The muscles are more immediately dependent on oxygen than any other substance. Lactic acid accumulates within them when they do not receive this gas in adequate amounts. The accumulation of lactic acid in the blood and muscles up to the fatigue maximum will certainly stop the machine. It is evident that the factors which limit the intake and delivery of oxygen to the tissues are ordinarily the cause of failure of the machine.

The results of experiments, previously discussed, have pointed out the close relationship between oxygen consumption, blood flow, and other cardiovascular indexes. Its very definite relationship to the intensity and speed of work is demonstrated, and its superiority to other cardiovascular measures as a predictor of performance has been rather clearly established. The effects of training show significant increases in capacity for intake and its ability to distinguish between champions and normal men is unquestionable.

It is postulated that the ability to take in oxygen during exercise is a reflection of all the various cardiovascular and respiratory adjustments of the human mechanism's attempt to maintain equilibrium during stress. Karpovich\textsuperscript{96} affirms this thesis by asserting.

There are many unsolved problems regarding the bodily changes taking place during training. The intimate nature of metabolic changes is also obscure. However, it (metabolic measures) offers a gross, and the most inclusive, index

\textsuperscript{96}P. V. Karpovich, loc. cit.
of physical fitness because it reflects the function of most of the bodily organs and systems. Inefficient heart, lungs, kidneys, or blood would result in a lowered metabolic capacity.

It is the writer's sincere hope that sometime the laboratory process involved in these tests may be simplified and that it might be possible to use some specially devised metabolism test as a practical index of fitness.

Indeed, considering the evidence available, it seems quite probable that the circulatory-respiratory capacity as measured by oxygen metabolism during exhaustive work is a valid indicator of fitness.

However, the exact relationship between circulatory-respiratory capacity and motor performance is yet to be established. One experiment found no relationship between motor fitness as measured by the Army Air Forces Physical Fitness Test and various cardiovascular-respiratory measures, such as blood pressure, sitting pulse rate, and pulse rate after exercise. It could be assumed that this indicates there is little relationship between motor fitness and cardiovascular fitness. On the other hand, it might be pointed out that actually the indexes of cardiovascular fitness which were tested were incomplete measures, i.e., they did not measure the total respiratory-circulatory capacity. At any rate, the relationship between these two aspects of fitness is still questionable. If there is any relationship between the two, then just what is the relative contribution of circulatory-respiratory capacity to the

various motor performance tests? Is it skill, intake capacity, strength, or some other factor which mainly determines a man's ability to run a long distance, to repeat a great number of chins, sit-ups, or squat-jumps, or to run a short distance in quick time, or to perform feats involving power?

Morehouse\textsuperscript{98} insists that the relationship between oxygen supply is not as distinct and unrelated as it might appear at first sight. He writes,

Although the final limiting factor in exercise appears to be the supply of oxygen, the capacity of the organism as a whole to utilize oxygen depends not only upon the transfer of this gas from the lungs to the blood and its transport to the tissues, but also upon the effect to which the rest of the body is adapted to meet the excessive demands of severe exercise.

Thus in exercises of speed, such as sprinting and boxing, the legs may appear to give out first, running up moderate grades may produce intolerable breathlessness, and climbing a steep grade or lifting heavy weights may produce pounding of the heart and other signs of cardiac distress. It is probable that these effects are not as distinct and unrelated as might appear at first sight; but that in each case the root of the trouble lies in a failure of the oxygen supply to meet the demands of exertion. If this is true, the organ or system which apparently fails first is simply the one most directly affected by the anoxia, or by chemical or nervous influences resulting from the anoxia.

The only study of this nature which compares motor performance with circulatory-respiratory capacity was conducted by Hodgson, Lopez, Pilliard, and Newman\textsuperscript{99} on a group of college women. They measured

\textsuperscript{98} L. E. Morehouse and A. T. Miller, \textit{op. cit.}, p. 205.

oxygen consumption during a standardized step test and also during an all-out step test to exhaustion. They labeled these measures as submaximal and maximal oxygen supply. They postulated that total capacity is determined by maximal capacity for transport and maximal oxygen debt tolerated. The submaximal oxygen ratio of net oxygen intake divided by total consumption was assumed to be the index of maximal transport; a maximal oxygen debt was taken to be that measured during the maximal work.

They combined the submaximal oxygen ratio and the maximal oxygen debt into a rating they called total oxygen capacity and compared the results with scores made on the U. S. Handbook Physical Fitness Test for College Women. They found a correlation of .77 with the total battery. The combined oxygen scores also correlated .74 with maximum number of steps during all-out exercise, .69 with time of the 300-yard run, and .64 with the Brouha Step Test. The maximal oxygen debt also correlated .64 with the total battery. Unfortunately, the relationship between the oxygen measures and scores on the other motor performance items is not known.

Although, whether or not their measure of combined oxygen supply is a measure of total oxygen capacity (and recent experiments would seem to indicate that it is not), their experiment does seem to indicate that there is considerable relationship between circulatory-respiratory capacity and total performance in a wide range of motor activities. At any rate, the relationship for women is questionable, and for men still remains a mystery.
VIII. THE TECHNIQUES INVOLVED IN MEASURING CIRCULATORY-RESPIRATORY CAPACITY BY MEANS OF OXYGEN METABOLISM DURING EXERCISE

The Types of Apparatus. According to Best and Taylor, energy metabolism can be studied by either of two methods, that of direct or indirect calorimetry. According to them the elaborate nature of the apparatus, the expensive equipment and the necessity for large groups of workers precludes the use of the latter method in the usual laboratory. The usual method, then, is to employ some form of indirect calorimetry, i.e., to measure energy production from respiratory exchanges. Various experiments have shown that results obtained from the indirect method agree within less than one per cent with those obtained with the direct method.

They also divide the indirect methods into two subdivisions.
(1) The closed circuit type whereby the subject breathes pure oxygen and the expired air passes through a carbon dioxide absorbent, usually soda lime. In this type of apparatus the amount of oxygen consumed can be measured by means of graphical tracings or by determining the volume of oxygen before testing and after testing and subtracting the two measures. If necessary, the carbon dioxide expired can be determined by subtracting the weight of the soda lime before and after testing. (2) The open circuit type whereby the subject breathes atmospheric air and the exhaled gases are collected and analyzed for their oxygen and carbon dioxide content. Since the composition of atmospheric air is stable and the amount of expired air is known, it

is possible to calculate the amounts of oxygen consumed and the carbon
dioxide exhaled.

The Regnault-Reisset, the Benedict, and the Benedict-Roth apparatus
are typical examples of the closed circuit method. The Zuntz-Geppert,
and the Tissot Spirometer and Douglas Bag technique used with the
Haldane gas-analysis apparatus are typical examples of the open circuit
method. A critical comparison of the various indirect methods was made
by Carpenter. He concluded that all of the different types of ap­
paratus gave comparable results insofar as the measurements of oxygen
consumption were concerned. However, the Tissot and Douglas had
distinct advantages in regard to carbon dioxide measurements. He
pointed out that the Haldane gas-analysis technique which had to be
used with the Tissot and Douglas methods was not only tedious, but
somewhat difficult, requiring special training to obtain accurate
results. On the other hand, he demonstrated that the closed circuit
apparatus which utilized a recording spirometer gave quick and ac­
curate results, produced a permanent graphic record of the entire
period under observation, and it did not require any special skills
which could not be mastered in a fairly short time.

He also investigated the different types of breathing appliances,
such as the pneumatic nose piece, the rubber mouthpiece, and the face
mask. He concluded that the face mask was the least preferable of the
breathing appliances. The mouthpiece was the most reliable from the

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101 T. M. Carpenter, A Comparison of Methods for Determining the
Respiratory Exchange of Man (Carnegie Institute of Washington, Publica-
standpoint of an airtight closure, but its use may be disagreeable to
the subject. The pneumatic nosepiece was found to be the most comfort-
able for the average subject.

Carpenter\textsuperscript{102} also investigated the possibility of adding additional
dead space to the Benedict apparatus without changing the accuracy of
the results. He found that an additional dead space of 224 cubic
centimeters did not affect the accuracy of measurements involving
oxygen consumption. He points out that the addition of a long tube
to the Benedict type of apparatus is quite permissible.

A large number of experiments concerning energy expenditure during
exercise have utilized the Tissot Spirometer of the Douglas Bag technique
along with the Haldane gas-analysis apparatus. Notable among the re-
searchers using such a technique are Cureton,\textsuperscript{103} Hodgson,\textsuperscript{104} Hill,\textsuperscript{105} and Robinson.\textsuperscript{106} However the closed circuit method has obvious ad-
vantages for the unskilled observer. It was found that Tuttle,\textsuperscript{107}

\begin{itemize}
  \item \textsuperscript{102}Ibid., pp. 213-219.
  \item \textsuperscript{103}T. K. Cureton, \textit{Physical Fitness of Champion Athletes}, p. 319.
  \item \textsuperscript{104}P. Hodgson, \textit{et al.}, loc. cit.
  \item \textsuperscript{105}F. W. Hill, \textit{Muscular Movement in Man: The Factors Governing
         Speed and Recovery from Fatigue}, p. 27.
  \item \textsuperscript{106}R. Robinson, \textit{loc. cit.}
  \item \textsuperscript{107}W. W. Tuttle, "The Effect of Weight Loss by Dehydration and
         the Withholding of Food on the Physiologic Responses of Wrestlers," \textit{Research
         Quarterly} (14:163, 1943).
\end{itemize}
Henry, Harp, and Grout had used a closed circuit recording spirometer of the Benedict-Roth type with very favorable results. Although they had to make certain modifications to increase the capacity of the apparatus for measuring the oxygen consumption during long intervals, they found it satisfactory for determining the individual differences in exercise metabolism.

The Benedict-Roth Closed Circuit Apparatus. According to Best and Taylor the Benedict-Roth apparatus is the type most commonly used to determine basal metabolism. In this type of apparatus the subject's nose is clipped and he breathes in and out of the instrument through a mouthpiece and two wide-bore tubes provided with one-way valves that limit one tube to inhaling and the other tube to exhaling. The main part of the instrument is a hollow double-walled cylinder. In the narrow space between the two walls fits a second inverted cylinder or bell which is filled with oxygen. The bell is counterweighted so that it rides freely up or down in the ring-shaped space of the double-walled cylinder. The annular space is filled with water which acts as a seal. The inner space of the


double-walled cylinder holds another enclosed cylinder which is filled with soda lime. When the subject inhales the inspiratory valve opens and oxygen is taken out of the apparatus. When the subject exhales, the inspiratory valve closes and the expiratory valve opens and the escaping gases are forced through the soda lime. Here the carbon dioxide is absorbed and the remaining oxygen is allowed to escape into the upper bell. Attached to the upper bell's counterweight is a pen which records the respiratory tracings on a kymograph. The volume of the upper bell and the speed of the kymograph are so regulated as to allow accurate calculations of oxygen consumed per minute from the graph of the respiratory tracings.

The recorded volume, however, is not an accurate indication of the true volume of oxygen. The true volume will vary according to the temperature of the gas and the barometric pressure. According to Kolmer,\textsuperscript{112} it is standard procedure to convert the volume of recorded oxygen consumption to SFT units, i.e., dry, 0 degrees Centigrade and 760 millimeters pressure. The corrected volume \(V\) at the observed temperature of the apparatus \(T\), the barometric pressure \(B\), and the recorded volume \(V_0\), can be determined by the following formula:

\[
V = \frac{B}{760} \times \frac{273}{T + 273} \times V_0
\]

However, most manufacturing firms furnish charts for the volume corrections. If these are not available then the tables developed

by Carpenter\textsuperscript{113} can be used. These tables permit quick and accurate calculations of a correction factor from temperature and pressure readings. The SPT volume is then found by multiplying the recorded volume by the correction factor.

**Mechanical Errors in the Closed Circuit Apparatus.** There are certain mechanical errors which may affect the accuracy of the oxygen consumption measures when the closed circuit method is used. They are (1) inaccurate construction, (2) leakage, and (3) poor carbon dioxide absorption. Benedict\textsuperscript{114} has devised a special alcohol combustion apparatus for testing the indirect methods. However, Bard\textsuperscript{115} maintains that repeated tests carried out on the same subject will give a good indication of the accuracy of the apparatus.

Hepler\textsuperscript{116} suggests that oxygen in the apparatus be allowed to pass through a ten per cent solution of barium hydroxide. If there is any carbon dioxide present, the solution will become cloudy. Carpenter\textsuperscript{117} recommends that a one hundred cubic centimeter Erlenmeyer flask be used for this means of testing insufficient carbon

\begin{itemize}
  \item \textsuperscript{113}T. M. Carpenter, *Computing Respiratory Exchange* (Carnegie Institute of Washington, Publication No. 3033), pp. 88-102.
  \item \textsuperscript{114}F. G. Benedict, "The Control of Gaseous Metabolism Apparatus," *Boston Medical and Science Journal* (193:583, 1925).
  \item \textsuperscript{117}T. M. Carpenter, *Computing Respiratory Exchange*, p. 29.
\end{itemize}
dioxide absorption. The McKesson Appliance Company, however, maintains that when there is insufficient absorption of carbon dioxide, the patient sighs frequently or progressively increases the depth of respiration, which is shown by the increasing length of respiratory strokes on the graph.

Hepler says that a good test for leaks in the apparatus is to place a heavy weight on the bell and leave overnight. If there is a leakage of oxygen the bell will be lower than when filled and the pen will be higher.

The Test. The general procedure for measuring the amount of energy used during exercise is explained by Karpovich as having four main steps. They are:

1. The subject rests for thirty to forty-five minutes during which he is given a chance to get used to breathing through the mask or mouthpiece. After this the following determinations are made:

2. Oxygen used per minute at rest in a sitting position (this test is usually continued for ten minutes and the total is divided by ten): resting oxygen.

3. Oxygen used during the activity under investigation: activity oxygen.

4. Oxygen used during the period of recovery after exercise: recovery oxygen.

118 Directions for the Care and Use of the McKesson Recording Metabolor (Toledo, Ohio: McKesson Appliance Company), p. 3.

119 E. Hepler, loc. cit.

120 P. V. Karpovich and E. C. Schneider, op. cit., p. 48.
He also points out that the subject should be free of infection of any nature and should not have indulged in physical exertion or smoking before the test. The subject should be tested preferably in a basal state or at least two or three hours after eating. However, Dear, after studying various rest periods before giving the sitting test, concluded that a five minute rest period was adequate for accurate determinations of sitting metabolism.

**Factors Affecting Basal Metabolism.** It is common knowledge that basal metabolism, or metabolism measured after a period of twelve hours of absolute rest and quiet and without food, is subject to variations if environmental factors are not controlled. Hafkesbring and Collet found that the BMR was five per cent higher in cold weather than in hot; also, Hafkesbring and Bergstrom discovered that the BMR in New Orleans was eighteen to fourteen per cent below that of northern climates.

Barnes found that subnormal body temperature accompanied every low BMR except when infection was present. Jenkins


discovered a one degree Fahrenheit rise above normal in body
temperature corresponded to a seven per cent rise in BMR for men.
DuBois\textsuperscript{126} computed it to be a seven point two per cent rise for
each degree Fahrenheit rise in body temperature and thirteen per
cent for each degree Centigrade.

The basal metabolism varies according to the amount of carbo-
hydrate food eaten, the exercise taken, the amount of rest obtained,
the weather and temperature, and many other factors. A revealing
study by Baldwin and Shaw\textsuperscript{127} demonstrated that the BMR of football
players increased as the season advanced and emotional tension and
competition became more intense.

