A comparison of predicted energy expenditures with actual energy expenditures while walking on a motor-driven treadmill

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A COMPARISON OF PREDICTED ENERGY EXPENDITURES WITH ACTUAL ENERGY EXPENDITURES WHILE WALKING ON A MOTOR-DRIVEN TREADMILL

by

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CHAPTER I

THE PROBLEM AND DEFINITIONS OF TERMS USED

I. INTRODUCTION

A great deal of research has been done on energy expenditure during walking, both treadmill walking and walking on regular surfaces. Zuntz and his associates (18) first became interested in determining energy expenditures of walking as applied to field soldiers carrying packs. Winsmann, Vanderbie and Daniels (20) studied the energy cost of wearing armored vests and carrying pack loads on the treadmill, level course and mountain slopes. They found that results could best be reproduced on the treadmill because of the small number of variables involved.

Based on past research, as well as upon his own studies, Bobbert (3) developed a predictive formula stating that the energy expenditure per kilogram of body weight increases with the square of speed. The most important variable affecting energy expenditure, body weight, is taken into consideration in Bobbert's formula; but other factors such as age, sex, morphology, training, extremes in body weight, are also known to influence energy expenditures (3).

A formula for predicting oxygen consumption was developed by Balke (1). He estimated the oxygen consumption by taking into account the speed and grade of the treadmill, the body weight, and a factor assessing the step lift. Since the oxygen consumption is directly dependent on the energy expended during activity, energy expenditure can be predicted from Balke's formula. In developing his formula, Bobbert (3) used grades up to 21 per cent or 12 degrees. Balke (1) tested his subjects on grades up to 18 per cent.

The value of these predictive formulas is apparent to researchers, especially for planning research. The gross estimate can be determined so the researcher can see what he will need in the way of equipment for the particular type of experiments he is planning. The formulas could sometimes be used in evaluating other phases of an experiment. For instance, a researcher measuring strength changes during exercise might later want to evaluate what the comparative energy expenditure would be under similar conditions.

II. STATEMENT OF THE PROBLEM

Since these two formulas have been checked at level grade and grades up to 21 per cent, it is not known exactly how well they predict at grades above 21 per cent. There is an indication that the relationship between grade and expenditure may be curvilinear rather than linear (9). Part of the writer's work has been done with subjects walking above 21 per cent. It will be beneficial to know how well the formulas apply to this higher grade.

The purpose of this study then is to investigate the applicability of formulas for predicting energy expenditure while walking at grades of 15 per cent, 20 per cent and 25 per cent. The energy expenditures predicted by both Balke and Bobbert will be compared to the actual test results.

Bobbert found that the influence of speed prompted a curvilinear increase in energy expenditure. This type of curve suggests a quadratic relationship, therefore, Bobbert plotted the square of the speed against energy expenditure. From this he obtained a nearly straight line for each gradient. The factor for speed in Bobbert's (3) predictive formula was derived from a regression equation based on the above assumptions.

Bobbert also found that energy evidently increased with gradient in a curvilinear way. Since this suggested a logarithmic rise, Bobbert (3) plotted the logarithms of Ew against the gradients and obtained a nearly linear relationship.

Combining the equations developed from his study of the effect of speed and grade, Bobbert (3) derived the following equation for predicting energy expenditure:

$$\text{Log Ew} = 1.4272 + (0.004591 \cdot v) + (0.024487 \cdot \quad) + (0.0002658 \cdot v \cdot \quad)$$

Where Ew = energy expenditure per kilogram of body weight;
v = speed in meters per minute;
= gradient in degrees.

Balke developed a formula for estimating oxygen consumption. From his treadmill tests on a large group of subjects, he found that oxygen intake was almost linearly related to the increase in work, and that the average oxygen consumption was found to be 1.8 milliliters for the performance of one kilogram-meter of work per minute. Balke experimented with vertical lift of weight during horizontal walking. From these experiments he assessed a value for this factor. From these factors Balke (1) developed the formula for predicting oxygen consumption--

$$VO_2 = v \cdot w \cdot 1.8 \left(.073 + \frac{oc}{100}\right)$$

Where VO_2 = estimated O_2 consumption in milliliters per minute;
v = treadmill speed in meters per minute;
w = body weight in kilograms;
oc = angle of treadmill in per cent;
.073 = factor most closely assessing the vertical lifting of weight during horizontal walking;
1.8 - average consumption of oxygen in milliliters for a performance of one kilogram-meter per minute.

III. BASIC ASSUMPTIONS

1. Oxygen consumption gives a true measurement of energy expenditure. The basic unit of all nutritional energy calculations is the large Calorie or kilocalorie. It is the amount of heat necessary to raise the temperature of one kilogram of water one degree Centigrade. The formula used

to figure the cost of a given task is:

$$\text{kcal./hr.} = O_2 \text{ consumption (liters/min.)} \cdot 60 \cdot 5.0$$
$$= O_2 \text{ (liters/min.)} \cdot 300$$

2. The caloric equivalent of one liter of oxygen consumed during moderate activity is represented by the factor 5.0 (5).

IV. LIMITATIONS

The number of subjects was limited to a sample selected from the student body of the Montana State University. The subjects were volunteer physical education majors.

The experimental design was limited to three grades, while speed remained a constant. Consequently, interaction between the two factors of speed and grade was not possible. This limitation was due to the number of necessary tests and the available time.

V. DEFINITIONS

1. Calorie--the amount of heat necessary to raise the temperature of one kilogram of water one degree Centigrade.
2. Curvilinear--consisted of or bounded by curved lines.
3. Degree of inclination--the angle that the walking surface of the treadmill makes with the base of the treadmill

when level; expressed in degrees.

4. Empirical--derived from or depending upon experience or observation alone.

5. Ergometry--measurement of work.

6. Linear--extended in a line.

7. O_2 debt--a deficit in oxygen intake during exercise that must be repaid during a recovery period.

8. Per cent of inclination--the angle of the treadmill expressed in the per cent of vertical rise for distance walked, which is figured from the tangent of the angle made by the walking surface and the base of the treadmill.

9. Pulmonary ventilation--liters of air expired per minute.

10. Quadratic relationship--a relationship involving the swuare and no higher power of the unknown quantity.

11. Recovery expenditure--the energy expended during a fifteen minute recovery period munus the resting energy expenditure.

12. Respiratory quotient--the ratio of the volume of carbon dioxide produced to the volume of oxygen consumed.

13. True oxygen--the number of milliliters of oxygen consumed for every one hundred milliliters of air expired.

14. Work expenditure--the energy expended while working minus the resting energy expenditure.

15. VO_2--oxygen consumption in milliliters per minute.

CHAPTER II

RELATED RESEARCH

I. VARIABLES AFFECTING ENERGY EXPENDITURE DURING WALKING

Caloric outputs vary greatly among individuals. This became apparent to investigators when it became possible to compute the caloric expenditure from the carbon-dioxide produced and the oxygen consumed by subjects. Methods developed by Zuntz for experiments conducted from 1896 to 1904 are still used to determine the caloric expenditure of subjects. Through the years, experiments have revealed many factors such as body structure, mechanics, speed and grade, that have a bearing on the expenditure during walking. Several factors that are related to energy expenditure during walking are discussed in this report.

Body Structure

Weight. Weight has been shown to be linearly proportional to the energy expenditure during walking and running. Mahadeva, Passmore and Woolf (12) show this relationship with data on fifty subjects. Taking age, sex, race or resting metabolism into consideration did not increase the precision of an individual energy assessment in their experiments. A study by Roninson also indicates a linear relationship between weight and energy expenditure while walking. In each subject that Robinson (14) studied, heat was produced in proportion to body weight.

In his tests to determine a formula for predicting energy expenditures, Bobbert (3) assumed that a linear relationship existed between body weight and energy expenditure. Tests by numerous investigators before him had shown this to be true.

Apparently, weight has the same effect whether it is intrinsic or extrinsic. Goldman and Impietro (10) concluded tentatively that the energy cost per unit of weight is about the same whether or not the weight is from the external load or of the body itself. Brezina and Kolmer, as related by Smith (18), had previously drawn this conclusion from their experiments.

Stature. Studies by Seltzer (16) indicate a relationship between the morphology of individuals and their consumption of oxygen. "Linear" subjects had a higher intake of oxygen when in the resting state than did "lateral" subjects. The "lateral" subjects showed a greater degree of mechanical efficiency during moderate exercise than did the "linear" ones. The "linear" subjects showed a higher capacity for supplying oxygen to the tissues during strenuous work on the treadmill. "Linear" subjects are those with short upper and lower extremities, long torsos, flat chest outlines, and narrow hips relative to breadth of shoulders (16).

Environment

Moderate changes in the environment do not appear to affect energy expenditure during walking. Durnin (8) conducted experiments with ten men and ten women. While walking on the treadmill, the subjects showed no measurable differences in their energy expenditures due to external temperature or barometric pressure. Durnin varied atmospheric pressure from twenty to thirty millimeters of mercury and temperature over a range of several degrees centigrade.

Step Lift

Benedict (2) felt that the type of step used in walking might be a very important factor in the energy expenditure. He tested one man while he was walking on the treadmill at an average speed. The total vertical distance per minute that the man raised his body was calculated by counting his steps and using the records of Dr. Tigerstedt's tracing pointer. The subject raised his body in a vertical direction an average of 3.78 meters per minute. Since his weight was seventy-three kilograms, the work equivalent was 0.65 Calories per minute. Walking added 2.81 Calories per minute to the standing metabolism. From these findings, Benedict (2) calculated that about 23 per cent of the energy expended in walking was used to raise the subject's body vertically.

Smith ran similar tests using eight subjects. Walking at average speeds, the step lifts of the subjects caused an 8 to 14 per cent rise in energy expenditures. These experiments showed that the lift per step--the vertical lift of the trunk as measured from a waist belt (6)--increased with higher grades and speeds. For example, the lift per step for one subject was 1.18 centimeters for horizontal walking and between six and seven centimeters for the higher grades and speeds. The increase in the lift per step was accompanied by an increase in energy expenditure (18).

Cotes and Meade (6) found that the energy expenditure of walking on the horizontal treadmill at natural step frequency was linearly related to the vertical lift work. Lift work is the product of lift per step, step frequency and body weight. They derived a formula to find the vertical lift, which is based on the assumption that vertical lift per step is a geometric function of the length of the leg, foot and pace (6). The relationship between energy expenditure and vertical lift work does not exist when the step frequencies are faster or slower than those chosen spontaneously (6).

Mechanical Factors

Winsmann and his associates (20) ran tests on a group of soldiers wearing armored vests and carrying packloads while walking on a treadmill, on a level course and on mountain slopes. In almost all tests, the eight pound vests added about 6 per cent to the metabolic cost of walking whether or not the subjects carried forty pound packs. There was no measurable difference between treadmill walking and actual walking conditions.

Ralston's data from tests comparing floor walking with treadmill walking support this finding. Ralston (13) concluded that no significant difference existed between the two.

Other Variables

Durnin (8) tried to determine what effect a number of factors had on energy expenditure. He calculated the energy expenditures for ten men and ten women while they were performing four activities--lying, sitting, horizontal walking on a treadmill at a speed of 3.2 miles per hour, and walking at a speed of 2.7 miles per hour on a 10 per cent slope. He concluded that there were no measurable effects due to the specific dynamic action of the midday meal, practice in the use of the apparatus, emotion, time of day or day.

From a study of the energy expenditures of fifty-four young men, Erickson (9) noticed a slight variability between days amounting to 2.57 per cent of the mean, which is not significantly different from the 3.12 per cent variability which he found within an experiment. Erickson also noted that training does bring about a slight increase in walking efficiency. It was noted that subjects should have at least one

:e the results of walking experiments are used.

II. RELATIONSHIP OF SPEED AND GRADE TO ENERGY EXPENDITURE DURING TREADMILL WALKING

Smith (18) studied the efficiency of work during walking in relation to gradelift. On a 3.6 per cent grade the efficiency was approximately 40 per cent, and the subjects performed less than two hundred kilogram-meters of work. On a low grade, the average efficiency was 33.4 per cent. Increasing the speed at a given grade caused a decrease of efficiency as well as an increase in the energy expenditure. In comparison, results of tests by Zuntz, Durig and their associates (18) showed that men walking from 12.68 per cent to 36.2 per cent grades had net efficiencies that ranged from 25.7 per cent to 46.5 per cent.

Erickson and his associates (9) noted that their two subjects expended much more energy during grade walking at 2.5 to 4.0 miles per hour than during horizontal walking at these same speeds. They used Zuntz' method of computing climbing efficiency, wherin the caloric equivalent of the absolute amount of body lift is divided by the difference of energy expenditure between grade and horizontal walking (9). Benedict and Murschhauser, Smith and others have used this method. Erickson found that in his two subjects the highest climbing efficiency was reached at a grade of 5 per cent.

Erickson's (9) study pointed toward a curvilinear rather than a linear relationship between energy expenditure, speed and grade during treadmill walking. Bobbert (3) also found that energy expenditure increases curvilinearly with increasing speed and grade.

It appears that in horizontal walking the energy expenditure is proportional to the square of speed. Ralston (13) stated this belief from his own data and from previous literature. Bobbert (3) found this statement true for grade walking as well as for horizontal walking.

Bobbert (3) developed a formula for calculating energy expenditure per kilogram of body weight for groups of normal adult males walking on a treadmill at speeds ranging from 35 to 115 meters per minute and grades from zero to twelve degrees. He used the preceding grades and speeds for testing his two subjects because they are the ones most frequently employed in ergometry. From his data, he concluded that "Ew increases with the square of speed both in level and grade walking and that log Ew increases linearly with the geometric angle" (3). To test the validity of this formula, Bobbert took data from previous literature and found the results predicted by his regression equation were highly correlated with the actual results.

Another empirical formula was developed by Balke (1) for estimating oxygen consuption during treadmill walking. From tests on a large group of subjects, he found the oxygen intake to be almost linearly related to the increase in work performance. For the performance of one kilogram-meter per minute, the average consumption was found to be 1.8 milliliters. Balke's (1) formula states that:

$$VO_2 = v \cdot w \cdot 1.8\ (0.73 + \frac{oc}{100})$$

Where VO_2 = estimated O_2 consumption in milliliters per minute;
v = treadmill speed in meters per minute;
w = body wight in kilograms;
oc = angle of treadmill in per cent;
.073 = factor most closely assessing the vertical lifting of weight durning horizontal walking;
1.8 = average consumption of oxygen in milliliters for a performance of one kilogram-meter per minute.

CHAPTER III

PROCEDURES OF THE STUDY

I. SUBJECTS

Eight male students who were enrolled at Montana State University volunteered to be subjects for this study. The subjects varied in age from 19 to 33 years, with a mean age of 24.1 years. Height of the subjects varied from 169.64 to 203.20 centimeters, with a mean height of 179.71 centimeters. Weight varied from 61.9 to 88.6 kilograms, with a mean weight of 75.5 kilograms. The Dubois body surface area of the subjects ranged from 1.91 to 2.29 square meters, with a mean of 1.97 square meters. The anthropometric measurements of the test subjects are found in Table I.

TABLE I

ANTHROPOMETRIC MEASUREMENTS OF TEST SUBJECTS

Subject	Height (Centimeters)	Weight (Kilograms)	Age	Body Surface Area (Sq.m.)
I. J.	175.26	73.7	33	1.97
R. L.	175.26	61.9	22	1.83
D. M.	177.80	72.8	19	1.91
C. M.	167.64	79.5	28	1.91
G. N.	172.72	77.5	29	1.92
H. P.	182.88	71.4	20	1.93
J. S.	182.88	78.8	22	2.01
T. S.	203.20	88.6	20	2.29
Mean	179.71	75.5	24.1	1.97