Wishart\textsuperscript{128} found that error due to hourly or daily variations
averages some five per cent. It should be pointed out that the
surface area estimate is erroneous by about the same extent.\textsuperscript{129}
Jenkins\textsuperscript{130} reported that if two BMR's were taken one after the
other the second one averaged a little over five per cent lower

\textsuperscript{126}E. F. DuBois, \textit{Basal Metabolism in Health and Disease}

\textsuperscript{127}F. M. Baldwin and R. J. Shaw, "Variations in Metabolic
Levels as Shown by Oxygen Consumption of Football Athletes Through­

\textsuperscript{128}M. Wishart, "The Variability of the BMR," \textit{Quarterly

\textsuperscript{129}Edith Boyd, "The Experimental Error Inherent in Measuring
the Growing Human Body," \textit{American Journal of Physical Anthropology}

\textsuperscript{130}R. L. Jenkins, \textit{loc. cit.}
than the first. However, DuBois\textsuperscript{131} estimated the retest training effect to be low in adults but more pronounced in children. Cureton\textsuperscript{132} says the most important point of control is to eliminate severe workouts the day before giving a BMR.

It is generally accepted that the basal metabolism measures are highly related to age and body surface factors. It is common procedure to express the BMR in Calories per square meter per hour and then to convert this to a per cent rating above or below the normal as established for different age and sex groups. However, the procedure involved in a sitting test is quite different. There are no definitely established norms for this test. According to Cureton\textsuperscript{133} it is standard procedure to express the sitting metabolism in terms of liters of oxygen per minute per square meter of surface area.

Factors Affecting Exercise and Sitting Metabolism. All of the above named factors probably affect the sitting metabolism rate, also. On the other hand, Cureton\textsuperscript{134} found that it was stable enough to subtract from the gross oxygen measures, but that it should not be taken on a day following hard exercise. Care must be taken to remove

\begin{footnotesize}
\begin{enumerate}
\item \textsuperscript{131}F. DuBois, "Clinical Calorimetry Paper Twelve," \textit{Archives of Internal Medicine.} (17:887, 1916).
\item \textsuperscript{132}T. K. Cureton, \textit{Physical Fitness of Champion Athletes,} p. 299.
\item \textsuperscript{133}Ibid., p. 309.
\item \textsuperscript{134}Ibid., p. 312.
\end{enumerate}
\end{footnotesize}
fear or apprehension if a reliable figure is to be obtained.

Although it is apparent that many factors can influence the rate of oxygen consumption during rest, experiments carried out during various types of activity have shown that the retest reliability of such measures as net intake and oxygen debt are high if certain precautions are met. Henry\(^\text{135}\) found a reliability coefficient of .55 during slow movement work and .69 during fast movement work for oxygen intake measured during a standardized time interval of five minutes. Taylor\(^\text{136}\) observed that the reliability of intake measures for standardized work was .59. Hodgson\(^\text{137}\) taking certain precautions to standardize the time of testing and the maintenance of normal eating and sleeping habits found a retest reliability of .96 for maximal oxygen intake.

Berg\(^\text{138}\) reported a reliability coefficient of .67 for oxygen debt measured during moderate exercise. But Henry\(^\text{139}\) reported a reliability of only .41 for slow moving work and .45 for fast moving work for durations of five minutes. On the other hand,

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\(^{135}\) F. M. Henry, *op. cit.*, p. 329.


\(^{139}\) F. M. Henry, *op. cit.*, p. 329.
Hodgson\(^{140}\) found the coefficient of reliability for oxygen debt during submaximal work to be .75. It should be pointed out that the experiment conducted by Hodgson made a marked effort to control the effects of sleep, rest, diet, and time of testing. Her figures are more in agreement with the results of Adair\(^{141}\) and Wyckes\(^{142}\) than those of Henry. The first two investigators reported a reliability of .87 for oxygen debt measured during submaximal work and .91 for maximal work to exhaustion. At any rate, it seems quite evident that the measures obtained during all-out work to exhaustion are the most reliable measures, especially if during the retest intervals the factors of diet, rest, sleep, and testing time remain normal or as constant as is normally possible.

According to Mill,\(^{143}\) the effects of temperature between fifty-four degrees and ninety-three degrees Fahrenheit on exercise metabolism are negligible. However, the report by Mill\(^{144}\) and his co-workers may have some indications insofar as diet is concerned.

\(^{140}\) P. Hodgson, \textit{et al.}, \textit{loc. cit.}


\(^{142}\) \textit{Ibid.}


They found that a runner in an alkaline state was able to run for a longer time than when in a normal state. Krogh and Lindhard point out that a carbohydrate diet will give eleven per cent greater efficiency (less energy expended per same amount of work) than a fat diet. And Henderson and Haggard found that a high fat diet resulted in greater distress and earlier onset of fatigue when rowing than did an average mixed diet. However, Gembill maintains that efficiency is practically the same as all diets. There is a slight increase in efficiency following a high carbohydrate diet, but not more than five per cent. According to Dill, the effects of diet are not too pronounced during short strenuous work but during prolonged work, such as a marathon race, the importance of carbohydrates becomes fairly evident.

**The Exercise to Determine Circulatory-Respiratory Capacity.** The exercises used to determine circulatory-respiratory capacity usually involve running on a motor driven treadmill, pedalling a stationary bicycle and stepping up and down on a stool. According to Morehouse

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these tests are used because they involve the large muscle groups in fairly heavy work but do not demand unusual skills. In the previously mentioned works of Henry, Mill, Robinson, Hodgson, and others, various adaptations of these exercises have been utilized. Either of the three types is an accepted procedure. However, the question remains as to whether a maximal or submaximal exercise should be utilized. Brouha\textsuperscript{150} says that capacity for hard muscular work can be measured only if certain physiological reactions of the subject to hard work are known. Reactions to moderate work are unreliable because the easier the work, the less clear cut are the differences between the fit and the unfit. In respects to this thesis, Mill\textsuperscript{151} says,

\begin{quote}
The fact that there is such a wide range in performance is all the more interesting when one bears in mind that these individuals would be rated as normal by an examining physician. It is another illustration of the old principle that the performance of a machine can best be judged, not when idling, but when running under a heavy load.
\end{quote}

Morehouse further affirms this position. He writes,\textsuperscript{152}

\begin{quote}
Differences between the fit and unfit are less regular the lower the metabolic rate. Measurements made in the resting state and during moderate work which all subjects can carry out in a steady state do not show significant differences between
\end{quote}

\begin{footnotes}
\textsuperscript{152}L. E. Morehouse and A. T. Miller, \textit{op. cit.}, p. 270.
\end{footnotes}
fit and unfit groups.

Cureton\(^{153}\) made a study of various exercises of submaximal and maximal intensities. He came to a very definite conclusion. According to him, the best known way to determine all-out circulatory-respiratory capacity is to give the all-out treadmill run test at ten miles per hour, eight point six per cent grade along with oxygen intake and oxygen debt determinations. The step test at forty steps per minute on a seventeen-inch stool done to complete exhaustion is about as good as the treadmill run to indicate maximal circulatory-respiratory involvement. Submaximal exercises are not good indicators of total capacity.

**Interpretation of the Measures.** Various investigators have attempted to explain the capacity and efficiency of energy expenditure during exercise through the use of numerous equations and ratios. Hodgson\(^{154}\) introduced the ratio of oxygen intake during exercise divided by the total oxygen consumed (debt plus intake) expressed as net measures to explain what she called maximal transport efficiency. She postulates that the capacity of an individual for work is in proportion to the percentage of oxygen requirement provided by oxygen intake. In other words, during submaximal work, the greater the proportion of oxygen taken in during exercise, and the smaller the


\(^{154}\)P. Hodgson, *et al.*, *op. cit.*, p. 213.
oxygen debt associated with a given exercise, the greater the maximal transport efficiency and the greater the capacity for work.

Henry also investigated several other ratio indexes, such as oxygen debt divided by total oxygen and oxygen intake divided by oxygen debt. He found that there was no loss of information in either case and that any of the three ratios would provide the same information regardless of which measure was used. He also made semi-log plots of detailed oxygen intake during recovery and the individual "alactic" debt recovery curves were fitted to the exponential equation \( y = a e^{-kt} \) which gives the rate of oxygen intake during recovery \( (y) \) at any time \( (t) \), based on the peak intake at the beginning of recovery \( (a) \). \( (k) \) was labeled as the debt velocity constant. He found that \( (k) \) was a measure of individual differences in oxygen transport efficiency whereas \( (a) \) the peak recovery intake was a measure of individual differences in oxygen requirement. Hence, he concluded that oxygen debt which is a composite of these two unrelated factors could easily be misinterpreted as a measure of differences in physiological adjustment to work. When a person has a poor oxygen transport there is a large oxygen debt and a slow rate of pay-off, while with good transport there is a small debt and a rapid pay-off.

It should be pointed out here that all of these measures investigated by Hodgson and Henry were derived from oxygen measures during submaximal exercises for a standardized time interval. Their

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relationship in all-out work to exhaustion has not been established.

Hill\textsuperscript{156} maintains that mechanical efficiency in the utilization of oxygen can be expressed by the ratio of work (in foot-pounds) divided by the oxygen requirement of the exercise (in liters) times 15,860. He points out that work and energy should be expressed in the same units, i.e., Calories, foot-pounds, or horsepower. Since one liter of oxygen, used in the combustion of glycogen, liberates 15,860 foot-pounds of energy, the oxygen requirement should be multiplied by this figure to obtain an accurate estimation of efficiency. It is standard procedure to express the oxygen requirement in terms of net figures, i.e., gross consumption minus resting consumption (which represents processes not involved in work at all).

Cureton,\textsuperscript{157} in an attempt to explain the processes involved in energy metabolism, has set up numerous interpretations of the measures of gross oxygen intake, net oxygen debt, and gross total oxygen consumption. Gross indicates that the resting consumption has not been subtracted, whereas net indicates that it has. The gross total is a combination of gross intake during exercise plus net debt during recovery.

He expresses sitting metabolism in terms of liters of oxygen per minute per square meter of body surface area. The various metabolic measures during exercise are expressed in terms of liters of oxygen, liters of oxygen per minute, liters of oxygen per kilogram of weight,

\begin{footnotesize}
\textsuperscript{156}A. V. Hill, \textit{Muscular Movement in Man: The Factors Governing Speed and Recovery from Fatigue}, p. 21.

\end{footnotesize}
and liters of oxygen per minute per kilogram of weight. Capacity is expressed in terms of liters. Relative capacity is expressed in terms of liters per kilogram of weight. It is interesting to point out here that the measures of relative capacity produced greater differences between champions and normal men, and also gave better predictions of the treadmill run than did the capacity measures.

He also maintained that efficiency in the utilization of energy is expressed in terms of liters per minute. Relative efficiency is expressed in terms of liters per minute per kilogram of weight. It is noted that the relative efficiency measures also produced greater differences between champions and normal men and were better predictors of performance than were the total efficiency measures.

Insofar as prediction is concerned, it should be pointed out that the rate measures are subject to some degree of spuriousness due to time being in the criterion and also in the variable.

He also asserts \(^{158}\) that dividing the oxygen used by the time of the run is similar to reducing gross work to horsepower terms, (33,000 foot-pounds per minute). If one liter of oxygen is taken as five Calories the conversion to horsepower is obtained by multiplying 5 x 3086 ft.-lb., which is equal to \(\frac{4675}{33,000}\) horsepower for each liter of oxygen. The horsepower rating of any individual is, therefore, proportional to the total oxygen available (intake plus debt) per minute, i.e., the rate of oxygen availability.

In terms of physiological indexes the measures are interpreted as follows:

(1) gross intake (liters) reflection of total blood flow during the exercise.

(2) gross intake rate (liters/minute) reflection of the rate of blood flow throughout the exercise.

(3) net oxygen debt (liters), reflection of certain amount of skill, will power, and lactic acid buffering capacity.

(4) net oxygen debt rate (liters/minute), reflection of ability to build up oxygen deficiency at a slow rate and indicates efficiency in buffering lactic acid, skill, and will power.

(5) gross total oxygen (liters), the energy requirement of the exercise.

(6) gross total oxygen rate (liters/minute), reflection of total horsepower rating of the individual during exercise.

If the above terms are divided by weight, usually in terms of kilograms, the measures indicate relative capacities and efficiencies. Cureton\(^{159}\) has also set up an equation which he says is the basis for rating physical fitness for treadmill running. Capacity is best expressed in terms of oxygen intake (liters/kilogram) and efficiency in terms of oxygen debt rate (liters/minute/kilogram), i.e., in relative terms. Combining the two measures and applying proper regression weighting he arrives at an equation which is highly predictive of the all-out treadmill run \((r = .97)\). This equation, however, is

subject to some spuriousness due to time being in the debt rate measure and in the criterion. The equation is \( T = 0.75 \text{ gross intake (liters/kilogram)} - 0.46 \text{ rate of oxygen debt (liters/minute/kilogram)}. \)

IX. PHYSICAL FITNESS AS MEASURED BY MOTOR PERFORMANCE AND TESTS OF STRENGTH

Motor Fitness. The emphasis placed on physical fitness during World War II resulted in the development of various motor fitness tests which were empirically designed to measure the basic, fundamental aspects of all-around performance. According to Clarke, all branches of the armed forces utilize these tests to determine the fitness of their personnel and to evaluate the effectiveness of their physical training programs. Various civilian organizations also apply this same pattern of testing to their school and college programs.

Brock maintains that motor fitness is the final criterion through which all other elements of physical fitness are seen and measured in man. An individual might know little or nothing of scientific facts concerning body structure, organic functions, dynamometer strength testing, or organic efficiency tests; but he can understand an outstanding performance displaying power, speed, and endurance. In addition, Brock states,

\[\begin{align*}
\end{align*}\]
A number of factors enter into efficient performance whether it be mainly of strength, speed, endurance, or skill. There is not one thing alone, but the body type or structure, the chemistry, the mechanics, the organic functioning and the emotional state, can all be considered as composing the elements that make for fitness in motor or skill performance.

Cureton defines motor fitness as a limited phase of motor ability which emphasizes capacity for vigorous work or athletic effort. He says,

The specific aspects of emphasis in motor fitness are (1) endurance, (2) power, (3) strength, (4) agility, (5) flexibility, and (6) balance. Motor fitness emphasizes the fundamental or gross big muscle movements or held positions dominated by muscular energy, kinaesthetic sense, and suppleness of the major tissues and joints, i.e., those aspects which are fundamental to athletic or work skills rather than the higher refinements pertaining to specialized skills which require years to perfect.

More specifically, by motor fitness, we mean the capacity for efficient performance in the basic requirements of running, jumping, dodging, falling, climbing, swimming, lifting weights, carrying loads, and enduring under sustained effort in a variety of situations. Quick and efficient control of the body in an emergency situation may save the life of one individual or many. One should be able to change his position quickly to avoid capture, fire, flood, bombs, gas, shells, or gun fire.

According to Clarke, the motor fitness tests have advantages which it is well to consider. These tests are designed to secure ease of administration. Little training is required to master the testing technique, and large numbers can be given the tests in a short time with relatively few testers. A major consideration has been to

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provide a test which is easy to administer, economical, and as simple as possible.

However, there is one main question which still remains to be answered. Do these tests actually measure essential phases of physical fitness? Put another way: just exactly what do these tests measure? Larson\textsuperscript{164} writes,

The advantage of this approach in measurement is that all factors are indicated in the individual performance. It is the total organism in action. The disadvantage is that the contributions made by each factor in the total performance are unknown.

The following are typical examples of the various motor fitness tests. Unless otherwise noted, the exercises listed are all-out, i.e., carried out until complete exhaustion. The runs are for best time for the distances indicated.

\textbf{Navy Standard Physical Fitness Test.}\textsuperscript{165} The Navy battery consists of five motor performance items. T score tables have been constructed based upon a group of well-conditioned Navy men. The P.F.R. is the sum total of the five tests divided by five. A score of fifty is average. Reliability and validity coefficients are not presented.

The test items are:

1. Burpee (squat thrusts for one minute)
2. Sit-ups
3. Push-ups
4. Squat-jumps
5. Pull-ups


\textsuperscript{165}H. H. Clerke, \textit{op. cit.}, p. 179.
Army Air Forces Physical Fitness Test. The Army Air Force battery consists of three motor performance items. The test items are scaled according to T scores based on Air Force personnel. The P.F.R. is the total of all three scores divided by three. The P.F.R. ratings are classified as excellent, very good, good, poor, and very poor. Combat standards are established as excellent or very good. The test correlates .86 with the criterion battery which contained fifteen variables. The test items are:

1. Pull-ups
2. Sit-ups
3. 300-yard shuttle run outdoors (five laps of sixty yards) or a 250-yard run indoors (five laps of twenty-five yards)

Naval Aviation Physical Fitness Test. The aviation test consists of five items. Performance on the tests are scaled from zero to twenty points. The P.F.R. is the sum total of all points scored on five items. The P.F.R.'s are classified according to superior, above average, average, below average, and poor ratings. The test items are:

1. Pull-ups
2. Sit-ups
3. Jump-reach (Sargent Jump), best of three trials
4. Speed-agility-run
5. Step test (thirty steps per minute, twenty inch stool, for five minutes


The Army Specialized Training Program Physical Efficiency Test.

The A.S.T.P. battery consists of seven motor performance items. Scoring tables have been constructed for each item and a final efficiency rating is determined. The items included in the battery and the days on which they should be administered are as follows:

<table>
<thead>
<tr>
<th>First Day</th>
<th>Second Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Push-ups</td>
<td>1. 100-yard pick-a-back</td>
</tr>
<tr>
<td>2. Squat-jumps</td>
<td>2. Burpees (squat-thrust for twenty seconds)</td>
</tr>
<tr>
<td>3. Sit-ups</td>
<td>3. 300-yard shuttle run (two laps of 150 yards each)</td>
</tr>
<tr>
<td>4. Pull-ups</td>
<td></td>
</tr>
</tbody>
</table>

The Indiana Motor Fitness Test.

The Indiana battery consists of three motor performance items. Norms based on Indiana University men are presented and the test scores are converted to T scores. This test diverges from the normal procedure of adding all of the scores and then dividing by the number of test items. Instead, the T scores for the number of chins and the number of push-ups are added and the sum is multiplied by the T score for the best standing broad jump out of three trials. This procedure is based on the power formula $P = F \times V$. The result is a M.F.R. which is classified as superior, good, fair, poor, or inferior. If it is desired, straddle-chins can be substituted for chins and the vertical-jump can be used in place of the standing broad-jump.

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The Illinois High School Physical Condition Test.170 The Illinois battery consists of five different test items. T scores are presented for each test item and different age groups. The P.F.R. is the sum total of the T scores for the five tests. A score of 250 is considered average. It should be pointed out that this test is rather extensively used. Each year every high school student in the state of Illinois must take this test unless he is excused for medical reasons. The test items are:

1. Pull-ups
2. Push-ups
3. Sit-ups
4. Squat-jumps
5. Mile run

Strength Tests and Physical Fitness. Strength is defined by Cureton171 as the capacity of the body to exert force on some external resistance. In this case, the body pushes, pulls, kicks, lifts, or carries some object. Obviously a great part of the labor that man does is composed of such efforts.

The advocates of strength testing maintain that strength is an important aspect of physical fitness. It is asserted that significant changes in strength result in corresponding changes in work capacity, vitality, and organic efficiency. Lack of exercise, improper diet, and illness are said to result in a lowered strength capacity.


Rogers considers strength synonymous with physical power, robustness and health. He says,

The positive and very high relationship of muscular strength can hardly be questioned. With no strength there can be no physical activity; moreover, when muscular strength is low, all other life functions are handicapped. Practically every change in the conditioning of the vital organs has a corresponding change in the condition or functioning of voluntary muscles. It is the prime function of respiration, circulation, digestion, elimination, and even cerebration, to maintain the effectiveness of muscles as a means of locomotion and manipulation.

This position is further defended by McCloy, who writes,

Each individual is required to carry or support his bodily weight from morning to night. He must do this with the musculature he has. It is known that a muscle that is too weak for its task works at a lower efficiency than one that is adequately developed. Hence, an individual who is markedly underdeveloped is working inefficiently, so far as his muscles are concerned, and is suffering greater fatigue, both locally and generally. He has less energy with which to approach his tasks, suffers more from fatigue toxaemia, and works under a greater nervous strain. Hence, in addition to its indication as to general "medical" condition, the strength tests in the form of the Physical Fitness Index tell much about the individual's general fitness for living and working.

Clarke sums up the logic of strength testing by stating,

If such conditions as body fatigue, lack of exercise, improper diet, diseased tonsils, abscessed teeth, ulcers, cancers and the like have total body

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reactions, the strength of the muscle is affected and the P.F.I. declines. The P.F.I. is a generalized index, as the name implies — not a diagnosis. A low P.F.I. indicates a lowered body vitality, a lack of physical condition, but not what the cause may be.

He also cites certain case studies to show the relation between physical condition and strength, adopting and following-up the technique of Rogers.175

A number of studies are available to show that changes in strength also result in a change in fitness. The investigations by Rogers176 Chamberlain and Smiley177 and Metheny178 would seem to indicate a substantial relationship between strength and a physician's medical rating of fitness. Fatigue and illness are shown to result in lowered strength. However, studies such as that of Anderson179 question this relationship. Studies conducted by McCloy,180 Cozens,181

175 F. R. Rogers, _loc. cit_.

176 Ibid.


Wendler,182 and Larson,183 to name a few, support Roger's original conclusion of the significant relationship of strength to general athletic ability.

Whether or not this relationship permits us to establish a strength test as a test of physical fitness is questionable. At least in the opinion of many physiologists such as Schneider and Karpovich,184 the strength test does not permit an adequate interpretation of the fitness of the entire body.

The following are typical examples of the dynamometer strength tests and strength indexes.

Roger's Strength Test and Physical Fitness Index.185 This test can be divided into five separate measurements of strength. They are:

1. Lung capacity (measured by a wet spirometer)
2. Right and left grip strength (measured by a hand dynamometer)
3. Back strength (measured by a dynamometer)
4. Leg strength (measured by a dynamometer)
5. Arm strength (measured by dips and chins)

Lung capacity is measured in terms of cubic inches. Grip, back and leg strength are in terms of pounds of lift or squeeze. Arm strength is determined by means of a formula which expresses the dips and chins

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184 E. C. Schneider and P. V. Karpovich, op. cit., p. 263.

in terms of pounds according to the height and weight of the subject. The sum total of all these measures is called the strength index, or total strength. The P.F.I. is obtained by dividing total strength by the norm established for individuals of the same age and weight. A rating of 100 is considered average.

McCloy's Strength Test and Physical Fitness Index.186 This test is actually a modification of Roger's Strength Test. Lung capacity is eliminated and the formula for the computation of arm strength has been revised. This modified version of Roger's test consists of four separate measurements of strength. They are:

1. Right and left grip strength (measured by a grip dynamometer)
2. Back strength (measured by a dynamometer)
3. Leg strength (measured by a dynamometer)
4. Arm strength (measured by dips and chins)

The total strength, or the Strength Index, is the sum of all these strengths expressed in pounds. Norms for the revised test are presented and the P.F.I. may be obtained by dividing total strength by the norm for individuals of the same age and weight.

CHAPTER III

PROCEDURES FOR THE DEVELOPMENT OF THE STUDY

I. POLICIES REGARDING PARTICIPATION IN THE STUDY

In a study of this nature where the responses of several individuals to numerous tests and indexes of performance are to be compared, there is an obvious limitation to the number of students which can be tested and the number of tests which can be selected for investigation. There is the difficult task of arranging the testing schedule to fit the subject’s class schedule without having such an arrangement deter from the accuracy of subsequent measurements.

There is also the problem of reducing the effects of such variables as diet, rest, sleep, fatigue, illness, muscle soreness, testing time, and failure to perform at maximum level of capacity. Although the exact effects of some of these factors cannot be completely established, it was felt that an effort should be made to standardize these factors insofar as was possible under the circumstances. Therefore, certain policies regarding participation were established for the subjects undertaking the experiment. The following statements were read to the subjects before they volunteered and were emphasized throughout the subsequent period of investigation.
1. All types of subjects are desired for this study. Whether you are a top performer in good condition or a poor performer in poor condition makes no difference. However, performance must be all-out and to the maximum of your capabilities.

2. Throughout the period of investigation, performers must maintain consistent and normal eating and sleeping habits and must not partake of alcohol at any time during the study nor smoke the day of testing. All of your habits should be standardized. You do not have to change them particularly, but you do have to attempt to keep them stable.

3. Strenuous exercise the day of testing is prohibited. Save your energy for the tests.

II. SECURING SUBJECTS FOR THE STUDY

Securing a normal group of subjects for the study presented a major problem. The testing schedule required three weeks for completion and would require some individuals to report at undesirable hours. The specifications of all-out performance and the control factors of adequate rest, sleep, normal diet without alcohol, and no smoking the day of performance seemed likely to weed out certain individuals that should be included in the study. This, in itself, was undesirable, for the group to be studied was to be a normal one.

With the proper authority from the head of the physical education department, it was decided to excuse the students from participation in their regular activity classes if they took part in the experiment. It was hoped that this would encourage all types of individuals to join in the study.

An attempt at mass announcements during activity classes secured only two volunteers out of approximately two hundred students. This technique was discarded as being useless, and the author made personal
contact with as many of the students as possible. It is estimated that at least three hundred of them were contacted in the locker rooms, before classes and after classes, and in the student field house. These efforts resulted in twenty-seven volunteers for the experiment.

It should be emphasized that all types of students were encouraged to take part in the experiment. This included the obese, the thin, the short, the tall, the weak, the strong, the experienced and the inexperienced. It should also be pointed out that no one was prohibited from taking part so long as he agreed to follow the outlined policies.

III. SELECTING THE TESTS TO BE INVESTIGATED

The Test to Determine Circulatory-Respiratory Capacity. The recommendations for this phase of the testing program are quite specific. Either the all-out treadmill run or the all-out step test may be used with comparable results. Both tests have certain advantages and disadvantages. The treadmill is comparatively expensive to construct, but it allows for a more accurate interpretation of the onset of fatigue. The cadence of the run is controlled mechanically. Thus, the run is accurately standardized for all participants. The step test does not require expensive equipment, but the cadence of the step is liable to serious error unless certain precautions are taken. It is also difficult to determine the exact onset of fatigue.

The expense involved in constructing a treadmill precluded its selection as the test. Therefore, the all-out step test at forty steps per minute on a seventeen-inch stool was selected as the exercise most desirable, all things considered, for the determination of all-out
circulatory-respiratory capacity in this study. Certain precautions were met to assure accurate determinations of all-out capacity; namely, (1) the subjects were thoroughly briefed on the procedures involved in taking the test; (2) the subjects were thoroughly indoctrinated with the necessity of going all-out; (3) the subjects were thoroughly familiarized with the cadence; (4) exhaustion was defined as that point when the subject could not continue or when he could not maintain the cadence. Two breaks in the step rhythm were allowed, but the subject was expected to regain the cadence immediately. If not, he was told to discontinue the exercise.

The Physical Fitness Tests. It was considered desirable to investigate physical fitness ratings obtained from batteries of tests as well as to determine the relationship of circulatory-respiratory capacity to performance in certain generally accepted individual tests. A survey of the typical batteries and tests revealed that a few of the batteries utilized the same tests and other batteries repeated tests which were used interchangeably in other batteries. It was discovered that a selection of the Illinois, Indiana, Army Air Force, and Navy motor fitness batteries and the McCloy Strength Test would allow an investigation of the physical fitness ratings from these batteries as well as the performance scores on nine different motor performance tests. As it was hardly feasible to attempt to investigate a larger number of tests, these batteries were selected as being typical physical fitness batteries which allowed a study of a maximum number of motor performance tests as well as motor fitness and strength fitness ratings.
This selection allows an investigation of four motor fitness ratings and one strength fitness rating, as well as the performance scores made on sit-ups, pull-ups, dips, squat-jumps, standing broad jump, Burpee, 300-yard run, and the mile run.

IV. ORGANIZING THE TESTING SCHEDULE

The testing schedule was so organized as to allow at least one week's rest between batteries. It is felt that this allowed sufficient time between batteries for all of the subjects to recuperate from the effects of soreness and fatigue, but did not deter from the accuracy of the measurements by allowing too long a lapse between testing intervals. The longest time interval separating one test from the other is two weeks.
It should be pointed out here that out of necessity these tests were administered at different times of the day. It was impossible to arrange the schedule in such a way that all students could take the test at the same hour. The subjects' class schedules were too irregular to allow such an arrangement.

Test II (the oxygen metabolism test) was the control test insofar as time was concerned. If Test II was to be taken at a certain hour, then Test I and Test III had to be taken within at least two hours of that time. In this way time was held as constant as was possible under the circumstances.

Test I (first week)

1. Push-ups (all-out)
2. Standing broad jump (best of three trials)
3. Squat-jumps (all-out)
4. Sit-ups (all-out)
5. 300-yard shuttle run (five laps of sixty yards each)

Test II (second week)

1. Sitting oxygen intake for ten minutes
2. Oxygen intake during the all-out step test (forty steps per minute on a seventeen-inch stool)
3. Oxygen intake during fifteen minutes recovery

Test III (third week)

1. Dips (all-out)
2. Pull-ups (all-out)
3. Burpee (for one minute)
4. Strength tests (right and left grip, back lift, and leg lift)
5. Mile run (for time)
V. SELECTING THE APPARATUS FOR DETERMINATION OF OXYGEN METABOLISM

A review of the literature revealed that either the closed circuit or open circuit type of apparatus is adequate for the measurement of oxygen consumption during exercise. However, the advantages of the closed circuit apparatus for an investigation of this nature are quite apparent. This type of metabolor will produce a permanent record which permits an analysis of the entire period under observation at any time interval desired and, most important, it does not require any special skills which cannot be mastered in a short time.

On the other hand, the open circuit apparatus has very definite advantages in the determination of the amounts of carbon dioxide exhaled during exercise; but as this phase of circulatory-respiratory adjustment was not to be investigated, the distinct disadvantages of this type of apparatus in requiring considerable skill and necessitating long and tedious gas analysis technique precluded the selection of any type of open circuit apparatus.

After considerable review of the literature concerning the measurement of oxygen consumption during vigorous exercise to exhaustion it was discovered that the largest debt recorded was 18.6 liters and the greatest intake was that of 5.05 liters. Applying these figures on the basis of five minutes exercise and fifteen minutes recovery it is calculated that the apparatus should have a capacity of almost fifty liters. Although it is unlikely that any normal man will be able to reach such levels of capacity, the possibility of such an occurrence must be considered.
A McKesson Metabolor with a capacity of four and a half liters was utilized to run preliminary investigations on the possibility of perhaps modifying the upper bell and refilling during the test. However, such a technique was found to allow too much room for error and was discarded as being too inaccurate.

After consulting with several manufacturing firms and after investigating thoroughly the catalogues from various others, it was discovered that the largest metabolor in production had a capacity of only six liters. Thus, it became necessary to have the apparatus custom built.

A modified Benedict-Roth closed circuit recording spirometer with a capacity of fifty liters was so designed that for each drop of two centimeters in the upper bell there was a corresponding decrease in volume of one liter. Such an arrangement allows for quick and accurate determinations of decrease in volume.