II. EQUIPMENT AND APPARATUS

Treadmill

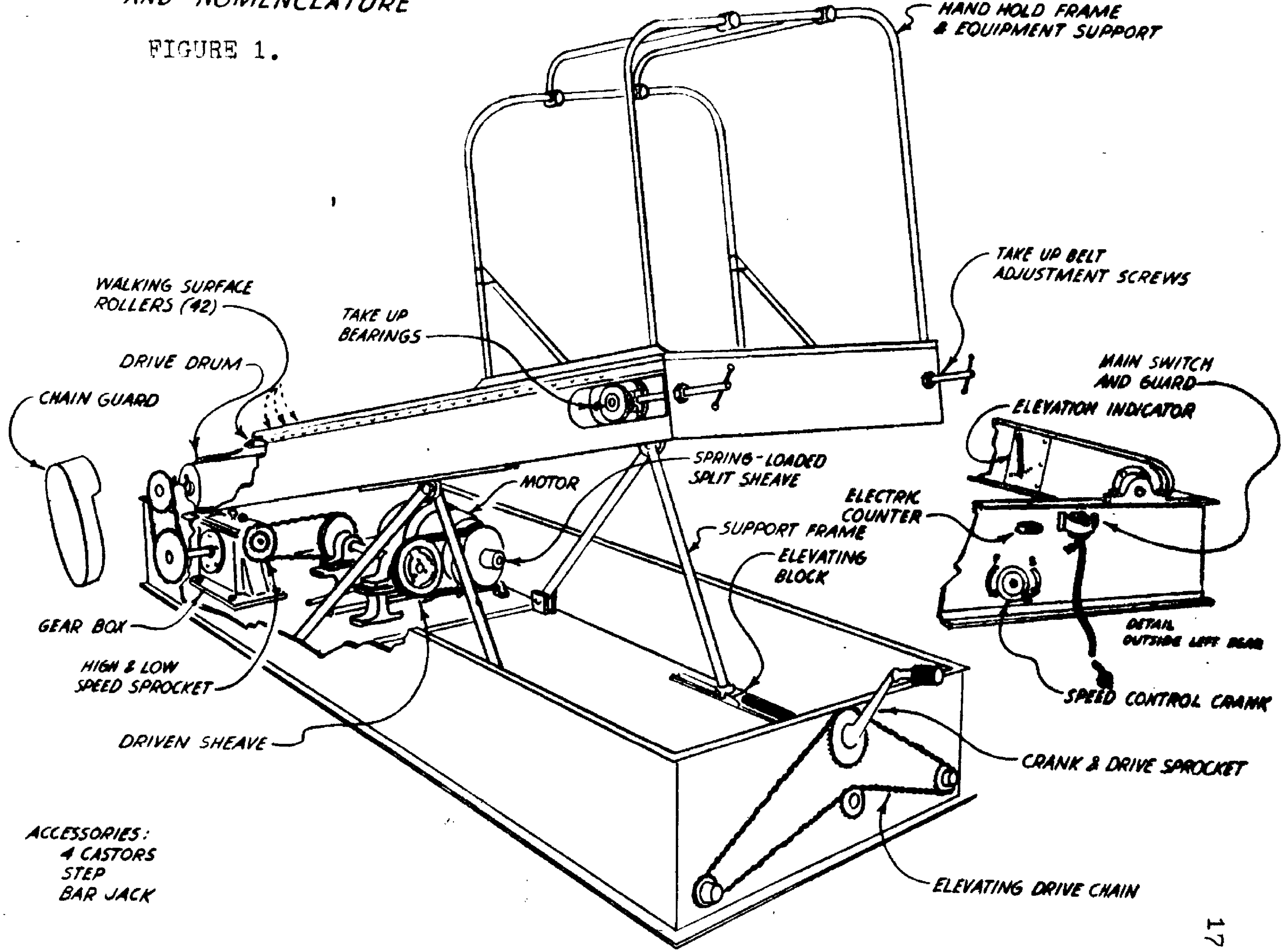
Subjects walked on a motor-driven treadmill which was constructed by the Missoula Equipment Development Center, United States Forest Service. The walking surface was a three by eighteen foot Goodyear Wedgegrip belt that was turned over forty-two 1.9-inch diameter rollers. The walking surface was 48 inches wide and 108 inches long. Treadmill speed could be varied from one-half to ten miles per hour, and grades could be varied from 0 per cent to 51 per cent (19). Treadmill components and nomenclature can be found in Figure 1.

Gas Collection Apparatus

The open circuit method for the collection of expired gases was used because of its adaptability to treadmill experiments. A diagram of the collection apparatus is shown in Figure 2. During air collection the subject wore a face mask that fit over his nose and mouth. The mask contained a valve (AV_1) which enabled the subject to inhale air from the atmosphere and exhale into the collection chambers through rubber hoses (H) and a network of pipes (P). The expired gases were collected in a Tissot Gasometer (G) and two Douglas bags (DE). Two three-way valves (MV_1, MV_2)

TREADMILL COMPONENTS
AND NOMENCLATURE

FIGURE 1.



were positioned so that expired air could be directed into a pipe leading to the Douglas bags (P_2), into a pipe leading into the gasometer (P_5), or into a pipe leading into the atmosphere (P_4). The manual valves (MV_3, MV_4) were located above the Douglas bags so that the expired air could be channeled into either of the Douglas bags or into the atmosphere.

Gas Analysis Apparatus

Micro-Scholander Analyzer. Samples of air were taken from the gas collection chambers and analyzed to find the per cent of oxygen, carbon dioxide and nitrogen by use of the micro-Scholander (15) method. The sample was introduced into the reaction chamber that was connected to a micrometer burrett. The absorbing fluids, which were located in the side arms, were introduced into the reaction chamber by tilting the apparatus. In this way, the carbon dioxide and oxygen were absorbed without any change in the total content of the system. Changes in volume were measured in terms of micrometer divisions, and from these changes the per cent of carbon dioxide and oxygen was calculated. The per cent of nitrogen was determined by subtracting the sum of the per cent of oxygen and the per cent of carbon dioxide from 100 per cent.

Because the accuracy of the micro-Scholander apparatus

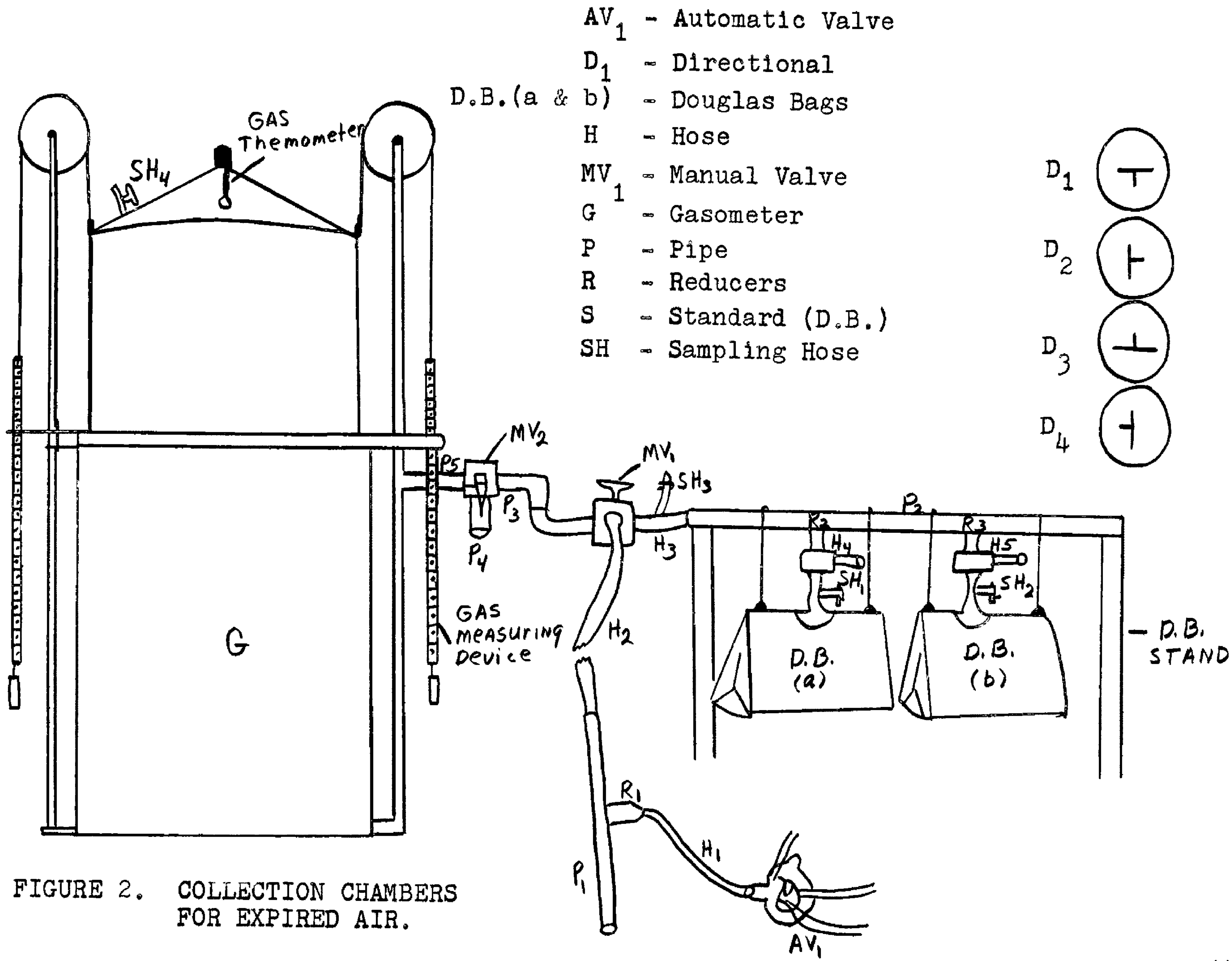


FIGURE 2. COLLECTION CHAMBERS FOR EXPIRED AIR.

is as acceptable as older methods of gas analysis, and the time consumed while taking an analysis is shorter than with those methods, this method was suitable for all measurements of gas samples during this study. The per cent of oxygen, carbon dioxide and nitrogen in 0.5 cubic centimeter samples or less can be determined to an accuracy within plus or minus 0.05 volume per cent. It will handle samples containing from 0 to 99 per cent absorbable gases. The time taken to run one analysis was from six to eight minutes.

Miscellaneous Measurement Apparatus

Pulse Rate. The pulse rate was measured at the radial pulse. Each measurement was taken for fifteen seconds, then multiplied by four to give pulse beats per minute.

Blood Pressure. A mercury sphygmomanometer was used to measure blood pressure. It was wrapped around the right upper arm so that the pressure change was read at the brachial artery.

Barometric Pressure. A mercury barometer was used to measure atmospheric pressure. The measurement was taken each time an air sample was taken.

Height and Weight. A balance scale with an attached stadiometer was used to measure the height and weight of each subject. The measurements obtained were then converted from English into metric measurements.

Gas Temperature. All gas temperatures were measured by the thermometer in the gas chamber of the Tissot Gasometer. The location of this thermometer may be seen in Figure 2. The temperature was taken at the time the volume of each sample was measured.

III. SELECTION OF GRADE AND SPEED

Grade

In treadmill tests by Balke (1) and in similar tests by Bobbert (3) for developing their predictive formulas, the grades used were between 1 and 21 per cent. Since this study was more interested in the higher levels of treadmill walking, it was necessary to choose the highest grade possible that would permit a uniform walking period. From trials during which subjects walked at various grades in pilot tests, it was found that 25 per cent was the highest grade at which most subjects could walk for fifteen minutes at the selected speed. Grades of 15, 20 and 25 per cent were then selected for the actual testing. This gave one grade (25 per cent) that was higher than those used by Bobbert and Balke during the testing of their predictive formulas. The other two grades were comparable to grades used by Bobbert and Balke.

Speed

Erickson (9) found that the net efficiency while treadmill walking was highest at speeds of 3.0 to 3.5 miles per hour. From other studies, it was found that speeds ranging from 2.7 to 4.0 miles per hour were most frequently employed during treadmill experiments. After pilot tests in which various combinations of speed and grade were used, a speed of three miles per hour was chosen.

IV. TESTING PROCEDURES

Test Preparation

Before beginning the actual tests, the eight subjects walked for thirty minutes at each different grade used. The first test for each subject was on the 15 per cent grade, the second test was on the 20 per cent grade and the final test was on the 25 per cent grade.

Before each test, the treadmill was checked for adjustment to correct speed and grade. A scale was devised so that miles per hour could be read from the scale by knowing the time it took for six revolutions of the treadmill. Six revolutions were chosen as a timing basis because this lessened the chance of timing error that would arise with less revolutions and seemed an adequate allowance for normal treadmill variability. The grade was adjusted by either cranking the treadmill up or down until the grade indicator attached to its side showed the desired grade in per cent of inclination. The treadmill was leveled on the floor prior to beginning the study to assure that the grade indicator would be accurate.

The Douglas bags were rolled up to be sure all atmospheric air had been forced out. All valves were checked to make sure they were open toward the proper direction. An equipment check list was referred to before each test so that none of the important items would be overlooked.

Testing Period

The testing period lasted forty-five minutes. The first fifteen minutes, or pre test period, was a period of rest in which the subject sat quietly beside the treadmill so that he would attain a resting rate of energy expenditure. During the second fifteen minute period, or test period, the subject walked at a set grade and speed. Following the test the subject had a fifteen minute recovery period during which he sat beside the treadmill. The object of this post test period was to determine oxygen debt. A work sheet which included space for recording data from all three periods of the test was completed for each subject. A sample work sheet is shown in Appendix A.

Pre Test Period. Just prior to the pre test period, the subject was weighed while wearing gym clothes and tennis shoes, and his height was measured. This data was recorded on the test work sheet.

The pulse rate was taken after one, five, ten and fifteen minutes. Blood pressure was taken after fifteen minutes of rest. During the last five minutes of the pre test period, the subject breathed through the face mask, which he wore for the remainder of the test. His expired air was collected in the gasometer, and the volume recorded after each minute of collection. The temperature of the gas collected in the gasometer was read after the end of the collection period. A sample was drawn from the gasometer into a sampling tube.

Test Period. On signal, the subject began his walk on the treadmill. Valves MV_1 and MV_2 (Fig. 2) were placed in positions D_4 and D_2 (Fig. 2) respectively during the first seven minutes of the test period so that the expired air was released back into the atmosphere. From the eighth through the ninth minute of the test, the gasometer was rinsed with expired air three times to replace the small amount of atmospheric air it contained at the beginning of the test. During this rinsing, the expired air was directed back into the atmosphere by closing valves MV_3 and MV_4 (Fig. 2) from the Douglas bags. At the beginning of the tenth minute of walking, the valves MV_1 and MV_2 (Fig. 2) were placed in positions D_4 and D_3 (Fig. 2) respectively so that the expired air could be directed into the gasometer. The collection period lasted from three to five minutes, depending upon the ventilation rate of the subject and the grade of the treadmill. While walking at the upper grades of the treadmill, the subjects' ventilalation rate increased and caused the gasometer to be filled sooner. If the collection period was stopped before the usual three minute walking period was over, the subject continued walking until the fifteen minutes were completed. In these cases, the expired air was directed back into the atmosphere. The volume was read from the gasometer measuring stick (Fig. 2) at one minute intervals during the collection period and was utilized in computing ventilation rate. Also, the temperature of the collected gas was recorded.

Post Test Period. At the completion of the fifteen minute walking period, the subject sat on a stool beside the treadmill with the mask still on, and the expired air was directed through valves MV_1, MV_3 and MV_4 (Fig. 2) into the Douglas bags, while the test period sample was drawn from the gasometer. After the sample was drawn and the gasometer flushed out, the expired air was directed into the gasometer for collection during the remainder of the post test.

Following the fifteen minutes of recovery, the volume of expired air was measured. A sample was then drawn into the sampling tube through SH_4 (Fig. 2). After this, the expired air in the Douglas bags was transferred to the gasometer while a sample was drawn through SH_3 (Fig. 2). After all of the expired air had been transferred from the Douglas bags to the gasometer, the volume and temperature were recorded.

Pulse rate and blood pressure measurements were taken at various intervals during the post test.

Barometric pressure was recorded immediately after the samples were drawn.

Calculation for Energy Expenditure

Energy expenditure was computed for each of the four collection periods--pre test, test, post test (Douglas bags) and post test (gasometer). An energy expenditure work sheet which shows the needed information and the steps involved in arriving at the amount of energy expended may be found in Appendix B. The formulas used were taken from Consolazio, Johnson and Pecora (5). Below are the three steps used in computing energy expenditure:

1. Pulmonary ventilation or liters of air expired per minute was determined by subtracting V_1 from V_2, then multiplying the result times the Tissot factor (5.158) and that result times the Standard Temperature Pressure Dry factor. The STPD factor was obtained from charts included in the book by Consolazio, Johnson and Pecora (5). This result was then divided by the number of minutes for which the sample was taken.

$$PV = \frac{V_2 - V_1}{\text{min.}} \cdot 5.158 \cdot \text{STPD Factor}$$

2. The true oxygen was computed by multiplying the per cent of nitrogen in the expired air times

0.265, and then subtracting the per cent of oxygen in the expired air from this sum. The answer was then multiplied by the pulmonary ventilation and divided by 100 to give the true oxygen.

$$VO_2 \text{ consumed} = \frac{PV}{100} (\%\text{ N expired air} \cdot 0.265 - \%O_2).$$

3. The energy expenditure in kilocalories per minute per kilogram of body weight was computed by multiplying the true oxygen times 5 (one liter of oxygen consumed is assumed to be equal to 5 kilocalories) and dividing by kilograms of body weight.

$$\text{kcal./min./kgm. body weight} = \frac{VO_2 \cdot 5}{\text{kgm. body weight}}$$

CHAPTER IV

ANALYSIS AND DISCUSSION OF RESULTS

I. INTRODUCTION

The following chapter presents the analysis of the data that was obtained while running energy expenditure experiments on eight male subjects. The main purpose of the experiments was to compare the actual measurements of energy expenditure for each subject with the predicted values obtained from formulas developed by Balke (1) and Bobbert (3). This data can be found in Table VII and will be discussed later in this chapter. Along with the measurements of energy expenditure, other basic data was obtained and analyzed in order to gain a truer picture of the experiment as well as to gain standardizing data for future use in treadmill experiments. This data is also presented in this chapter.

II. ANALYSIS OF RESULTS

The pulse rate and blood pressure measurements are included in Appendix D and Appendix E.

Pulmonary Ventilation

Because the human body has the ability to regulate pulmonary ventilation in relation to its oxygen requirements, investigations have been made to find out if pulmonary ventilation can be used as an index of energy expenditure (5). Consolazio (5) reviewed investigations of this nature by Durnin and Edwards in 1955 and by Ford and Hellerstein in 1959. Formulas were developed from these investigations which proved fairly accurate between the ventilation range of fifteen to fifty liters per minute.

Karpovich (11) found that the pulmonary ventilation varied at rest from three to ten liters per minute, with the average being eight liters per minute. The eight subjects tested by the writer ranged from 6.86 to 14.77 liters per minute with an average of 9.48. For comparison of pulmonary ventilation and energy expenditure, the figures can be found in Table IV.