After consulting several firms the contract was finally given to the Baton Rouge Iron and Sheet Metal Works. This firm constructed the fifty liter metabolor according to the specifications given in Plate I. Such items as the tubing, mouthpieces, valves, noseclips, pens, and kymograph motor were either purchased from supply houses in New Orleans or borrowed from the physiology laboratory at Louisiana State University.
PLATE I

CLOSED CIRCUIT RECORDING SPiroMETER
(50 LITER CAPACITY)
VI. TESTING THE ERROR OF THE APPARATUS

Leakage. The apparatus was first checked to determine the extent of leakage. A weight placed on top of the upper bell caused it to drop five millimeters in a twenty-four hour period. A subsequent check of the various parts revealed a leak in the base next to the expiratory piping. This was corrected and the test was repeated every night through the period of investigation without an error of leakage again appearing.

Carbon Dioxide Absorption. A preliminary test on one subject was carried out with the expressed purpose of determining whether or not the soda lime container was large and efficient enough to obtain complete carbon dioxide absorption. Utilizing an Erlenmeyer flask containing a ten per cent solution of barium hydroxide the gases which still remained in the spirometer after completion of an all-out test were forced through the solution. The solution did not turn cloudy until after the sixth test. This indicated that the three quarts of soda lime would give sufficient absorption for about five runs. However, to be certain, it was decided to test the absorption after each run. As it turned out later, this was a necessary precaution.

Computing the Construction Error. This phase of error testing was conducted on three different subjects while sitting in a chair and breathing out of the spirometer. The first subject was given twelve different tests one after the other. The tests were of ten minutes duration and the upper bell was placed at different heights for each test. The second subject was given eight different sitting
tests at different times during the day. Each test consisted of two different oxygen consumption determinations; one on the newly constructed apparatus with the upper bell at mid-level, and one on a McKesson Metabolor of four and a half liter capacity. The third subject was given six consecutive tests with the bell of the spirometer at mid-level each time.

First Error Test

Subject J. C.

<table>
<thead>
<tr>
<th>Sitting Intake (ml./min.)</th>
<th>Deviation From the Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>299</td>
<td>+11.5</td>
</tr>
<tr>
<td>299</td>
<td>+11.5</td>
</tr>
<tr>
<td>295</td>
<td>+7.5</td>
</tr>
<tr>
<td>270</td>
<td>-17.5</td>
</tr>
<tr>
<td>270</td>
<td>-17.5</td>
</tr>
<tr>
<td>294</td>
<td>+6.5</td>
</tr>
<tr>
<td>283</td>
<td>-4.5</td>
</tr>
<tr>
<td>295</td>
<td>+7.5</td>
</tr>
<tr>
<td>285</td>
<td>-2.5</td>
</tr>
<tr>
<td>294</td>
<td>+6.5</td>
</tr>
<tr>
<td>276</td>
<td>-11.5</td>
</tr>
<tr>
<td>299</td>
<td>+2.5</td>
</tr>
</tbody>
</table>

Total 3,450       Total 107.00
Mean 287.5        Mean Deviation 8.92

Average Error 3.10%

The results from the first error test indicated that the apparatus gave fairly accurate results regardless of the position of the bell. This would seem to indicate that the machine was accurately constructed within the specifications given in Plate I.

The computed average error of 3.10 per cent is well within the expected precision of 5.00 per cent for the closed circuit apparatus.
Second Error Test

Subject S. F.

<table>
<thead>
<tr>
<th>McKesson Metabolor</th>
<th>Fifty Liter Spirometer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting Intake</td>
<td>Sitting Intake</td>
</tr>
<tr>
<td>Deviation (ml./min.)</td>
<td>Deviation (ml./min.)</td>
</tr>
<tr>
<td>From the Mean</td>
<td>From the Mean</td>
</tr>
</tbody>
</table>

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>312</td>
<td>-27.4</td>
<td>296</td>
</tr>
<tr>
<td>351</td>
<td>-11.6</td>
<td>340</td>
</tr>
<tr>
<td>362</td>
<td>-22.6</td>
<td>353</td>
</tr>
<tr>
<td>362</td>
<td>-22.6</td>
<td>350</td>
</tr>
<tr>
<td>344</td>
<td>-4.6</td>
<td>331</td>
</tr>
<tr>
<td>327</td>
<td>-12.4</td>
<td>309</td>
</tr>
<tr>
<td>339</td>
<td>-0.4</td>
<td>321</td>
</tr>
<tr>
<td>318</td>
<td>-21.4</td>
<td>303</td>
</tr>
</tbody>
</table>

Total 2,715  Total 123.00  Total 2,603  Total 145.00  
Mean 339.4  MD 15.38  Mean 325.4  MD 18.12  
$\sigma_M$ 2.24  AE 4.53%  $\sigma_M$ 2.54  AE 5.57%  

Difference

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>-16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-09</td>
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<td>-18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-15</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total -113  
AD -14.1  
MD  2.75  
AE  1.95%  

$D = m_1 - m_2 = 14.0$

$\sigma_D = 3.39$

C. R. = 4.12

The results of the second error check revealed, as was to be expected, that the metabolism of subjects varied from hour to hour. However, the difference was not as great as was anticipated. The average deviation of the McKesson machine was only 15.38 or an average
error of 4.53 per cent. Whereas the fifty liter spirometer had an average deviation of 18.12 or an average error of 5.57 per cent.

Calculating the difference between the two means and the sigma of the difference, a critical ratio or "t" value of 4.12 is found. For eight cases, a "t" value of 3.50 is significant at the one per cent level of confidence.

It is concluded, therefore, that this is a significant difference. Apparently, the large spirometer is in error of an average difference of -14.1 milliliters per minute. Computing the mean difference and the mean deviation of the difference we find an average error of 1.95 per cent. This indicates that the differences were constantly in the same direction and varied little from the average difference. It is concluded that the large spirometer is comparatively as accurate as the smaller McKesson Metabolor for ranking individuals according to their intake capacity.

### Third Error Test

<table>
<thead>
<tr>
<th>Sitting Intake (ml./min.)</th>
<th>Deviation From the Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>341</td>
<td>419</td>
</tr>
<tr>
<td>333</td>
<td>411</td>
</tr>
<tr>
<td>328</td>
<td>4 6</td>
</tr>
<tr>
<td>317</td>
<td>-5</td>
</tr>
<tr>
<td>307</td>
<td>-15</td>
</tr>
<tr>
<td>306</td>
<td>-16</td>
</tr>
<tr>
<td>Total 1,932</td>
<td>Total 72</td>
</tr>
<tr>
<td>Mean 322.0</td>
<td>MD 12.00</td>
</tr>
<tr>
<td></td>
<td>AE 3.73%</td>
</tr>
</tbody>
</table>

The third error check revealed that measurements taken with the bell of the spirometer at mid-level were not any more accurate than those taken with the bell at various positions. This seems to indicate that the upper bell was accurately constructed at all levels according to the specifications, and that factors such as interior pressure and weight changes
remained fairly constant or were cancelled out.

VII. ADMINISTERING THE TESTS

The following is a step by step discussion of how the tests were administered, the procedures followed, and the rest intervals allowed between each performance item.

Test 1

(1) Subject's mouth temperature is recorded

(2) Subject is directed to take warm-up exercises

(3) Push-ups (all-out)
   (a) Subject starts face downward, hands on floor at sides of shoulders, fingers pointed forward, toes resting on floor.
   (b) Subject extends arms, raises straight body from the floor, lowers body until chest touches floor. Performs as long as possible.
   (c) Score: One point for each complete push-up. No score if arms are bent at top of movement, if any part of body touches floor other than hands, chest, or toes, or if there is not a straight shoulder-hip-feet line.

(4) Ten minutes rest

(5) Standing broad jump
   (a) Subject takes natural standing position with feet slightly apart and toeing the take-off line with both feet. Takes any number of arm swings and knee flexions. The arms are swung backwards as knees are flexed, and then swung vigorously forward as one jumps.
   (b) Allow two trials and then record the best of three attempts.
   (c) Scoring: The distance from the take-off line to the backwardmost part of the body in inches. Stepping over take-off line counts as a foul.

(6) Ten minutes rest

(7) Sit-ups (all-out)
   (a) Subject lies on back, legs straight, feet twelve inches apart and hands clasped behind head. Partner kneels on floor and holds the soles of the subject's feet against his knees, pressing them firmly against the floor.
   (b) Subject raises trunk, touches right elbow to left knee, lowers trunk to floor; raises trunk, touches left elbow to right knee. Performs as long as possible.
(c) Score: One for each complete movement of touching elbow to knee. No score if arms are unclasped, subject rests on floor, or bends knees when lying on back or when beginning the sit-up.

(8) Fifteen minutes rest

(9) Squat-jumps (all-out)
(a) Subject stands with hands clasped, palms down on top of head, feet from four to six inches apart, heel of left foot on line with toes of right foot.
(b) Subject squats on right heel, springs into air immediately, body and legs straight, and interchanges feet position. Continues for as long as possible.
(c) Score: One for each spring into the air. No score if squat is not complete, no leg interchange, hands removed from the head, fails to straighten legs completely while in the air.

(10) Fifteen minutes rest

(11) 300-yard shuttle run (five laps of sixty yards each)
(a) Subject runs around two stakes sixty yards apart, keeping within three feet to either side of the stake and turning around stakes from right to left. The run is five laps of sixty yards each.
(b) Score: Best time to the nearest tenth of a second.

Test II

(1) Administrator records age, height, and weight of subject.

(2) Subject washes off mouthpiece and nose clip with soap and water.

(3) Administrator fills soda lime container with three quarts of soda lime and replaces bell. Washes out spirometer three or four times and then fills bell with oxygen.

(4) Kymograph drum is wrapped with graph paper.

(5) Subject rests for five minutes in sitting position while mouth temperature is recorded. Administrator explains the testing procedure and what is expected of the student.

(6) Administrator checks alignment of spirometer, tubing, mouthpiece, valves, etc. Fills pen with ink.

(7) Nose piece is clipped on subject's nose. Mouthpiece is inserted into subject's mouth and headgear is strapped on. Administrator checks tubing for kinks, then turns on "T" valve.
(8) Administrator records the temperature of the apparatus and the barometric pressure, turns on the kymograph motor and records sitting intake for ten minutes.

(9) Administrator turns off kymograph motor, closes "T" valve and allows subject to take out mouthpiece and expectorate.

(10) Administrator winds and sets metronome, lets subject listen until he is certain of cadence.

(11) Administrator returns kymograph to starting point and fills pen with ink.

(12) Administrator adjusts subject's nose clip, mouthpiece and headgear; checks for tubing kinks; records temperature of the apparatus and barometric pressure.

(13) Administrator turns on "T" valve and records standing intake for two minutes.

(14) Administrator starts kymograph and at signal subject begins to step up and down on seventeen-inch stool at forty steps per minute. (Step is begun with the right foot up followed by the left foot, then the right foot is stepped down followed with the left foot.) Subject repeats to exhaustion or until unable to continue the cadence. (Two breaks in the rhythm are allowed, but if the cadence is not immediately regained the subject is told to discontinue the exercise. A mark is made on the graph to indicate where exercise began and ended. An assistant is necessary at this phase of the test.)

(15) Subject sits down on the bench and leans back on the wall. Administrator checks tubing during the change in position to be certain there are no kinks; turns off metronome.

(16) Administrator records recovery oxygen for fifteen minutes; fills pen as needed; records temperature and pressure during the last minute of test.

(17) Administrator stops kymograph motor and removes pen. "T" valve is closed, head gear, noseclip, and mouthpiece are removed. The remaining gases in the spirometer are checked for carbon dioxide absorption. If there was complete absorption the soda lime can be used for the next test up to five tests. After the fifth test the container must be emptied and refilled. If there was not complete absorption the test should be discarded and run over.

(18) Administrator removes tubing and drains saliva from tubing and spirometer; removes graph paper.
(19) Administrator replaces tubing and washes out spirometer with oxygen; fills bell with oxygen; replaces graph paper and fills pen.

(20) Machine is now ready for the next test.

Test III

(1) Subject's mouth temperature is recorded.

(2) Subject is directed to take warm-up exercises.

(3) Right grip
(a) The tester takes the hand dynamometer and places it in the subject's right palm in such a way that the concave edge of the dynamometer is between the first and second joints of the fingers and the rounded edge is against the base of the hand. The dial is placed toward the palm.
(b) The subject's elbow should be slightly bent and his hand should make a sweeping arc downward as he squeezes the dynamometer.
(c) Score should read to the nearest pound.

(4) Left grip (same as test for right grip—except hands reversed).

(5) Back lift
(a) Subject should wipe hands with chalk dust, then assume a position on the base of the dynamometer facing the tester, feet parallel, about six inches apart, with the center of the foot opposite the chain.
(b) The tester should hook the chain so that the bar level is just below the finger tips of the erect subject. The subject grasps the handle firmly at the ends of the bar, one palm forward, one palm back, thumb clinching fingers, back slightly bent at hips. Keeps legs straight, head up and eyes straight ahead. Subject maintains position and pulls, almost straightening back. The lift is steady, not in jerks. If the back is not almost straight at the end of the pull, then adjust the chain and repeat the test.
(c) Read and record the strength of the lift on the outer dial.

(6) Leg lift
(a) Subject should hold bar, both hands together in the center, feet parallel, six inches apart, center of feet opposite chain, legs bent at 115 to 124 degrees, arm and back straight, facing tester.
(b) The tester should slip one end of the belt over one end of the bar. The free end of the belt should be looped around the other end of the bar, tucking it in under so that it rests next to the body. The belt should be as low as possible over the hip and gluteal muscles. 

(c) The tester should hook the chain to the bar so as to allow the subject’s legs to be nearly straight at the end of the lift. Record the best out of three tests.

(7) Ten minute rest

(8) Dips (all-out)

(a) Tester adjusts the parallel bars to shoulder height.

(b) Subject stands at the end of the bars and grasps one bar in each hand. The subject jumps to a front support with the arms straight. He lowers his body until the angle of the upper arm and forearm is less than a right angle, then pushes up to the straight arm position.

(c) Scoring: The initial jump scores one, and every push up to a straight arm position after that counts one. A half point is scored if the subject does not go down to the proper bent-arm angle or all the way up to a straight-arm extension. The subject is not allowed to jerk or kick and a maximum of four half-credits is allowed.

(9) Ten minutes rest

(10) Pull-ups (all-out)

(a) Subject hangs from bar, palms outward, thumbs under bar, feet above floor.

(b) Subject pulls up so that chin is over bar. Returns to full hanging position, arms fully extended. Repeats as many times as possible.

(c) Scoring: One point for each correct and complete chin. Half counts are recorded if the subject does not pull all the way up, if he does not straighten his arms completely when lowering the body, or if he kicks or kips in performing the movement. Only four half-counts are permitted.

(11) Ten minutes rest

(12) Burpee for one minute

(a) Subject stands at attention and upon command performs the following four count exercise as rapidly as possible for one minute.

1. Bend knees and hips and place hands on floor (squat-rest position). Fingers should point forward, arms may be between, outside of, or in front of the bent knees.

2. Extend legs backward until body is straight from shoulders and heels (front leaning rest).
3. Return to squat-rest position.
4. Stand straight.

(b) Scoring: One for each successful performance of squat thrust or Burpee. If the subject is not in straight position at the conclusion of the exercise a fourth, one-half, or three-fourths of a point may be scored according to the count at which the subject is stopped.

(13) Fifteen minutes rest

(14) Mile run
   (a) Subject is directed to jog until loosened up.
   (b) Subject runs four laps of a 440 yard track for best time. Tester should call out the time of each lap and record the final time to the nearest second.

It should be pointed out here that before each test the subject was encouraged to do his best to go all-out. During the actual testing period the subjects were urged on not only by the tester but also by the other participants. A fine spirit prevailed and the results are held to be accurate indications of all-out performance.

It is perhaps important to observe that the dynamometers utilized in this study were not accurately calibrated for error. They were, however, in good working order and it is assumed that the error, if any, is constant, i.e., it will constantly be in the same direction. The same two dynamometers (one for grip and one for leg and back strength) were used by all of the participants. The error should be the same for each subject.