<u>Respiratory Quotient</u>

When using indirect calorimetry as a means for measuring energy expenditure, it is necessary to determine the heat equivalent of the oxygen consumed since there is no direct measurement of heat production as is found during direct calorimetry. Since the heat produced when consuming a liter of oxygen varies with the type of food the body is using for fuel at the time, it is necessary to determine the type of food being burned to arrive at the true heat or caloric equivalent. The determination of this factor is

TABLE IV

PULMONARY VENTILATION*

Subject	Pre Test	Test	Post Test
	15 Per Cent Grade		
I. J.	9.06	51.45	13.33
R. L.	8.58	41.11	10.02
D. M.	10.09	48.93	16.31
C. M.	8.64	64.78	18.81
G. N.	6.86	48.10	12.49
H. P.	7.75	41.89	11.49
J. S.	9.77	55.96	15.12
T. S.	10.46	62.91	16.86
Mean	8.90	51.90	14.30
	20 Per Cent Grade		
I. J.	8.71	82.49	23.70
R. L.	8.73	45.59	11.15
D. M.	10.34	82.49	18.53
C. M.	10.99	110.39	26.86
G. N.	8.31	70.57	16.68
H. P.	9.61	85.79	19.93
J. S.	8.35	76.20	19.18
T. S.	14.77	84.91	17.76
Mean	10.00	79.80	19.22
	25 Per Cent Grade		
I. J.	9.21	100.62	16.49
R. L.	8.58	86.67	9.54
D. M.	9.63	71.16	12.99
C. M.	11.48	108.25	29.23
G. N.	7.56	82.63	14.74
H. P.	9.47	87.93	21.05
J. S.	9.65	106.15	23.73
T. S.	10.94	97.30	20.71
Mean	9.60	92.60	18.56
Grand Mean	9.48	78.90	17.36

*Pulmonary ventilation is expressed as liters of air expired per minute. The volume of air has been reduced to STPD.

brought about by computing the respiratory quotient, which is expressed as the ratio of the carbon dioxide produced to the volume of oxygen consumed (5).

The respiratory quotient has a usual range of one down to 0.7, depending upon the type and combination of foodstuffs. If only carbohydrates are being used, the respiratory quotient is 1; if only fats, it is 0.7; and if only protein, it is 0.81. With a normal mixture of these foods, the average respiratory quotient is 0.82. At times the respiratory quotient can go beyond 1 to as high as 1.5. This could indicate the transformation of carbohydrate, which is oxygen-rich, into fat, which is oxygen-poor, or could result from hyperventilation and the blowing off of carbon dioxide (7).

It has been a common practice for many investigators of energy expenditure to disregard the oxidation of proteins during exercises of short duration since the error involved is so small (11). If this is done, the heat equivalent when the respiratory quotient is calculated can be read from a standard table based on carbohydrates and fats alone. The table used in the present work is by Dukes (7).

Consolazio (5) uses the factor 5.0 as an energy value which represents the caloric equivalent of one liter of oxygen consumed during moderate activity. If this is done, then it is not necessary to calculate respiratory quotient when determining energy expenditure.

The writer calculated energy cost by both methods, first by computing respiratory quotient, then by obtaining the heat equivalent from Dukes' table. Energy expenditure was then calculated by assuming a heat equivalent of five. A comparison of these two can be found in Table VII. Energy expenditure ran slightly higher in all cases but two when using the assumption of five as the heat equivalent. The average heat equivalent based on respiratory quotient of subjects used in the tests was 4.87, which was below the average of five used by Consolazio.

The range of respiratory quotient calculated from the test results of the subjects used in the test by the writer was from 1.02 by subject J. S. on the 15 per cent grade to 0.74 by subject R. L. on the same grade. This gave a range of 5.07 to 4.73 respectively for the heat or caloric equivalents. All test respiratory quotients may be found in Table V. The total average test respiratory quotient was found to be 0.88, with an average of 0.88 during 15 per cent, 0.88 during 20 per cent and 0.87 during 25 per cent.

Work and Recovery Expenditures

Work and recovery expenditures were calculated for

TABLE V

TEST RESPIRATORY QUOTIENT*

Subject	15% Grade	20% Grade	25% Grade
I. J.	0.90	0.91	0.82
R. L.	0.85	0.74	0.85
D. M.	0.90	0.91	0.92
C. M.	0.83	0.77	0.80
G. N.	0.81	0.95	0.81
H. P.	0.89	0.99	0.87
J. S.	1.02	0.90	0.92
T. S.	0.86	0.86	0.91
Mean	0.88	0.88	0.87
Grand Mean for all Grades: 0.88			

*Consolazio's (5) formula for determining respiratory quotient is used:

$$R.\ Q. = \frac{\%CO_2 \text{ in expired air} - 0.03}{\%N_2 \text{ in expired air} \cdot 0.265 - \%O_2 \text{ in expired air}}$$

each subject. To find these values, the pre test or resting expenditure was subtracted from the test energy expenditure to find actual work expenditure, and the resting expenditure was subtracted from the post test expenditure to find recovery expenditure. These figures may be found in Table VI. The highest work expenditure was found on the 20 per cent grade by subject C. M.*, while the lowest work expenditure was found on the 15 per cent grade by subject J. S. The high was 0.397 kilocalories per kilogram per minute, and the low was 0.089. The highest recovery expenditure was found on the 25 per cent grade by subject J. S. The lowest recovery expenditure was found in subject D. M. on the 15 per cent grade. The high was 0.044 kilocalories per kilogram per minute and the low was -0.001.

Energy Expenditure

Energy expenditure was calculated for all subjects while walking on the treadmill at a speed of three miles per hour and at grades of 15 per cent, 20 per cent and 25 per cent. The calculations were figured by two different methods, each using a different value for the caloric heat

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*It is interesting to note that the subject who had the highest work expenditure is a scuba diver. Another scuba diver (I. J.) had the third highest work expenditure on all three tests.

TABLE VI

WORK EXPENDITURE AND RECOVERY EXPENDITURE*

Subject	Pre Test	Test	Post Test	Work Exp.	Rec. Exp.
		15 Per Cent Grade			
I. J.	.024	.178	.035	.154	.011
R. L.	.022	.184	.041	.162	.019
D. M.	.037	.161	.036	.124	-.001
C. M.	.023	.188	.042	.165	.019
G. N.	.020	.173	.038	.153	.018
H. P.	.020	.152	.027	.132	.007
J. S.	.022	.111	.034	.089	.012
T. S.	.022	.169	.035	.147	.013
Mean	.024	.165	.036	.141	.012
		20 Per Cent Grade			
I. J.	.023	.294	.060	.271	.037
R. L.	.027	.240	.035	.213	.008
D. M.	.033	.287	.049	.254	.016
C. M.	.028	.425	.059	.397	.031
G. N.	.025	.210	.042	.185	.017
H. P.	.028	.324	.061	.296	.033
J. S.	.021	.223	.051	.202	.030
T. S.	.035	.257	.044	.222	.009
Mean	.028	.257	.050	.255	.023
		25 Per Cent Grade			
I. J.	.021	.399	.054	.378	.033
R. L.	.026	.423	.044	.397	.018
D. M.	.021	.252	.038	.231	.017
C. M.	.024	.404	.067	.380	.043
G. N.	.022	.265	.037	.243	.015
H. P.	.027	.385	.064	.358	.037
J. S.	.019	.340	.063	.321	.044
T. S.	.026	.293	.048	.267	.022
Mean	.023	.345	.052	.322	.029
Grand Mean	.025	.256	.046	.239	.021

*Energy expenditures are expressed in kilocalories per kilogram per minute.

equivalent. In the first method, the caloric equivalent was assumed to be five calories per liter of oxygen consumed. This is an average used by many investigators (5). In the second method, the respiratory quotient was calculated and the caloric equivalent was read from a table by Dukes (7). Both actual measurements of energy expenditure were compared to the two different formulas by Bobbert (3) and Balke (1), for predicting energy expenditure. These comparisons may be found in Table VII.

Since the energy expenditures based on actual caloric equivalent were found to most closely resemble the predictive values of both Bobbert and Balke, these values for energy expenditure will be used when comparing the actual results with the predictive values.

Bobbert's formula expresses energy expenditure in calories per kilogram per minute. It is generally accepted in ergometric studies that the oxygen consumption is a truc measurement of energy expenditure, therefore, the oxygen consumption value was converted into calories per kilogram per minute by multiplying the oxygen times five (the caloric equivalent of one liter of oxygen).

On the 15 per cent grade, the predicted energy expenditure as calculated by Bobbert's formula was 0.154 calories per kilogram per minute. Balke's formula predicted an expenditure of 0.161. The work sheet used to compute

TABLE VII

ENERGY EXPENDITURE

Subject	15% Grade		20% Grade		25% Grade	
	A*	B**	A*	B**	A*	B**
I. J.	.178	.175	.294	.290	.399	.385
R. L.	.184	.178	.240	.227	.423	.412
D. M.	.161	.159	.287	.283	.252	.249
C. M.	.188	.182	.425	.405	.404	.388
G. N.	.173	.167	.210	.209	.265	.255
H. P.	.152	.150	.324	.327	.385	.376
J. S.	.111	.113	.223	.219	.340	.337
T. S.	.169	.165	.257	.251	.293	.289
Mean	.165	.161	.283	.276	.345	.336
Bobbert's Prediction	.154		.207		.276	
Balke's Prediction	.161		.198		.234	

*Energy expenditure expressed in kilocalories per kilogram per minute. One liter of oxygen consumed is assumed to equal 5 kilocalories.