The accuracy of the thermometer and barometer utilized in the metabolism test was compared against instruments with known degrees of error.

The speed of the kymograph drum was also accurately calibrated with a stop watch.

Mouth temperature was considered to be normal if it fell between
the limits of 97.5 and 99.0 degrees Fahrenheit, which Wiggers asserts is the normal variation. Any variation outside of these limits was considered as indicative of illness and the subject was not allowed to continue the experiment.

Of the twenty-seven students volunteering for the study, complete data were collected on twenty-five. One student became ill during the study and one failed to show up for the third test. Of the twenty-five complete records two had to be discarded. Subsequent checks of carbon dioxide remaining in the spirometer after test number two revealed that there had been insufficient carbon dioxide absorption. These two students completed test number three, but unfortunately an attempt to reschedule the oxygen intake test met with failure. This left a total of twenty-three subjects from whom accurate data were collected for all of the performance and metabolic tests.

VIII. INTERPRETING THE SCORES

Interpreting the Performance Scores. By means of tables and norms accompanying each of the motor fitness and strength fitness tests, performance scores were transferred into P.F.I. and M.F.R. ratings. The strength test was divided into four different phases of total strength: namely, total grip strength, total arm strength, total back strength, and total leg strength. A classification index utilizing McCloy's formula of six times height plus weight was determined for each subject. This gave exactly twenty-one different scores which

could be analyzed in order to determine their relationship with circulatory-respiratory capacity. The results are shown in Tables IX and X in the Appendix.

**Interpreting the Metabolic Measures.** This phase of the investigation was quite tedious and time consuming. The graphs first had to be analyzed for recorded sitting intake, recorded exercise intake, and recorded recovery intake. These figures then had to be converted to true volume measures according to the temperature of the apparatus and the barometric pressure. Carpenter's tables were utilized to facilitate these conversions.

Perhaps the most difficult interpretation of all, was that of determining the curve of intake during exercise. Most curves progressed upwardly in a constant fashion, but a few showed slight irregularity. A French curve was utilized to aid in averaging out these irregular responses. (See Plate II.)

There also remained the question of whether to use net or gross measures of intake. Most investigators recommended the net measures, however, others have utilized gross measures of intake. It was decided to calculate both measures and then to compare the two by statistical analysis.

Another major problem was that of determining the net debt measures. Some investigators measure recovery intake for a specified time interval (usually fifteen minutes) and then merely subtract the sitting intake from the same period. Although the recovery time is not constant for different individuals, it is assumed that all will recover the same amount within the specified time interval. After
INTERPRETATION OF RECORDED EXERCISE METABOLISM

PLATE II

COLLINS, ROBERT S.
APRIL 4, 1932
Oxygen Metabolism: All-out Sprint Test
Temperature 41°C
Duration 14.5 min.

90% RECOVERY, TIME 90 MINUTES
RECORDED O2% DEBT 6.3 L.
RECORDED O2% DEBT = 93 L.
RECORDED O2% DEBT = 6.97 L.
Net O2% Debt at 90% Recovery = 5.75 L.

RECOVERY FOR FIFTEEN MINUTES
RECORDED O2% DEBT 10.6 L.
CORRECTION 0.30
Gross O2% Debt 10.9 L.
Net O2% Debt = 8.87 L.
Net Debt = 4.95 L.

RECORDED GROSS MAXIMUM INTAKE 2.48 L./MIN.
Correction 0.20
Gross Maximum Intake 2.28 L./MIN.
Net Maximum Intake 2.05 L./MIN.

Net O2% Debt for 15 min. = 5.75 L.
Net O2% Debt for 90 min. = 5.75 L.

Max. O2 intake = 2.48 L./MIN.
Min. O2 intake = 0.89 L./MIN.

Graphs show the change in oxygen intake over time.
recovery, any subsequent subtracting of sitting intake from recovery intake will result in a net intake of zero. It is possible, however, that such a technique is liable to error.

Other investigators would measure oxygen debt at a certain specified degree of recovery. If a graph of the recovery intake is available, this is a rather simple matter. The slope of the sitting intake graph can be compared with the recovery intake graph by means of parallel rulers. The degree of slope or the actual intake can be computed to determine the point of recovery.

It is not known just exactly how these two measures compare in accuracy of results. It was decided to take a measure of the recovery intake at eighty per cent recovery and at the end of the fifteen minute recovery period. The results could then be compared by statistical analysis.

Measures of net total consumption, gross and net exercise intake, and net oxygen debt in liters of oxygen were then converted to various rates and relative capacity indexes by dividing each measure by the time of the exercise and the weight of the subject in kilograms. The result was oxygen intake, oxygen debt, and total oxygen consumption measures expressed in liters, liters per kilogram of weight, liters per minute of exercise, and liters per minute per kilogram.

It was also deemed feasible to investigate certain other indexes of all-out capacity. The transport-efficiency ratio was calculated by dividing net total oxygen consumption into net oxygen intake. Net maximum intake during the exercise was determined by measuring the
amount of consumption during the last minute of activity. This score was then expressed in terms of liters per minute and liters per minute per kilogram of weight.

Body surface area expressed in square meters was determined through the use of a nomogram based on the formula of DuBois.² Sitting intake was then expressed in terms of liters per minute and liters per minute per square meter of body surface area. (See Table VIII in the Appendix.)

CHAPTER IV

DISCUSSION OF THE FINDINGS

The data derived from the experiment were arranged according to the various indexes of metabolism and performance. The response of each individual was then ranked from one to twenty-three according to its position in the series of scores. The rank-difference method of correlation was then utilized as an exploratory device.

This method of correlation is subject to some degree of criticism. It takes into account only the positions of the items in the series. The product-moment method, on the other hand, takes into account the size of the score as well as its position in the series. According to Garret\(^1\) it is the method most commonly utilized when comparing test scores and other determinations of performance.

The product-moment method of correlation is relatively more time consuming than the rank-difference method. Its calculation, however, may be speeded up by the use of mechanical calculators. Consequently, the data were turned over to the Psychology Department at Louisiana State University, Baton Rouge, Louisiana, for subsequent analysis utilizing the product-moment method of correlation.

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Here the data were transformed to ten scores utilizing a one digit scale from zero to nine. The ten score is advantageous in that it transforms the scores to a common scale with a mean of 4.5 and a sigma of 2.0. The one digit scale enables the use of mechanical calculators for accurate and rapid calculations of the product-moment correlations. According to Bass and Canfield, the ten score is the most modern technique available for accurate and rapid calculations of correlation coefficients with small samples.

It should be pointed out here that this investigation is admittedly based upon a relatively small sample of twenty-three cases. The opportunity for chance to play havoc with correlation coefficients is much higher in small samples than in larger samples of, for example, two hundred subjects. Consequently, for a small sample correlation to be significant, it must be larger, relatively speaking, than a large sample correlation coefficient.

According to Garret and McNemar, the significance or reliability of a small sample coefficient of correlation can best be determined by testing against the null hypothesis. Entering the table furnished by Garret with $n - 2$ or twenty-one degrees of freedom it is discovered

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2E. M. Bass, Head, Department of Psychology, Louisiana State University. (Personal Interview, May 6, 1951).


4H. E. Garret, op. cit., p. 299.


6H. E. Garret, loc. cit.
that for a correlation coefficient to be significant at the five per cent level of confidence it must be higher than .413. For an $r$ to be significant at the one per cent level of confidence it must be higher than .526.

These levels of confidence are in terms of chances out of a hundred. Thus a five per cent level of confidence stands for ninety-five chances out of a hundred and the one per cent level stands for ninety-nine chances out of a hundred. Put another way, the odds are one hundred to one at the one per cent level of confidence that the obtained $r$ of .526 or larger would arise through sampling accidents. We may be confident at the one per cent level that the true $r$ is not zero.

According to McNemar, the one per cent level of confidence is the borderline of significance for small samples of less than thirty cases. This level of confidence was accepted in main for the following discussion of the results of this experiment. Unless otherwise noted, the correlations discussed here are significant at the one per cent level of confidence, i.e., they are equal to or greater than a $\pm .526$.

Furthermore, the results are discussed here as they appeared in this study. It should be pointed out that unless there is substantial evidence to support the findings of a small sample study, the results can best be described as suggestive of possible relationships.

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7Quinn McNemar, loc. cit.,
I. THE RELATIONSHIP BETWEEN GROSS AND NET INTAKE

A comparison of gross and net oxygen intake during exercise resulted in a coefficient correlation of .93 when the measures were expressed in terms of liters of oxygen, and .94 when expressed in terms of liters of oxygen per kilogram of weight. This would seem to indicate that there is relatively little difference between the two measures and either could be utilized as an indicator of intake capacity.

Gross intake is a measure of all the oxygen taken in during exercise and is a reflection of the total amount of blood moved, whereas, net intake is a measure of the oxygen consumed during exercise over and above the amount required purely for sitting. The latter measure is more meaningful from the standpoint of interpretation, i.e., it is concerned only with the metabolic adjustments during the exercise and does not include the energy requirements for sustenance of life and other factors not directly associated with the exercise itself.

For these reasons and in order to maintain consistency throughout the study, the measurement of net intake was chosen to be investigated. All of the subsequent measurements of intake, debt, and total consumption are expressed in net terms.

II. THE RELATIONSHIP BETWEEN OXYGEN DEBT MEASURED AT THE END OF A STANDARDIZED TIME INTERVAL AND AT EIGHTY PER CENT RECOVERY

Two measures of oxygen debt were calculated. One measure was derived by calculating the gross intake during fifteen minutes of recovery and subtracting the sitting intake for a similar time interval. The second measure was calculated at eighty per cent
recovery and the sitting intake for that period of time was subtracted. A comparison of the two measures resulted in a coefficient correlation of .97. It seemed to make little difference which of the two measures were chosen to be analyzed, therefore, the debt measured in a fifteen minute period was accepted as the index of net oxygen debt.

It seems rather obvious that, although recovery time is not a constant factor, the degree of recovery had to be practically the same for each individual. A further investigation revealed that all of the subjects were at least ninety per cent recovered at the end of fifteen minutes. This would seem to explain the rather high relationship between the two measures. Apparently, in fast exercise to exhaustion, there is a rapid and almost complete recovery within a period of fifteen minutes.

III. A COMPARISON OF THE RELATIONSHIPS OBTAINED BY CORRELATING THE METABOLIC MEASURES WITH TIME OF THE ALL-OUT TREADMILL RUN AND WITH TIME OF THE ALL-OUT STEP TEST

As mentioned previously in the review of the literature, Cureton found that oxygen intake was the important measure insofar as differentiating between champions and normal men and in the prediction of all-out treadmill running. The step test utilized in this study is an exercise that should be highly related to treadmill running on an inclined grade. Both are exercises in which a great amount of external work is performed. For the treadmill run this is computed on a basis of body weight and the sine of the angle of grade. For the step test, this is calculated on a basis of the height of the stool and body weight. Knowing the time of the exercise and the two
variables concerned, the calculation of external work is a relatively simple matter.

A comparison of the correlation obtained by Cureton and those obtained in the present study reveal a very close agreement even in those correlations which are below the one per cent level of confidence, i.e., below a $r$ or $-0.526$. (See Table I). It appears highly probable that the two exercises of maximal circulatory-respiratory capacity are closely related. The metabolic measures obtained in this study closely parallel those obtained by Cureton and further emphasize the importance of oxygen intake as a predictor of performance in the all-out treadmill run and step test.

It should be pointed out here that the correlation of .85 for oxygen intake (liters/kilogram) and the step test was the highest obtained. The addition of debt did not increase the correlation, in fact, it lowered it somewhat, $r = .81$ for total consumption (liters/kilogram) and the step test. Although the small difference is not too important, it does stress the importance of intake as compared to debt. Intake appears to be the most important single measure.

IV. THE RELATIONSHIP BETWEEN VARIOUS METABOLIC MEASURES OF CIRCULATORY-RESPIRATORY CAPACITY

The various measures of capacity and efficiency can be expressed in total or relative terms, however, the latter appears to be more meaningful. It is logical that a large man would require relatively more oxygen than a small man. When weight is divided out the relative efficiency and capacity is more clearly reflected and is not just a reflection of the body weight. Thus, in making a
### TABLE I

**The Correlation of Metabolic Measures with the All-Out Step Test Compared with the Correlations Obtained by Cureton for the All-Out Treadmill Run**

<table>
<thead>
<tr>
<th>Metabolic Measures</th>
<th>Cureton's Study Correlations With All-Out Treadmill Run</th>
<th>Present Study Correlations With All-Out Step Test</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Intake:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.</td>
<td>.75</td>
<td>.82</td>
</tr>
<tr>
<td>L. /kg.</td>
<td>.87</td>
<td>.85</td>
</tr>
<tr>
<td>L. /min.</td>
<td>.24</td>
<td>.16</td>
</tr>
<tr>
<td>L. /min. /kg.</td>
<td>.34</td>
<td>.41</td>
</tr>
<tr>
<td><strong>Debt:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.</td>
<td>.30</td>
<td>.49</td>
</tr>
<tr>
<td>L. /kg.</td>
<td>--</td>
<td>.52</td>
</tr>
<tr>
<td>L. /min.</td>
<td>-.60</td>
<td>-.54</td>
</tr>
<tr>
<td>L. /min. /kg.</td>
<td>-.64</td>
<td>-.62</td>
</tr>
<tr>
<td><strong>Total Consumption:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L.</td>
<td>.81</td>
<td>.74</td>
</tr>
<tr>
<td>L. /kg.</td>
<td>--</td>
<td>.81</td>
</tr>
<tr>
<td>L. /min.</td>
<td>-.57</td>
<td>-.49</td>
</tr>
<tr>
<td>L. /min. /kg.</td>
<td>--</td>
<td>-.06</td>
</tr>
</tbody>
</table>
comparison between the different metabolic measures it is considered appropriate to express these measures in relative terms, i.e., in liters per kilogram of weight and liters per minute of exercise per kilogram of weight. However, it is customary to express sitting intake in liters of oxygen per minute per square meter of body surface area. It is apparent that the transport efficiency ratio of oxygen intake divided by total consumption would give the same calculation regardless of whether weight was divided out or not. The presence of weight in both the numerator and denominator would not affect the measure.

Thus, the measures of intake, intake rate, debt, debt rate, total consumption, and total consumption rate were expressed relative to kilograms of body weight; the transport efficiency ratio in terms of the per cent of total oxygen which is furnished by intake; and the sitting intake rate relative to square meters of body surface area. The resulting measures were intercorrelated to determine, if possible, the relationship between the various measures. (See Table II.)

**Intake Capacity.** The high relationship of intake capacity to the intake rate \((r = .77)\) and the maximum intake or peak rate of intake \((r = .77)\) only indicate that the ability to take in large quantities of oxygen during exercise was closely related to the ability to obtain a high peak of intake and to maintain a high average rate of intake during exercise. A closer examination reveals a very high correlation of .92 between maximum intake rate and average intake rate. This appears to be a fairly obvious relationship. The higher the level of intake obtained, the higher the average rate of intake during
<table>
<thead>
<tr>
<th></th>
<th>Intake (L./kg.)</th>
<th>Intake Rate (L./min./kg.)</th>
<th>Debt (L./kg.)</th>
<th>Debt Rate (L./min./kg.)</th>
<th>Total Consumption (L./kg.)</th>
<th>Total Consumption Rate (L./min./kg.)</th>
<th>Maximum Intake Rate (L./min./kg.)</th>
<th>Efficiency Ratio (Intake/Total)</th>
<th>Sitting Intake Rate (L./min./m.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intake (L./kg.)</td>
<td>--- (.72)*</td>
<td>.49</td>
<td>-.44</td>
<td>(.84)</td>
<td>.01</td>
<td>(.77) (.77) .21</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intake Rate (L./min./kg.)</td>
<td>(.72)</td>
<td>--</td>
<td>.17</td>
<td>-.16</td>
<td>(.58)</td>
<td>.42 (.92) (.74) .14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Debt (L./kg.)</td>
<td>.49</td>
<td>.17</td>
<td>--</td>
<td>.28</td>
<td>(.76)</td>
<td>.45 .28 .02 - .03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Debt Rate (L./min./kg.)</td>
<td>-.44</td>
<td>-.16</td>
<td>.28</td>
<td>--</td>
<td>-.15 (.74)</td>
<td>-.17 (-.69) .00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Consumption (L./kg.)</td>
<td>(.84) (.58) (.76) -.15</td>
<td>--</td>
<td></td>
<td>.28</td>
<td>(.63)</td>
<td>.46 .04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Consumption Rate (L./min./kg.)</td>
<td>.01</td>
<td>.42</td>
<td>.45 (.74)</td>
<td>.28</td>
<td>--</td>
<td>.40 -.10 -.24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Intake Rate (L./min./kg.)</td>
<td>(.77) (.92)</td>
<td>.28</td>
<td>-.17 (.63)</td>
<td>.40</td>
<td>--</td>
<td>(.72) .15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Efficiency Ratio (Intake/Total)</td>
<td>(.77) (.74)</td>
<td>.02</td>
<td>-.69</td>
<td>.46</td>
<td>-.10 (.72)</td>
<td>-- .34</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sitting Intake Rate (L./min./m.)</td>
<td>.21</td>
<td>.14</td>
<td>-.03</td>
<td>.00</td>
<td>.04</td>
<td>-.24 .15 .34</td>
<td>--</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*( ) Signifies one per cent level of confidence.
exercise and subsequently the greater the capacity for taking in large quantities of oxygen and maintaining a high rate of intake during the exercise.

**Total Capacity.** The very high relationship of intake to total consumption ($r = .84$) indicates that a major portion of total oxygen was obtained during the exercise. However, the high relationship of debt ($r = .76$) further obscures the picture. Obviously, total consumption is composed of both intake and debt, with perhaps a slightly larger proportion coming from intake. If we could accept the postulation that debt is a fairly constant factor with slight fluctuations, then the relative ability of intake to be a better predictor of performance than total consumption (which contains both debt and intake) could be accounted for in part by the debt fluctuations. The relationship, however, is not too clear. Apparently, there are other factors to be considered.

The lack of relationship between intake and total consumption rate ($r = .01$) indicates that the ability to take in large quantities of oxygen during exercise was not related to the ability to utilize total oxygen at a high or low average rate. However, the high correlation between debt rate and total consumption rate ($r = .74$) indicates that the ability to develop an oxygen debt at an average low rate was highly related to the ability to utilize the total oxygen over a long period of time. However, the presence of time in both variables could account for the high correlation.

A closer study of the efficiency ratio would appear to clarify the issue somewhat. The high correlation between the efficiency ratio and
intake \((r = .77)\) and the substantial or marked inverse relationship between this measure and debt rate \((r = -.69)\) would indicate that the ability to obtain a large percentage of total oxygen from the intake during exercise was dependent upon a large intake capacity as well as the ability to develop an oxygen distress (the same as oxygen debt) at a slow rate. Apparently, the larger the amount of oxygen taken in, the greater the proportion of total oxygen provided for by intake oxygen. And, conversely, the lower the rate of oxygen debt, the greater the proportion of total oxygen obtained from intake during the exercise.

The high correlations between the efficiency ratio and intake rate \((r = .74)\) and maximum intake rate or peak of intake rate \((r = .72)\) indicate that this ability to take in a large percentage of total oxygen during the exercise was closely related to an ability to develop a high rate of intake and to maintain a high average rate throughout the exercise. Apparently, the ability to take in a high percentage of total oxygen during exercise was dependent upon a large intake capacity, the development of a high maximum rate of intake, the maintenance of a high average rate during the exercise, and the development of an oxygen debt at a slow rate.

It should be pointed out here that the presence of intake and debt in the efficiency ratio could explain to a large degree these relationships. It is probable that the measure of intake is still the most important single measure of metabolic capacity. The efficiency ratio, however, does emphasize the relationship between debt and intake. It seems apparent that the more oxygen taken in during exercise, the greater the proportion of total oxygen provided for during exercise and the slower the rate of oxygen debt built up.
Perhaps the most obvious relationship existing between the metabolic measures is the apparent lack of correlation between sitting intake rate and any other measure of oxygen consumption. Apparently, sitting metabolism is not related to exercise metabolism.

V. THE RELATIONSHIP BETWEEN CIRCULATORY-RESPIRATORY CAPACITY AND PERFORMANCE

Scores were obtained from ten different motor performance tests and four different indexes of strength. These scores were correlated with the various metabolic measures in order to determine the extent of relationship between performance and circulatory-respiratory capacity. The subsequent correlations are shown in Table III.

At first glance it is apparent that the static strength measures did not demonstrate any substantial relationship to the metabolic measures. The same is true of the performance tests of pull-ups, push-ups, Burpee, mile-run, and dips. It is also noted that the metabolic measures of total consumption rate and sitting intake rate were not related to any of the performance tests.

Intake capacity, or the ability to take in large quantities of oxygen during exercise, demonstrated a substantial almost significant relationship with sit-ups ($r = .51$), a marked to high relationship with the 300-yard run ($r = .69$) and squat-jumps ($r = .69$) and a very high relationship with the step-test ($r = .85$). Intake rate displayed a substantial relationship to the 300-yard run ($r = .59$) and debt capacity was substantially reflected in the step test ($r = .52$). Debt rate demonstrated a substantial inverse relationship to performance in squat-jumps ($r = -.53$) and a marked inverse relationship to the step test ($r = -.62$).
**TABLE III**

THE CORRELATION OF METABOLIC MEASURES WITH PERFORMANCE TESTS

<table>
<thead>
<tr>
<th>Performance Tests</th>
<th>Intake Rate (L./kg.)</th>
<th>Intake Rate (L./min./kg.)</th>
<th>Debt Rate (L./kg.)</th>
<th>Debt Rate (L./min./kg.)</th>
<th>Total Consumption Rate (L./kg.)</th>
<th>Total Consumption Rate (L./min./kg.)</th>
<th>Maximum Intake Rate (L./kg.)</th>
<th>Efficiency Ratio (Intake/Total)</th>
<th>Sitting Intake Rate (L./min./kg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step-Test (.85)*</td>
<td>.41 (.52)</td>
<td>(.62) (.81)</td>
<td>-.06</td>
<td>.47 (.53)</td>
<td>-.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squat-Jumps (.69)</td>
<td>.39 (.17)</td>
<td>(.53) (.56)</td>
<td>-.26 (.26)</td>
<td>.50 (.57)</td>
<td>.22</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pull-Ups .29</td>
<td>.25 (.14)</td>
<td>.02 (.24)</td>
<td>.15</td>
<td>.34 (.13)</td>
<td>.13</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S.B.J. .46</td>
<td>.28 (.29)</td>
<td>-.40 (.58)</td>
<td>-.01</td>
<td>.33 (.33)</td>
<td>.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>300-Yard Run (.69)</td>
<td>(.59) (.27)</td>
<td>-.39 (.59)</td>
<td>.01</td>
<td>(.64) (.61)</td>
<td>.11</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Burpee .38</td>
<td>.03 (.08)</td>
<td>-.27 (.21)</td>
<td>-.10</td>
<td>.15 (.30)</td>
<td>.39</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mile Run .45</td>
<td>.47 (.14)</td>
<td>-.04 (.40)</td>
<td>.20</td>
<td>.49 (.48)</td>
<td>.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dips .42</td>
<td>.29 (.06)</td>
<td>-.22 (.31)</td>
<td>-.07</td>
<td>.28 (.35)</td>
<td>.07</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sit-Ups (.51)</td>
<td>-.17 (.37)</td>
<td>-.31 (.59)</td>
<td>-.10</td>
<td>.20 (.30)</td>
<td>.28</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Push-Ups .34</td>
<td>.25 (-.21)</td>
<td>.00 (.27)</td>
<td>-.31</td>
<td>.03 (.32)</td>
<td>.03</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip Strength -.02</td>
<td>.00 (-.22)</td>
<td>-.27 (.03)</td>
<td>.01</td>
<td>-.01 (.07)</td>
<td>-.01</td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Leg Strength -.16</td>
<td>-.31 (.01)</td>
<td>-.28 (.17)</td>
<td>-.28 (.36)</td>
<td>-.02 (.20)</td>
<td>.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Back Strength .00</td>
<td>-.27 (-.02)</td>
<td>-.37 (.01)</td>
<td>-.28</td>
<td>-.20 (.07)</td>
<td>.01</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arm Strength .02</td>
<td>-.25 (.27)</td>
<td>-.24 (.19)</td>
<td>-.17</td>
<td>-.30 (.01)</td>
<td>-.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*( ) Signifies one per cent level of confidence.
Maximum intake rate or the ability to reach a high peak of intake revealed a marked relationship to the 300-yard run \( (r = 0.64) \). The transport efficiency ratio demonstrated a marked relationship with the 300-yard run \( (r = 0.61) \) and a substantial to marked relationship with the step-test \( (r = 0.53) \) and the squat-jump \( (r = 0.57) \). Total consumption or total capacity displayed a substantial to marked relationship to squat-jumps \( (r = 0.56) \), sit-ups \( (r = 0.59) \), 300-yard run \( (r = 0.59) \), and the step test \( (r = 0.81) \).

**The Standing Broad Jump.** Strangely enough, the ability to obtain a high amount of total oxygen was substantially related to performance in the standing broad jump \( (r = 0.58) \). Apparently this measure of power was significantly related to total capacity. The correlation of 0.46, although significant at only the five per cent level of confidence (i.e., above 0.413 and below 0.526), between intake capacity and the standing broad jump, possibly indicates that a fair portion of this total capacity was provided by intake ability. This relationship of total consumption capacity and power should be verified by further experimentation.

**The Mile Run.** Quite frankly, the low relationships obtained between the mile run and the various measures of exercise metabolism were a major disappointment. There were several low correlations of 0.45 with intake, 0.47 with intake rate, 0.49 with maximum intake rate, and 0.48 with the transport efficiency ratio which are significant at only the five per cent level of confidence. Possibly these indicate that performance in the mile run was partly due to the ability to take in large amounts of oxygen, to obtain a high level of intake, to use
it at a high average rate, and to obtain a majority of exercise oxygen during the exercise itself. However, the correlations were not sufficiently significant to draw definite conclusions. Apparently there were other factors such as skill and judgment of pace which entered in the picture. For very skilled runners the relationship between the mile run and circulatory-respiratory capacity might be more pronounced; however, for normal men it appears to be slight if not even doubtful.

The 300-yard Run, Squat Jumps, Step Test, and Sit-Ups. Apparently the relationship between circulatory-respiratory capacity and motor performance was most marked in the tests of squat-jumps, the 300-yard run, the step test, and sit-ups. These performance tests exhibited substantial to marked to high relationship with intake during exercise and with total oxygen consumption. The step test and the squat-jump were inversely related to debt rate and the step test was substantially related to debt capacity. The step test, squat-jumps, and the 300-yard run were substantially related to the transport efficiency ratio, indicating that the ability to take in a major portion of total oxygen during the exercise was substantially related to performance in these tests. The 300-yard run exhibited a marked relationship to maximum intake rate, indicating that performance in this test was dependent on a great part to the ability to obtain a high peak of intake.

In terms of intake capacity and total consumption capacity and after considering these other metabolic factors it is apparent that performance in these tests was dependent to a great extent upon
circulatory-respiratory capacity. The relationship was most marked in intake capacity. Conversely, it may be stated that circulatory-respiratory capacity was, to a marked degree, accurately measured by these performance tests. Perhaps the best test in terms of intake capacity was that of the step test, followed closely by the 300-yard run and the squat-jumps. To a lesser extent the sit-ups also indicated circulatory-respiratory capacity.

Repetition of Exercise and Circulatory-Respiratory Capacity. In an effort to clarify the relationship of circulatory-respiratory capacity to the various exercises, the mean of repetition for each performance test (excluding the two runs and the standing broad jump) was computed. Ranking the individual tests according to their mean of repetition and according to their relationship to oxygen intake capacity a definite similarity was observed between these two factors in vigorous all-out exercise. (See Table IV.)

Utilizing the rank-difference correlation technique a correlation coefficient of .94 was obtained between the mean of repetition and the relationship of the exercise to oxygen intake capacity. The only change in rank occurred with the dips which rated slightly higher than the push-ups in its relationship to intake capacity.

It seems quite safe to assert that oxygen intake capacity was highly related to performance in those motor tests involving a large number of repetitions during vigorous all-out exercise. The larger the number of repetitions, the higher was the relationship to intake capacity.

It should be pointed out that this relationship was true only
TABLE IV
THE RELATIONSHIP BETWEEN CIRCULATORY-RESPIRATORY CAPACITY AND REPETITION OF EXERCISE IN VIGOROUS ALL-OUT PERFORMANCE

<table>
<thead>
<tr>
<th>All-Out Exercise</th>
<th>Mean of Number of Repetitions</th>
<th>Correlation With Oxygen Intake Capacity (L./kg.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step-Test</td>
<td>75</td>
<td>.85</td>
</tr>
<tr>
<td>Squat-Jumps</td>
<td>70</td>
<td>.69</td>
</tr>
<tr>
<td>Sit-Ups</td>
<td>52</td>
<td>.51</td>
</tr>
<tr>
<td>Push-Ups</td>
<td>30</td>
<td>.34</td>
</tr>
<tr>
<td>Dips</td>
<td>8</td>
<td>.42</td>
</tr>
<tr>
<td>Pull-Ups</td>
<td>7</td>
<td>.29</td>
</tr>
</tbody>
</table>
for those all-out exercises in which performance was scored in terms of the number of times the exercise was repeated. It is apparent that the mile run involved more repetitions than the 300-yard run, but here we are concerned with two quite different exercises. The former is a vigorous all-out exercise which was highly related to intake capacity. The latter, however, is probably more concerned with the maintenance of a high steady state level than it is with an all-out intake capacity. At any rate, performance in the mile run was not highly related to all-out capacity. Apparently, this relationship of repetition of exercise holds true only for those exercises which are scored in terms of repetitions during vigorous all-out exercise lasting for a comparatively short time-interval. For normal young college men, the exercises of the step-test, squat-jumps, sit-ups, dips, push-ups, and pull-ups may be included in this category.

VI. THE RELATIONSHIP BETWEEN CIRCULATORY-RESPIRATORY CAPACITY AND CERTAIN TESTS OF PHYSICAL FITNESS

The motor fitness and strength indexes were correlated with the various metabolic measures to determine the extent of relationship between these two aspects of physical fitness and circulatory-respiratory capacity. Although the classification index is not strictly speaking a test of physical fitness, it was included here for the sake of convenience. (See Table V.)