**Energy expenditure expressed in kilocalories per kilogram per minute, using respiratory quotient and conversion tables from Dukes for assessing caloric equivalent.

predicted values of energy expenditure can be found in Appendix C. The difference between the two predictions for the 15 per cent grade was 0.007. The mean energy expenditure for the eight subjects was 0.161. This expenditure is the same as the one predicted by Balke, and only 0.007 higher than Bobbert's prediction. The range of energy expenditures went from a low of 0.113 by subject J. S. to a high of 0.182 by subject C. M. This gave a difference of 0.069 between the two.

The predicted energy expenditure for the 20 per cent grade was 0.209 by Bobbert's formula and 0.198 by Balke's formula. This gave a 0.009 difference between the two predictions. The subjects had a mean energy expenditure of 0.276. The expenditures ranged from a low of 0.209 by subject G. N. to a high of 0.405 by subject C. M. A difference of 0.196 was found between the low and high. Mean energy expenditure was 0.069 higher than Bobbert's prediction and 0.078 higher than Balke's prediction.

For the 25 per cent grade, Bobbert's formula predicted an energy expenditure of 0.276 and Balke's formula predicted 0.234. The difference between the two was 0.042. The eight subjects had a mean energy expenditure of 0.336. Subject D. M. had the low energy expenditure with 0.249, and subject R. L. had the high with 0.412. The difference between the high and low was 0.163. Bobbert's predicted expenditure was 0.060 lower than the mean, and Balke's was 0.102 lower.

III. DISCUSSION OF RESULTS

Energy expenditures were calculated for eight subjects who walked on a motor-driven treadmill at three different grades and at a constant speed. The results of these tests were compared to predictive values computed from two different formulas. One formula, which was developed by Bobbert for predicting energy expenditure while walking on a treadmill, gives energy expenditure in calories per kilogram per minute. The oxygen consumption predicted by Balke was converted into energy expenditure by changing milliliters into liters then multiplying liters times the average caloric equivalent of one liter of oxygen (five). The results of these measurements can be found in Table VII.

Factors such as age, weight, height, morphology, emotion, time of day, work load, type of walking surface and training are just some of the many variables that have been analyzed by past investigators to find out their effect upon measurements of energy expenditure. These factors were reviewed in Chapter II. Balke and Bobbert also took these factors into consideration when developing their individual formulas. Although most of these variables have little effect upon energy expenditure, when they are all taken into consideration one can see why there can be so much individual variation, giving a wide range of scores with different subjects taking the same test. Bobbert and Balke didn't expect to develop a formula for predicting all of the various scores on the wide range of energy expenditure scores, but instead they each picked out what they thought to be the main factors concerned with energy expenditure and combined these factors within a formula to predict oxygen consumption in Balke's case and energy expenditure in Bobbert's case. The factors taken into account by Bobbert were weight of subject, speed of treadmill and grade of treadmill. Balke used the same factors as Bobbert except that he also used a factor assessing step lift.

Fifteen Per Cent Grade

At the grade of 15 per cent the mean value for energy expenditure was 0.161 calories per kilogram per minute. Bobbert's formula predicted a value of 0.154 calories per kilogram per minute, while Balke's formula for oxygen consumption, when converted to calories per kilogram per minute, gave the same value as the actual mean of energy expenditure which was 0.161 calories per kilogram per minute. This grade is the only grade used that is in the range tested by both Balke and Bobbert when developing their formulas. Bobbert tested grades up to 21 per cent and Balke tested grades up to 18 per cent. For this grade both formulas were very successful in predicting energy expenditure, with only a 0.007 difference between predictions.

Twenty Per Cent Grade

The mean value for energy expenditure was 0.276 calories per kilogram per minute for the 20 per cent grade. Bobbert's predicted value was closest to this figure with a value of 0.207, giving a difference of 0.069. Balke's predictive value was 0.198 calories per kilogram per minute, giving a difference of 0.078. From the 15 per cent grade, Bobbert's value for energy expenditure has increased 0.053 calories per kilogram per minute while Balke's value has increased only 0.037 calories per kilogram per minute. Both formulas still agree closely in their predictions with only a 0.009 difference between the two, but now Bobbert's value has become the higher of the two.

Twenty-five Per Cent Grade

The mean value of energy expenditure at the grade of 25 per cent was 0.326 calories per kilogram per minute with Bobbert's most closely resembling this value with 0.276 calories per kilogram per minute. The difference between the two is 0.060 which gives a slightly closer prediction of energy expenditure at the 25 per cent grade by Bobbert than at the 20 per cent grade. Balke's predictive value dropped further away from the actual mean value with a prediction of

0.234 calories per kilogram per minute which gives a difference of 0.102 calories per kilogram per minute from the actual measurement. Bobbert's value was increased to 0.042 calories per kilogram per minute more than Balke's prediction at the 25 per cent grade. Balke's values for energy expenditure increased at a steady pace with each increase in grade, with the increase between grades of 15 per cent and 20 per cent being 0.053 calories per kilogram per minute and the difference between grades of 20 per cent and 25 per cent being 0.069 calories per kilogram per minute.

Bobbert (3) used a regression equation in predicting energy expenditure; therefore, he gave a different numerical weight to the three factors of speed, grade and body weight. For this reason, his values for energy expenditure do not necessarily rise at an even pace. Since in Bobbert's equation he assesses more numerical weight to the grade than to the speed being used, when the grade rises and the speed remains constant, the value for energy expenditure will increase more than if the speed was increased and the grade remained constant. Balke's (1) formula does not place numerical weights to the factors of speed and grade, therefore, his values are more uniform in their ascent. Since Bobbert does take into consideration that an increase in grade does raise energy expenditure more than an increase in speed, this is probably the reason that Bobbert's formula is more valuable in predicting energy expenditure at the higher grades of 20 and 25 per cent.

With an increase in the amount of subjects, it is very probable that the predictive values of both investigators would more closely resemble the mean values of energy expenditure. Even though the small number of subjects used provided more chance for deviation from the mean, the predictive values still proved very accurate at the 15 per cent grade and gave a fair prediction of the higher grades.

The graph in Figure 3 shows how the actual test results compare with the results predicted by Balke and by Bobbert in their formulas.

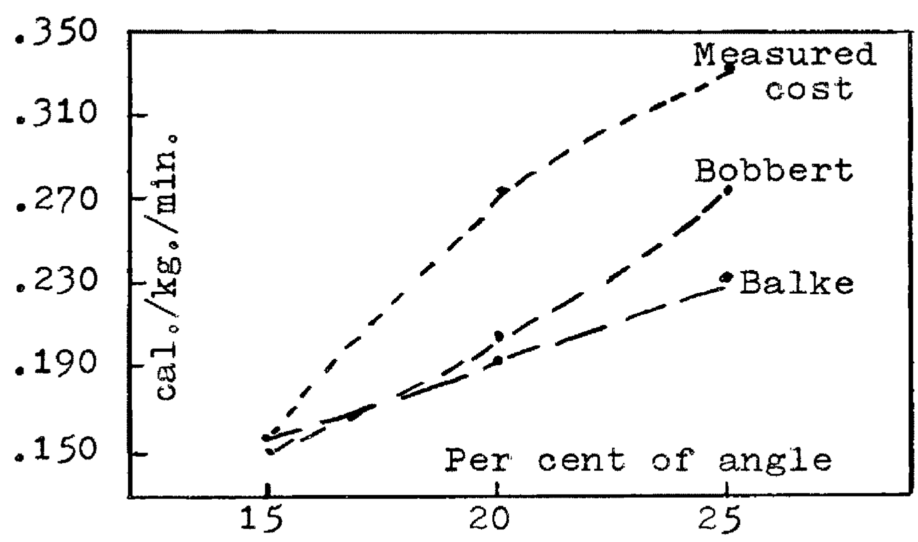

FIGURE 3

A COMPARISON OF THE PREDICTIVE FORMULAS OF ENERGY COST BY BALKE AND BOBBERT AND MEASURED ENERGY COST AT THE 15%, 20% AND 25% GRADES

Comparison of Energy Expenditure with Related Data

Consolazio (5) noted when reporting on pulmonary ventilation that the body has a remarkable ability to regulate pulmonary ventilation to oxygen requirements. Because of this relationship, investigations have been made to determine whether it was possible to use pulmonary ventilation as a prediction of energy expenditure. Consolazio (5) reported that Durnin and Edwards (1955) and Ford and Hellerstein (1959) both investigated the possibility of using pulmonary ventilation as an index of energy expenditure.