McCloy's Strength Index and Strength P.F.I. The measure of total strength (The Strength Index) and strength fitness (The Strength P.F.I.) were not significantly related to any of the metabolic measures. There
### TABLE V

**THE CORRELATION OF METABOLIC MEASURES WITH PHYSICAL FITNESS TESTS**

<table>
<thead>
<tr>
<th></th>
<th>Intake Rate (L./kg.)</th>
<th>Intake Rate (L./min./kg.)</th>
<th>Debt Rate (L./kg.)</th>
<th>Debt Rate (L./min./kg.)</th>
<th>Total Consumption (L./kg.)</th>
<th>Total Consumption Rate (L./min./kg.)</th>
<th>Maximum Intake Rate (L./min./kg.)</th>
<th>Transport Efficiency Ratio</th>
<th>Sitting Intake Rate (L./min./m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>McCloy's Strength Index</td>
<td>.02</td>
<td>-.16</td>
<td>-.23</td>
<td>-.44</td>
<td>.22</td>
<td>-.29</td>
<td>-.08</td>
<td>.16</td>
<td>.11</td>
</tr>
<tr>
<td>McCloy's Strength P.F.I.</td>
<td>.39</td>
<td>.22</td>
<td>.02</td>
<td>-.44</td>
<td>.29</td>
<td>-.17</td>
<td>.24</td>
<td>.40</td>
<td>.13</td>
</tr>
<tr>
<td>Illinois P.F.R. (.74)*</td>
<td>.46</td>
<td>.02</td>
<td>-.50</td>
<td>(.59)</td>
<td>-.20</td>
<td>.48</td>
<td>(.57)</td>
<td>.29</td>
<td></td>
</tr>
<tr>
<td>Indiana M.F.R. (.53)</td>
<td>.33</td>
<td>.14</td>
<td>-.31</td>
<td>(.51)</td>
<td>-.01</td>
<td>.33</td>
<td>.36</td>
<td>.00</td>
<td></td>
</tr>
<tr>
<td>A.A.F. P.F.R. (.67)</td>
<td>.44</td>
<td>.23</td>
<td>-.29</td>
<td>(.62)</td>
<td>-.01</td>
<td>.46</td>
<td>.45</td>
<td>.19</td>
<td></td>
</tr>
<tr>
<td>Navy P.F.R. (.64)</td>
<td>.35</td>
<td>.17</td>
<td>-.38</td>
<td>(.54)</td>
<td>-.22</td>
<td>.37</td>
<td>.50</td>
<td>.28</td>
<td></td>
</tr>
<tr>
<td>Classification Index</td>
<td>-.26</td>
<td>-.22</td>
<td>-.30</td>
<td>-.03</td>
<td>-.27</td>
<td>-.10</td>
<td>-.32</td>
<td>-.01</td>
<td></td>
</tr>
</tbody>
</table>

*( ) Signifies one per cent level of confidence.
is perhaps one relationship which should be mentioned here, and it was significant at only the five per cent level of confidence. The correlation of -.64 between the Strength Index and debt rate and strength P.F.I. and oxygen debt rate indicate that perhaps a small part of the ability to build up an oxygen deficiency at a slow rate was related to total strength or strength fitness. However, this is an obscure relationship and subject to questioning. This relationship should probably be verified by further experimentation.

**The Classification Index.** The classification index is ordinarily used to classify students for physical education classes. It is a combination of six times the height plus the weight. Apparently there was no relationship between this measure and any of the measures of circulatory-respiratory capacity.

**The Motor Fitness Tests.** Intake capacity demonstrated a high relationship with performance in the Illinois Test \( r = .74 \), a marked relationship with the Army Air Force Test \( r = .67 \), and Navy Test \( r = .64 \), and a substantial relationship with performance in the Indiana Test \( r = .53 \). There was a marked relationship between total capacity and performance in the Navy Test \( r = .62 \) and a substantial relationship with the Illinois Test \( r = .59 \), the Navy Test \( r = .54 \), and the Indiana Test \( r = .51 \).

These relationships can probably be explained by the fact that each of these tests, the Indiana Test excluded, contained from one to two of the performance tests which correlated highly with intake and total consumption capacity. Such tests were the sit-ups, (contained
in the Illinois, Army Air Force, and Navy Tests), the squat-jumps (contained in the Illinois and Navy Tests) and the 300-yard run (contained in the Army Air Force Test). Each of these batteries contained at least two of these performance tests. However, the substantial relationship between these metabolic measures and the Indiana Test cannot be so easily accounted for. Apparently the standing broad jump (which gave a fair correlation with intake and total consumption) combined with pull-ups and push-ups (which were not correlated at all) gave a fair estimate of all-around motor performance which also reflects a substantial relationship with oxygen intake capacity. This relationship will be investigated further.

Obviously, from the standpoint of prediction of intake capacity, the Illinois Test was the best, followed closely by the Army Air Force and the Navy tests. To a lesser extent, the Indiana Test was also related to intake capacity.

VII. THE INTERRELATIONSHIP BETWEEN PHYSICAL FITNESS TESTS

The intercorrelations of the McCloy Strength Index, the Strength P.F.I., the Illinois, Indiana, Navy, and Army Air Force motor fitness tests, the step test and intake capacity were quite revealing. Obviously, there was not a significant relationship between total static strength as measured by the McCloy Strength Index and any of motor fitness tests, the step test or intake capacity. Apparently total static strength was completely unrelated to performance in these other tests. (See Table VI.)

The marked relationship ($r = .66$) between the strength P.F.I.
<table>
<thead>
<tr>
<th>table VI</th>
<th>Intercorrelation Between Physical Fitness Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>McCloy Strength Index</td>
<td>McCloy Strength P.F.I.</td>
</tr>
<tr>
<td>McCloy Strength P.F.I.</td>
<td>Illinois P.F.R.</td>
</tr>
<tr>
<td>Illinois P.F.R.</td>
<td>Indiana M.F.R.</td>
</tr>
<tr>
<td>Indiana M.F.R.</td>
<td>Army Air Force P.F.R.</td>
</tr>
<tr>
<td>Army Air Force P.F.R.</td>
<td>Navy P.F.R.</td>
</tr>
<tr>
<td>Navy P.F.R.</td>
<td>Step Test</td>
</tr>
<tr>
<td>Step Test</td>
<td>Intake (L./kg.)</td>
</tr>
<tr>
<td>McCloy Strength Index</td>
<td>(.66)</td>
</tr>
<tr>
<td>McCloy Strength P.F.I.</td>
<td>.01</td>
</tr>
<tr>
<td>Illinois P.F.R.</td>
<td>.36 (.53)</td>
</tr>
<tr>
<td>Indiana M.F.R.</td>
<td>.47 (.71)</td>
</tr>
<tr>
<td>Army Air Force P.F.R.</td>
<td>.40 (.70)</td>
</tr>
<tr>
<td>Navy P.F.R.</td>
<td>.39 (.74)</td>
</tr>
<tr>
<td>Step Test</td>
<td>.40 (.70)</td>
</tr>
<tr>
<td>Intake (L./kg.)</td>
<td>.39 (.74)</td>
</tr>
</tbody>
</table>

*( ) Signifies one per cent level of confidence.
and the Strength Index was to be expected. However, it is interesting to note that the Strength P.F.I. was substantially related to performance in the Indiana Test ($r = .53$) and highly related to the Navy Test ($r = .71$), although the other tests were not significantly related to this measure of strength fitness. A closer examination reveals that all of the motor fitness tests were highly related. Whatever they measured, it was probable that they closely measured in the same direction.

The smaller batteries such as the Army Air Force and the Indiana gave close approximations of the larger batteries such as the Navy and Illinois Tests. From a standpoint of its ability to predict all of the various forms of strength and motor fitness and its high relationship to intake capacity, the Navy Test was probably the best all-around test, i.e., it was able to achieve a middle ground between these three aspects of fitness.

From the standpoint of motor fitness and intake capacity the Illinois Test was probably the next best. Its high relationship to all of the other motor fitness tests and its high relationship to intake capacity indicate its worthiness insofar as these two aspects of fitness are concerned. It was not, however, related to strength fitness in any way. In this same category is the Army Air Force Test. Its intercorrelations were not as high as the Illinois Test, but they were substantially greater than the Indiana Test. The Indiana Test was not as highly related to motor fitness and intake capacity as was the Illinois or Army Air Force Tests, but it did have a substantially higher relationship with strength fitness.
The step test itself was probably a good test of fitness. It demonstrated a high relationship with intake capacity and was substantially related to the other motor fitness tests. However, it was not related to strength fitness and its relationships to the motor fitness tests were lower than most of the other tests.

From the standpoint of predicting intake capacity, the step test was the best test, followed closely by the Illinois, Army Air Force and Navy tests, in that order. However, from the standpoint of predicting motor fitness and intake capacity, the Illinois was probably the best, followed closely by the Navy and Army Air Force tests. From a standpoint of utilizing a test which demonstrated a remarkable ability to predict all aspects of strength fitness, motor fitness, and intake capacity, the Navy Test was the best. Apparently, this is a mediating test which could be used to achieve standardization of fitness testing. Further experimentation with larger samples should prove or disprove this relationship beyond all doubt.

VIII. THE PREDICTION OF OXYGEN INTAKE CAPACITY FROM MOTOR PERFORMANCE TESTS

As it was pointed out earlier, the all-out step test at forty steps per minute on a seventeen-inch stool was the best single test for prediction of oxygen intake capacity. However, as a routine test to be given to large groups it has definite and serious disadvantages. To be properly administered there should be at least one tester for supervision of each subject taking the test. A strict cadence must be maintained throughout the test and the exact definition of onset of complete exhaustion is subject to variations in interpretation.
It is hard to achieve standardization when the test is administered by several different testers, but such a procedure is necessary if the test is to be utilized for large groups.

On the other hand, the various motor performance tests are much simpler to administer. Although they are subject to some degree of inaccuracy, standardization is easier to achieve and large groups may be given the tests with relatively few testers and in a comparatively short time. They are perhaps the simplest tests of performance ability available.

It was considered feasible, therefore, to investigate the prediction of intake capacity through some combination of the motor performance tests, excluding the step test. The various tests were correlated with the criterion, oxygen intake (liters/kilogram), and then intercorrelated to determine the extent of similarity in measurement. (See Table VII).

The Wherry-Doolittle method of multiple-regression was then utilized to find the smallest number of motor performance tests predictive of intake capacity. This method is adequately described by Garret.\(^8\) Briefly, the principles of the Wherry-Doolittle method are as follows. One starts with a single test that seems to offer most in prediction of the criterion. The method then aids in selection of the second test that will have most to add to prediction when combined with the first. A third can be selected which will add most by way of prediction when combined with the first two, and so on. At each step

\(^8\)H. E. Garret, *op. cit.*, p. 434.
### TABLE VII
INTERCORRELATION BETWEEN MOTOR PERFORMANCE TESTS AND OXYGEN INTAKE CAPACITY

<table>
<thead>
<tr>
<th></th>
<th>Oxygen Intake (L./kg.)</th>
<th>Squat-Jumps</th>
<th>Pull-Ups</th>
<th>Standing Broad Jump</th>
<th>300-Yard Run</th>
<th>Burpee</th>
<th>Mile Run</th>
<th>Dips</th>
<th>Sit-Ups</th>
<th>Push-Ups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen Intake (L./kg.)</td>
<td>--</td>
<td>.69</td>
<td>.29</td>
<td>.46</td>
<td>.69</td>
<td>.38</td>
<td>.45</td>
<td>.42</td>
<td>.51</td>
<td>.34</td>
</tr>
<tr>
<td>Squat-Jumps</td>
<td>.69</td>
<td>--</td>
<td>.41</td>
<td>.58</td>
<td>.57</td>
<td>.49</td>
<td>.36</td>
<td>.57</td>
<td>.29</td>
<td>.30</td>
</tr>
<tr>
<td>Pull-Ups</td>
<td>.29</td>
<td>.41</td>
<td>--</td>
<td>.19</td>
<td>.54</td>
<td>.02</td>
<td>.25</td>
<td>.82</td>
<td>.53</td>
<td>.42</td>
</tr>
<tr>
<td>Standing Broad Jump</td>
<td>.46</td>
<td>.58</td>
<td>.19</td>
<td>--</td>
<td>.67</td>
<td>.51</td>
<td>.46</td>
<td>.36</td>
<td>.31</td>
<td>.01</td>
</tr>
<tr>
<td>300-Yard Run</td>
<td>.69</td>
<td>.57</td>
<td>.54</td>
<td>.67</td>
<td>--</td>
<td>.49</td>
<td>.56</td>
<td>.49</td>
<td>.49</td>
<td>.36</td>
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<tr>
<td>Burpee</td>
<td>.38</td>
<td>.49</td>
<td>.02</td>
<td>.51</td>
<td>.49</td>
<td>--</td>
<td>.67</td>
<td>.40</td>
<td>.19</td>
<td>.13</td>
</tr>
<tr>
<td>Mile Run</td>
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<td>.36</td>
<td>.25</td>
<td>.46</td>
<td>.56</td>
<td>.67</td>
<td>--</td>
<td>.04</td>
<td>.32</td>
<td>.05</td>
</tr>
<tr>
<td>Dips</td>
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<td>.57</td>
<td>.82</td>
<td>.36</td>
<td>.49</td>
<td>.40</td>
<td>.04</td>
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<td>Sit-Ups</td>
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<td>.37</td>
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<td>Push-Ups</td>
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<td>.13</td>
<td>.05</td>
<td>.53</td>
<td>.37</td>
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</tr>
</tbody>
</table>
a shrinkage formula is applied in order to determine whether the shrunken $R$ is appreciably larger than the previous $R$. At the point where no further gain according to these standards is evident, no more tests are added.

Obviously, the best tests for inclusion in the regression equation were those which correlated highly with the criterion and were not highly intercorrelated. A preliminary investigation of Table VII revealed that the squat-jumps and the 300-yard run were both highly correlated with the criterion but were also highly interrelated. Application of the Wherry-Doolittle method revealed that only one of these tests could be included in the final regression equation. As the squat-jump test appeared to be appreciably lower in its correlations with the other variables, it was selected in preference to the 300-yard run.

Numerous juggling of the various variables eliminated the tests of pull-ups, push-ups, and the Burpee. The intercorrelations were then reduced to five motor performance tests and the criterion of intake capacity.

Of the remaining variables, it was discovered that a combination of the squat-jumps, the sit-ups, and the mile run produced the highest multiple correlation with the criterion. The addition of the standing broad jump and the dips did not add to the prediction; in fact, their inclusion in the equation substantially lowered the multiple regression coefficient. Thus, combining the tests of squat-jumps, sit-ups, and the mile run produced a high multiple correlation of .716 with oxygen intake capacity and the standard score regression equation is:
Oxygen Intake (liters/kilogram) = .601 Squat-Jumps (all-out) 
+ .242 Sit-Ups (all-out) - .054 Mile Run (for best time).

The beta values are "net coefficients." The intercorrelation effect between the three variables has been eliminated. Beta weights are used to predict a subject's criterion score only when his raw scores have been transformed into standard scores. Any form of standard scores may be utilized, including the sten scores for small groups or the C scores for large groups.

The multiple correlation coefficient of .716 is slightly lower than the correlation of .74 obtained with the Illinois Physical Fitness Test and intake capacity. However, it should be remembered that the Wherry-Doolittle method applies shrinkage to the multiple R to compensate for chance error. It is interesting to note that the Illinois Test, which correlated higher with intake capacity than any of the other Physical Fitness Tests contained the same three performance tests as the regression equation. This obviously explains why such a high correlation was obtained with this motor fitness battery.

It is also interesting to note that the major portion of the regression equation is taken up with the squat-jumps and the sit-ups. The addition of the mile run seems to add very little to the prediction. Computing a regression equation containing only the motor performance tests of squat-jumps and sit-ups, a shorter and perhaps more practical predictive battery with a slightly lower correlation coefficient of .708 is obtained. The equation in standard score form is:
Oxygen Intake (liters/kilogram) = .592 Squat-Jumps (all-out) / .336 Sit-Ups (all-out).

As these two tests are included in the Navy Physical Fitness Test, this probably explains its high correlation with oxygen intake capacity.

Apparently, the step test was the best single test for prediction of intake capacity. As a screening device its use is highly recommended. However, if an easily-administered and highly standardized test predictive of intake capacity is desired, the short battery of squat-jumps and sit-ups is suggested. The Illinois Physical Fitness Test, with its available norms and standard scores, is probably just as satisfactory for the same purpose.
CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. SUMMARY

In the foregoing discussion of the literature, several important factors concerning oxygen metabolism during exercise have been pointed out. Its value as a measurement of energy expenditure is established, and its relationship to other circulatory-respiratory indexes is discussed. Substantial evidence is presented to demonstrate that these metabolic measures are a gross index of the circulatory-respiratory systems' capacity to adjust to the increased demands of exercise.