In the present test, pulmonary ventilation does seem to have a linear relationship to energy expenditure in some instances. Subject C. M. had the highest energy expenditure in two of the tests and was second highest in the other test. He had the highest rate of pulmonary ventilation in all three tests. Subject I. J. had the third highest energy expenditure on all three tests, and he had the third highest pulmonary ventilation on one test and the fourth highest on the other two tests. Subject H. P. had the second lowest energy expenditure on the 15 per cent grade and the second lowest pulmonary ventilation. On the 20 per cent grade, he had the second highest expenditure as well as the second highest pulmonary ventilation. His expenditure on the 25 per cent grade was fourth highest and his pulmonary ventilation fifth highest. The relationship between the mean pulmonary ventilations and the mean energy expenditures may be seen in Figure 4.

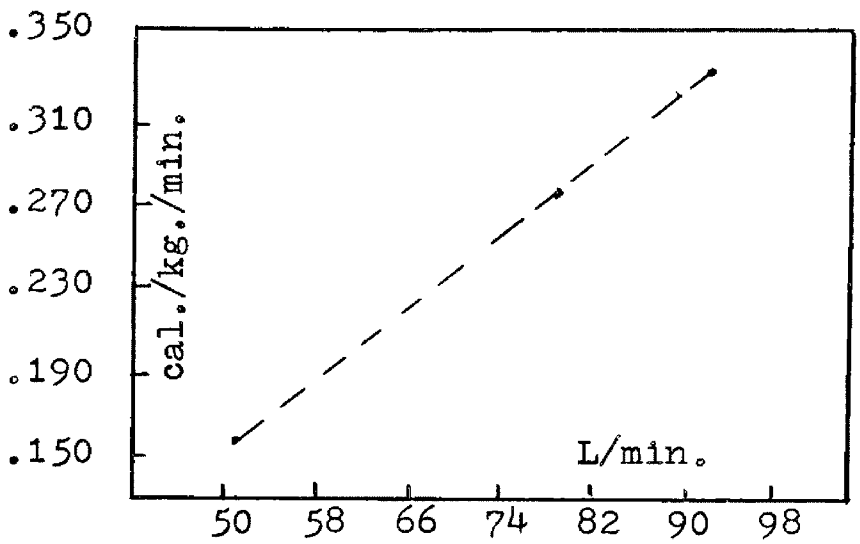

FIGURE 4

RELATIONSHIP BETWEEN MEASURED ENERGY EXPENDITURE (cal./kg./min.) AND PULMONARY VENTILATION (liters/min.)

According to Seltzer, body build plays a part in energy expenditure. In the present study subject C. M. had the highest energy expenditure on two grades and the second highest on the other grade. He has a short stocky body build with a height of 168 centimeters and a weight of eighty kilograms. Subject J. S. had the lowest energy expenditure on one grade, the second lowest on the second grade and the fourth lowest on the third grade. He has a tall slender body build with a height of 183 centimeters and a weight of seventy-nine kilograms.

In several instances recovery expenditure seems to be related to energy expenditure, but there is not a definite trend.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

I. SUMMARY

Actual energy expenditure measurements were calculated from the test results of eight subjects. The tests were run on a motor-driven treadmill at three different grades (15 per cent, 20 per cent and 25 per cent) with a constant speed of three miles per hour. The method of calorimetry used was the open, indirect type.

Results of energy expenditure found during the actual tests in calories per kilogram per minute were compared to predictive values derived from two formula, one developed by Bruno Balke, the other by A. C. Bobbert, to find which formula could best predict energy expenditure at the three given grades.

Other miscellaneous data was compiled from measurements taken during the tests and was analyzed so that trends related to energy expenditure could be discussed. Since this was the first year that the treadmill was used at Montana State University and since it was a new treadmill, it was of interest to develop basic standardizing data characteristic of the present treadmill and to develop a standardized method for running tests on energy expenditure. The table in Appendix F contains the pulse rate, blood pressure, pulmonary ventilation and energy cost measures as well as a summary of basic control data.

II. CONCLUSIONS

1. Predictive formulas for energy cost most closely resembled the actual results of this test at the 15 per cent grade, with Balke's values being the closer.

2. When taking into account all three grades, Bobbert's formula becomes the best prediction for the test results.

3. Variables become more pronounced with a raise in grade.

4. Energy expenditure measurements of all subjects more closely resemble the predictive values when the caloric equivalent is computed individually rather than by assuming the caloric equivalent of five calories per liter of oxygen consumed.

III. RECOMMENDATIONS

1. In future measurements of energy expenditure, it is suggested that the caloric equivalent be computed individually by obtaining the respiratory quotient rather than using an average for this measurement.

2. It is suggested that the formulas of Bobbert and Balke for predicting energy expenditure be compared further by conducting tests on a level grade while varying the speed of the treadmill.

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APPENDIX

APPENDIX A

Sample Work Sheet

Subject G. N.

Height 5' 8"

Weight (with clothes) 168 lbs.

Time 3:30 p. m.

Date June 17, 1963

Experimental Conditions
20 per cent grade at 3 mph.

Barometric Pressure
67 mm.

Pre Test:

Ventilation Readings Container--Gasometer	Heart Rate	Blood Pressure
10 min. 20.3	1 min. 15	15 min. 120/88
11 min. 22.3	5 min. 15	
12 min. 24.3	10 min. 17	
13 min. 26.1	15 min. 20	Temp. of Sample 25.8° C.
14 min. 27.5		Volume Collected 9.1
15 min. 29.4		

Test:

Ventilation Readings
Container-Gasometer

25 min. 20.2	27 min. 58.9	29 min. 95.6
26 min. 39.1	28 min. 77.5	30 min. 112.5

Temp. of Sample 25.8° C.   Volume Collected 92.3

Post Test:

Blood Pressure 40 min. 104/70
45 min. 108/76

Ventilation Readings
Container--Doug. Bags

30 min. 20.7
37 min. 63.7

Volume Collected 43.0
Temp. of Sample 25.8° C.

Container--Gasometer		Heart Rate
38 min. 20.3	42min. 31.2	31 min. 29
39 min. 23.4	43 min. 33.3	32 min. 26
40 min. 26.0	44 min. 35.7	33 min. 26
41 min. 28.8	45 min. 37.9	34 min. 24
		35 min. 24
Volume Collected 17.6		40 min. 24
Temp of Sample 25.8° C.		45 min. 23

APPENDIX B

Energy Expenditure Work Sheet

Subject Galen Nusbaum Grade 15%

Per Cent O_2	15.610
Per Cent CO_2	4.525
Per Cent N.................	79.865
Body Weight (kgms)..........	77.
Volume of Sample (V_2-V_1)...	58.8
Temperature of Sample......	24.2
Barometric Pressure	67.4
Time of Sample.............	5
STPD Factor................	0.793

1. Pulmonary Ventilation $= \frac{V_2 - V_1}{\text{mins.}} \times 5.158 \times \text{STPD Factor}$

$= \frac{58.8}{5} \times 5.158 \times 0.793 = \text{PV } 48.102$

2. VO_2 Consumed $= \frac{PV}{100}$ (%N expired air x 0.265 - $\%O_2$ expired air)

$= \frac{48.102}{100} (79.865 \times 0.265 - 15.610)$

$= .481 \times 5.554 = VO_2\ 2.671$

3. Kcal./min./kgm.Body Weight $= \frac{VO_2 \times 5}{\text{kgm. Body Weight}}$

$= \frac{2.671 \times 5}{77} = \text{kcal./min./kgm.} = 0.173$

APPENDIX C

Work Sheet Used Compute Predicted Values of Energy Expenditure

Bobbert's Formula:

Grade 8.533°

log Ew = 1.4272 + (0.004591·v) + (0.024487·) + (0.0002658·v·)

= 1.4272 + (0.004591·80.467) + (0.024487·8.533) + (0.0002658·80.467·8.533)

= 1.4272 + .3694 + .2089 + .1825

= 2.1881

Ew = .1542 = cal·/kg·/min.

Balke's Formula:

Grade 15%

VO_2 = V·1.8 (.073 + $\frac{15\%}{100}$)

= V·1.8 (.223)

= 80.467 · .4014

VO_2 = 32.2994538 ml·/kg·/min.

VO_2 = .0322994538 liters/kg·/min.

Cal./kg./min. = VO_2·4.87

Cal./kg./min. = .161

APPENDIX D

TABLE II

PULSE RATE

Fifteen Per Cent Grade

Subject	I	II	III	IV	V
I. J.	84	112	96	28	12
R. L.	68	100	76	32	8
D. M.	80	120	92	40	12
C. M.	64	108	84	44	24
G. N.	64	96	84	32	20
H. P.	96	136	108	40	12
J. S.	76	124	100	48	24
T. S.	64	104	84	40	20
Mean	74.5	112.5	90.5	38	16.5

Twenty Per Cent Grade

Subject	I	II	III	IV	V
I. J.	88	132	108	48	24
R. L.	68	128	84	60	20
D. M.	68	136	96	68	28
C. M.	80	148	104	68	24
G. N.	64	124	88	60	24
H. P.	88	152	120	64	32
J. S.	108	140	116	32	8
T. S.	92	140	100	28	8
Mean	81.5	135	102	53.5	21

Twenty-five Per Cent Grade

Subject	I	II	III	IV	V
I. J.	92	128	100	36	8
R. L.	68	144	100	76	32
D. M.	68	120	96	52	28
C. M.	80	140	120	60	20
G. N.	76	120	96	44	20
H. P.	100	148	132	48	32
J. S.	80	136	108	56	28
T. S.	72	164	104	92	32
Mean	79.5	137.5	104.5	58	25
Grand Mean	78.5	128.3	99	49.8	20.8

I--Pre Test; II--Post Test (1 minute); III--Post Test (15 min.); IV--Difference between I and II; V--Dif. between I and III.