Increase in activity is shown to result in increase of oxygen consumption according to the intensity of the exercise. The effects of training are reviewed, and the ability of oxygen intake to differentiate between trained and normal men is pointed out. It is demonstrated that the evidence available shows that tests of lactic acid concentrations, alkali reserve, and carbon dioxide exhaled during exercise are unreliable indicators of the effects of training. It is also shown that evidence concerning oxygen debt is not conclusive.

Oxygen intake during exercise is presented as the most important indicator of circulatory-respiratory capacity. However, other components of capacity and efficiency are shown to have certain implications in regard to interpretation of the total adjustments during exercise.
Three generally accepted aspects of physical fitness testing are presented as including tests based on strength indexes, cardiovascular ratings and motor performance. As the contribution of each type to the total picture of fitness is not known, this study was proposed in order to investigate the relationship of circulatory-respiratory capacity to strength and motor performance.

Accepting McCloy's dynamometer strength test as the criterion of strength and strength fitness, the oxygen metabolism test during the all-out step test at forty steps per minute on a seventeen-inch stool as the criterion of circulatory-respiratory capacity, and the Indiana, Illinois, Navy and Army Air Force motor performance batteries as typical, generally accepted tests of this phase of physical fitness, twenty-three normal young college men selected at random from the physical education activity classes at Louisiana State University were tested in all three aspects of these types of fitness and their scores statistically analyzed to determine the extent of relationship which existed between these measures.

The findings of this study are summarized in the following statements.

(1) Gross oxygen intake and net intake during the all-out step test at forty steps per minute on a seventeen-inch stool were very highly related. Either measure may be used as an indicator of intake capacity.

(2) Net oxygen debt calculated at the end of a standardized time interval of fifteen minutes was highly related to net debt measured at the end of eighty per cent recovery. Either measure may be used as an
indicator of debt capacity for vigorous all-out exercise.

(3) The apparent agreement between the correlations obtained in this study and those obtained in Cureton's study with all-out performance involving a comparatively large amount of external work emphasized the importance of intake as compared to debt in the prediction of regulated all-out work such as was involved in the step test and treadmill running.

(4) Sitting metabolism at rest was not significantly related to any measure of exercise metabolism explored.

(5) Static strength measures of arm, leg, back, and grip strength were not significantly related to any of the measures of exercise metabolism.

(6) Oxygen intake capacity was highly related to performance in the step test and substantially related to performance in the squat-jumps and 300-yard run. To a lesser extent, performance in sit-ups was also related to intake capacity.

(7) Oxygen debt capacity was not substantially related to any of the performance tests studied. However, a slight relationship was found to exist with the step test.

(8) Performance in pull-ups, push-ups, dips, the Burpee, and the mile run was not substantially related to any of the measures of exercise metabolism.

(9) The McCloy Strength Index and P.F.I., and the Classification Index were not significantly related to any of the measures of exercise metabolism.

(10) Intake capacity was highly related to performance in the
Illinois Physical Fitness Test and substantially related to performance in the Navy Test and the Army Air Force Test. To a lesser extent, intake capacity and the Indiana Test were substantially related.

(11) The McCloy Strength Index was not substantially related to any of the motor fitness tests.

(12) The Illinois, Army Air Force, Navy, and Indiana Tests were all highly interrelated.

(13) The Navy Test was highly related to all of the measures of motor fitness and strength fitness, and substantially related to intake capacity. From this viewpoint, the Navy Test was the best all-around test of physical fitness.

(14) In terms of its high relationship to all of the tests of motor fitness and to intake capacity, the Illinois Test was the next best test of physical fitness.

(15) The highest relationship between intake capacity and motor performance was found in the step test. Of the tests studied, the step test was the most indicative of circulatory-respiratory capacity.

(16) An equation for predicting oxygen intake capacity from motor performance is, in standard score form:

\[
\text{Oxygen Intake (liters/kilogram) } = .601 \text{ Squat-Jumps (all-out)}
\]
\[
+ .242 \text{ Sit-Ups (all-out)} - .054 \text{ Mile Run (for best time)}.
\]

\[R = .716.\]

(17) A shorter and perhaps more practical predictive equation is, in standard score form:

\[
\text{Oxygen Intake (liters/kilogram) } = .592 \text{ Squat-Jumps (all-out)}
\]
\[
+ .338 \text{ Sit-Ups (all-out)}.
\]

\[R = .708.\]
II. CONCLUSIONS

The following conclusions are drawn concerning the findings of this study.

(1) Oxygen intake (liters/kilogram) is the most important metabolic indicator of all-out circulatory-respiratory capacity.

(2) Sitting metabolism is not related to exercise metabolism or all-out exercise performance. The physiologic differences between normal individuals are most apparent when under stress of exercise.

(3) Oxygen debt capacity (liters/kilogram) is not substantially related to motor performance, motor fitness, strength or strength fitness. Apparently, oxygen debt capacity is not related to physical fitness.

(4) Oxygen intake capacity (liters/kilogram) is highly related to performance in those motor tests involving a large number of repetitions during vigorous all-out exercise. The larger the number of repetitions the higher the relationship. Included in this category are the all-out exercises of the step-test, squat-jumps, and sit-ups.

(5) Circulatory-respiratory capacity is not related to strength or strength fitness.

(6) Circulatory-respiratory capacity is related to motor fitness to the degree that the testing device utilized includes performance tests which are related to oxygen intake ability.

III. RECOMMENDATIONS

(1) The relationship between power, as measured by the standing broad jump, and total oxygen consumption capacity should be further investigated. The study probably should revolve around the reliability
of the standing broad jump as a measure of power and the significance of circulatory–respiratory capacity to this measure. If such a relationship were to be established beyond doubt, then the implications insofar as training is concerned are obvious.

(2) The almost significant inverse relationship between total strength and debt rate should probably be investigated further. A certain amount of strength may be necessary to efficiently hold down the rate of oxygen debt or oxygen distress. It is possible that total strength is a necessary, but not sufficient item in lactic acid buffering and the development of a low rate of oxygen distress.

(3) Future studies concerning oxygen metabolism during exercise should probably be concerned with measuring intake and debt during the various motor performance tests. Such studies would probably be more revealing from the standpoint of debt indications and debt rate measures. It is also apparent that if these measures were taken during the various exercises and each individual ranked according to his efficient utilization of capacity, definite conclusions regarding oxygen absorption as the ultimate limiting factor in any motor performance could be reached.

(4) The Navy Physical Fitness Test is recommended as a versatile indicator of three aspects of fitness: namely, motor fitness, strength fitness, and circulatory–respiratory capacity. Future studies should probably verify this relationship, but until then its use is highly recommended.

(5) The all-out step test at forty steps per minute on a seventeen-inch stool is recommended as the best practical screening device
for the prediction of circulatory-respiratory capacity.

(6) If an easily administered test is desired for utilization with large groups, the short and practical battery containing squat-jumps and sit-ups is recommended for prediction of oxygen intake capacity. The Illinois Physical Fitness Test with its available norms and standard scores is probably just as satisfactory for the same purpose.
SELECTED BIBLIOGRAPHY

A. BOOKS


B. PERIODICAL ARTICLES


Jenkins, B. L., "Basal Metabolism," Archives of Internal Medicine, 49:181-191, 1932.


C. PHAMPHLET

Directions for the Care and Use of the McKesson Recording Metabolox.
Toledo, Ohio: McKesson Appliance Company, 7 pp.


D. UNPUBLISHED MATERIALS


APPENDIX A

METABOLISM AND PERFORMANCE DATA

FOR NORMAL YOUNG MEN
## TABLE VIII

**Metabolism Data for Normal Young Men on All-Out Step Test**

<table>
<thead>
<tr>
<th>Subjects</th>
<th>Age (yr.)</th>
<th>Height (in.)</th>
<th>Weight (kg.)</th>
<th>Surface Area (eq.m.)</th>
<th>Sitting Intake Rate (L./min.)</th>
<th>Maximum Intake Rate (L./min./kg.)</th>
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<tbody>
<tr>
<td>Lott</td>
<td>20</td>
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<td>1.85</td>
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<td>64.9</td>
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<td>1.63</td>
<td>0.297</td>
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**Average** 19 68.6 66.8 1.79 0.289 1.62 2.14 0.0323
TABLE VIII (Continued)

METABOLISM DATA FOR NORMAL YOUNG MEN ON ALL-OUT STEP TEST

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<tr>
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<td>(L.) (L./kg.) (L./min.) (L./min./kg.)</td>
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</tr>
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<td>3.53 .056 1.92 .0307</td>
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TABLE IX (Continued)

PERFORMANCE DATA FOR NORMAL YOUNG MEN ON MOTOR TESTS AND STRENGTH INDEXES

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<th>Push-Ups (no.)</th>
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TABLE X

PERFORMANCE DATA FOR NORMAL YOUNG MEN ON PHYSICAL FITNESS TESTS

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Average 95 288 63 56 52 586
APPENDIX B

SAMPLE LABORATORY CALCULATIONS
Name: Collins, Robert S.  
Age: 19 yrs., 9 months

Height: 67.7 in.  Weight: 133 lbs., 60.6 Kgs. Surface Area: 1.70 M.

**ALL-OUT STEP TEST (40 Steps per Minute, 17-inch Stool)**

Temperature of Subject: 98.6 F.

**Sitting Metabolism**

Temp: 26 C.  Pressure: 30.15 in., 766 mm.  Time: 10 min.
Recorded sitting intake: 2.70 L.  Correction factor: .920
Total sitting intake: 2.48 L.
Sitting intake rate: 248 L/min., 146 L/min./S.A.

**Exercise Metabolism**

Temp: 26 C.  Pressure: 30.15 in., 766 mm.
Time of exercise: 261.1 sec., 4.35 min.  Number of steps: 176
Recorded gross intake: 8.65 L.  Correction Factor: .920
Gross intake: 8.65 L., 143 L/kg.
Gross intake rate: 1.97 L/min., 0.0325 L/min./kg.

Gross intake: 8.65 L. less sitting intake for duration of exercise: 1.02 L.
Net intake: 7.56 L., 125 L/kg.
Net intake rate: 1.73 L/min., 0.0285 L/min./kg.

Recorded gross maximum intake rate: 2.48 L/min.  Correction factor: .920
Gross maximum intake rate: 2.23 L/min. less sitting intake rate: 248

Net maximum intake rate: 2.03 L/min., 0.0335 L/min./kg.

**Recovery Metabolism**

Temp: 26 C.  Pressure: 30.15 in., 766 mm.  Time: 15 min.
Recorded gross debt: 11.60 L.  Correction factor: .920
Gross debt: 10.67 L., less sitting intake for 15 min.: 3.72 L.
Net debt: 6.95 L., 115 L/kg.
Net debt rate: 1.59 L/min., 0.0262 L/min./kg.

Recorded maximum intake: 67.0 degrees slope, 2.48 L/min.
Recorded sitting intake: 15.0 degrees slope, 270 L/min.
Total to recover: 52.0 degrees slope
Eighthy per cent of recovery: 41.6 degrees slope
Point of eighty per cent recovery: 25.4 degrees slope
Recorded gross debt at eighty per cent recovery: 8.90 L.
Time of eighty per cent recovery: 2.0 min.
Recorded sitting intake for time interval measured: 2.43 L.
Net recorded debt at eighty per cent recovery: 6.47 L.
Correction factor: .920
Net debt at eighty per cent recovery: 5.95 L.
Name: Collins, Robert S.

Total Metabolism

Net intake 7.56 L plus net debt 6.95 L.
Net total consumption 14.51 L, .239 L/kg.
Net total consumption rate 3.31 L/min, .0546 L/min/kg.

Transport efficiency ratio (Intake L/Total consumption L.) 52.1 %

Motor Performance Tests

Standing broad jump (1) 85.5 in. (2) 87 in. (3) 82.5 in.
Squat jumps (all-out) 74
300-yard run 52.5 sec.
Mile run 7 min. 39 sec.
Dips 94

Batteries and Indexes

McCLOY STRENGTH TEST Score

| Right grip | 111 |
| Left grip | 94 |
| Grip strength | 205 |
| Leg lift (with belt) | 662 |
| Pack lift | 328 |
| Pull-ups (7) | 213 |
| Dips (94) | 220 |
| Arm strength | 473 |
Strength index 1.628

Norm 1,529 / 172 = 1.668
Strength P.F.I. 98

INDIANA BATTERY No. Score

| Full-ups | 6 | 44 |
| Push-ups | 34 | 95 |

Sum 139

Times

SBJ 85.5 50
M.F.I. 69
Rating: Good

Classification Index Score

| Height | 67.7 x 6 | 406 |
| Weight | 173 |

C.I. 539
Class C

AAF BATTERY No. Score

| Full-ups | 6 | 42 |
| Sit-ups | 62 | 72 |
| 300-yard run | 52.5 | 46 |
| Total | 160 |
| P.F.I. | 53 |
Rating: Good

NAVY BATTERY No. Score

| Full-ups | 6 | 40 |
| Push-ups | 34 | 59 |
| Sit-ups | 62 | 66 |
| Burpee | 28 | 49 |
| Squat-jumps | 74 | 80 |
| Total | 294 |
| P.F.I. | 59 |

ILLINOIS BATTERY No. Score

| Full-ups | 6 | 42 |
| Push-ups | 34 | 77 |
| Sit-ups | 62 | 64 |
| Squat-jumps | 74 | 83 |
| Mile run | 7:39 | 33 |
| P.F.I. | 104 |
VITA

The author was born May 2, 1923, at Mount Berry, Georgia. He received his elementary and high school training at the Barry Schools. On May 25, 1942, he graduated from Berry College, Mount Berry, Georgia, with a major in Mathematics and a minor in Education.

On July 30, 1942, he enlisted in the Cadet Corps of the Army Air Forces and received navigational training at Selman Field, Monroe, Louisiana. Overseas, he served with the Eighth Air Force as a navigator in the 305 Bombardment Group. After twenty-one missions, he was shot down over enemy territory and taken prisoner. Here, in close confinement as a prisoner of war, he first fully realized the need for physical fitness and the inherent values of Physical Education for emotional, moral, and social adjustment.

After discharge from the service, December 31, 1945, he taught for one semester at the Northside Junior High School, Chattanooga, Tennessee. The following school year he enrolled at the University of Tennessee, where he completed the requirements for an undergraduate degree in Physical Education and served as an assistant instructor in Mathematics. On August 28, 1948, he received his M. S. Degree with a major in Physical Education from the University of Tennessee at Knoxville.

The following year he taught Mathematics at the Humboldt
County High School, Winnemucca, Nevada. During this time he also acted as assistant coach and part time recreation manager for the city of Winnemucca.

On February 5, 1950, he enrolled at Louisiana State University, Baton Rouge, Louisiana, and began advanced work in Health and Physical Education and Education. During the school year of 1951-1952, he served as a graduate assistant in the Department of Health and Physical Education.

He is a member of the A.A.H.P.E.R. and the Phi Delta Kappa Associations. From 1949 to 1951, he served as president of the Berry School's Alumni Association and as a member of the Board of Trustees of the Berry Schools, Mount Berry, Georgia.
EXAMINATION AND THESIS REPORT

Candidate: Walter L. Russell

Major Field: Health and Physical Education

Title of Thesis: A Study of the Relationship of Performance in Certain Generally Accepted Tests of Physical Fitness to Circulatory-Respiratory Capacity of Normal College Men

Approved:

[Signatures]

Major Professor and Chairman

Acting Dean of the Graduate School

EXAMINING COMMITTEE:

[Signatures]

Date of Examination:

July 23, 1952