APPENDIX E

TABLE III

BLOOD PRESSURE*

Subject	Pre Test*	Post Test I**	Post Test II***
	15 Per Cent Grade		
I. J.	120/88	120/90	120/88
R. L.	124/92	120/86	124/90
D. M.	134/80	130/90	129/90
C. M.	118/76	118/80	110/70
G. N.	104/74	100/72	104/78
H. P.	112/70	110/80	112/72
J. S.	120/88	120/88	120/88
T. S.	118/80	118/70	118/72
Mean	119/81	117/82	117/81
	20 Per Cent Grade		
I. J.	120/88	114/76	116/74
R. L.	128/90	118/94	118/98
D. M.	134/80	130/86	134/88
C. M.	130/80	118/86	120/80
G. N.	118/82	124/90	120/82
H. P.	90/60	98/68	92/64
J. S.	114/86	106/76	104/78
T. S.	124/82	128/88	130/90
Mean	120/81	117/83	117/82
	25 Per Cent Grade		
I. J.	126/88	134/90	136/96
R. L.	120/88	116/72	116/72
D. M.	134/80	126/80	130/84
C. M.	124/72	124/84	120/80
G. N.	118/74	118/80	118/80
H. P.	100/70	80/60	88/60
J. S.	108/64	120/86	118/80
T. S.	118/80	114/78	110/76
Mean	119/77	117/79	117/79
Grand Mean	119/80	117/81	117/70

*Systole/Dyastole
**After 10 minutes of recovery
***After 15 minutes of recovery

APPENDIX F

TABLE VIII

SUMMARY OF CONTROL DATA AND EXPERIMENTAL MEASURES

Subject	Height (cm.)	Weight (kg.)	Age	Date 1963	Time (p.m.)	Rm. Temp. (°C)	Bar. Pres. (mm.Hg.)
15 Per Cent Grade at 3 m.p.h.							
I. J.	175	74	33	6-24	8:15	19.1	67.3
R. L.	175	62	22	6-25	4:30	19.2	67.4
D. M.	178	73	19	6-3	8:00	21.5	67.1
C. M.	168	80	28	6-19	9:00	25.1	66.8
G. N.	173	78	29	6-14	3:30	25.0	67.4
H. P.	183	71	20	6-18	4:20	27.5	66.8
J. S.	183	79	22	6-25	3:30	18.9	67.4
T. S.	203	89	20	6-27	1:30	21.0	66.6
Mean	180	76	24				
20 Per Cent Grade at 3 m.p.h.							
I. J.	175	74	33	6-20	8:00	24.0	66.4
R. L.	175	62	22	6-27	4:30	22.5	66.6
D. M.	178	73	19	6-20	7:00	24.1	66.4
C. M.	168	80	28	7-5	7:30	24.0	66.9
G. N.	173	78	29	6-17	3:30	25.0	66.8
H. P.	183	71	20	6-20	3:30	25.0	66.5
J. S.	183	79	22	7-2	4:00	24.2	66.7
T. S.	203	89	20	7-1	6:30	21.5	66.9
Mean	180	76	24				
25 Per Cent Grade at 3 m.p.h.							
I. J.	175	74	33	6-28	8:30	22.6	66.5
R. L.	175	62	22	6-28	4:00	22.5	66.5
D. M.	178	73	19	7-1	8:00	22.0	66.9
C. M.	168	80	28	6-28	7:30	22.8	66.5
G. N.	173	78	29	6-27	3:00	21.5	66.6
H. P.	183	71	20	6-26	4:00	20.0	66.8
J. S.	183	79	22	7-3	1:00	24.7	66.8
T. S.	203	89	20	7-3	4:00	22.0	66.8
Mean	180	76	24				

APPENDIX F

Subj.	Body Surface (sq. Meters)	Rest Pulse (min.)	Post Ex. 1 (min.)	Post Ex. 2 (min.)	Rest Bl. Pr. (mm.Hg.)	Post Ex. Bl. Pr. (mm.Hg.)	R.Q.	Rest P.V.(L./min.)
			15 Per Cent Grade at 3 m.p.h.					
I. J.	1.97	84	112	96	120/88	120/90	.90	9.06
R. L.	1.83	68	100	76	124/92	120/86	.85	8.58
D. M.	1.91	80	120	92	134/80	130/90	.90	10.09
C. M.	1.91	64	108	84	118/76	118/80	.83	8.64
G. N.	1.92	64	96	84	104/74	100/72	.81	6.86
H. P.	1.93	96	136	108	120/70	110/80	.90	7.75
J. S.	2.01	76	124	100	120/88	120/88	1.02	9.77
T. S.	2.29	64	104	84	118/80	118/70	.86	10.46
Mean	1.97	75	113	91	119/81	117/82	.88	8.90
			20 Per Cent Grade at 3 m.p.h.					
I. J.	1.97	88	132	108	120/88	114/76	.91	8.71
R. L.	1.83	68	128	84	128/90	118/94	.74	8.73
D. M.	1.91	68	136	96	134/80	130/86	.91	10.34
C. M.	1.91	80	148	104	130/80	118/86	.77	10.99
G. N.	1.92	64	124	88	118/82	124/90	.95	8.31
H. P.	1.93	88	152	120	90/60	98/68	.99	9.61
J. S.	2.01	108	140	116	114/86	106/76	.90	8.35
T. S.	2.29	92	120	100	124/82	128/88	.86	14.77
Mean	1.97	82	135	102	120/81	117/83	.88	10.00
			25 Per Cent Grade at 3 m.p.h.					
I. J.	1.97	92	128	100	126/88	134/90	.82	9.21
R. L.	1.83	68	144	100	120/88	116/72	.85	8.58
D. M.	1.91	68	120	96	134/80	126/80	.92	9.63
C. M.	1.91	80	140	120	124/72	124/84	.80	11.48
G. N.	1.92	76	120	96	118/74	118/80	.81	7.56
H. P.	1.93	100	148	132	100/70	80/60	.87	9.47
J. S.	2.01	80	136	108	108/64	120/86	.92	9.65
T. S.	2.29	72	164	104	118/80	114/78	.91	10.94
Mean	1.97	80	138	105	119/77	117/79	.87	9.60

APPENDIX F

Subj.	Ex. P V.(L./ min.)	Rec.P. V.(L./ min.)	Rest En. Exp.(c./ kg./(min.)	Ex. En. Exp.(c./ kg./min.)	Work En. Exp.(c./ kg./min.)	Rec. En. Exp.(c./ kg./min.)
			15 Per Cent Grade at 3 m.p.h.			
I. J.	51.45	13.33	.024	.178	.154	.011
R. L.	41.11	10.02	.022	.184	.162	.019
D. M.	48.93	16.31	.037	.161	.124	-.001
C. M.	64.78	18.81	.023	.188	.165	.019
G. N.	48.10	12.49	.020	.173	.153	.018
H. P.	41.89	11.49	.020	.152	.132	.007
J. S.	55.96	15.12	.022	.111	.089	.012
T. S.	62.91	16.86	.022	.169	.147	.013
Mean	51.90	14.30	.024	.165	.141	.012
			20 Per Cent Grade at 3 m.p.h.			
I. J.	82.49	23.70	.023	.294	.271	.037
R. L.	45.59	11.15	.027	.240	.213	.008
D. M.	82.49	18.53	.033	.287	.254	.016
C. M.	110.39	26.86	.028	.425	.397	.031
G. N.	70.57	16.68	.025	.210	.185	.017
H. P.	85.79	19.93	.028	.324	.296	.033
J. S.	76.20	19.18	.021	.223	.202	.030
T. S.	84.91	17.76	.035	.257	.222	.009
Mean	79.80	19.22	.028	.257	.255	.023
			25 Per Cent Grade at 3 m.p.h.			
I. J.	100.62	16.49	.021	.399	.378	.033
R. L.	86.67	9.54	.026	.423	.397	.018
D. M.	71.16	12.99	.021	.252	.231	.017
C. M.	108.25	29.23	.024	.404	.380	.043
G. N.	82.63	14.74	.022	.265	.243	.015
H. P.	87.93	21.05	.027	.385	.358	.037
H. S.	106.15	23.73	.019	.340	.321	.044
T. S.	97.30	20.71	.026	.293	.267	.022
Mean	92.60	18.56	.023	.345	.322	.029