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Pulse rate as a predictor of energy cost while doing selected work tasks

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THE PULSE RATE AS A PREDICTOR OF ENERGY
COST WHILE DOING SELECTED WORK TASKS

By

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J.F.M.

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THE PROBLEM AND RELATED LITERATURE

I. Introduction

The amount of energy individuals expend during various activities has been a continual source of curiosity to man. People working in exercise and physical training programs, nutrition areas, and agencies that develop special equipment for helping man do work faster and more efficiently, need to know the caloric expenditure during the performance of given tasks.

The most common method presently used for estimating caloric expenditure while performing certain tasks is that of collecting expired gases during the performance of the task and analyzing these gases for oxygen and carbon dioxide content. This method is described by Consolazio, Pecora, and Johnson (17).

The method is still cumbersome and time consuming and is not readily adaptable for research by people that are not closely associated with laboratory experimental procedures. Various field methods have been tried. All of the methods aim at eliminating the gas analysis. Malhotra and associates (32) studied the possibility of determining energy expenditure from minute ventilation. The results of their study indicate it is possible if the individuals are grouped on the basis of duty or occupation.

There is a need for a method of measuring metabolic rate continuously over long periods with minimal disturbance to the subject, and without excessive labor on the part of the investigator. The development of the radio-electrocardiograph that will record an individual's pulse rate without connecting him to wire leads, has suggested additional investigation to determine energy expenditure from pulse rate.

II. The Problem

Statement of the Problem

The purpose of this study was to determine the usefulness of pulse rate as a predictor of energy cost while doing selected laboratory tasks involving different muscle groups in static and phasic contractions.

Significance of the Study

The study was done in cooperation with the Equipment Development Branch of the United States Forest Service, Missoula, Montana. They are presented with the problem of determining whether new kinds of machines they develop actually save energy on the part of the operator. Furthermore, people in recreation, physical education, and athletics could be more efficient in their teaching if they knew the energy cost of various movements and activities.

Many studies have been made to determine the metabolic cost of performing different tasks. The studies have ranged from direct calorimetry (25) to methods involving indirect calorimetry. Even with the most recently developed equipment and techniques, the measurement of metabolic rate is still cumbersome and requires the wearing of a face mask, gas collection bags, and a great deal of skill and precise measurements by the examiner.

If this study indicates that pulse rate can be a useful predictor of energy cost, then the people in physical education, industry, and equipment development will have an easily accessible tool to aid them in their calculations.

Limitations of the Study

1. The subjects were four male college students 22-25 years of age.
2. Only a small group of subjects was used due to the time involved in completing the necessary number of trials, and the time involved in the laboratory analysis of the collected gas.
3. The only analysis involved in the study was the oxygen consumption and pulse rate of the subjects while walking on the treadmill and while doing selected tasks.
4. The oxygen requirement for a given effort will be limited to the definition, "the oxygen used per minute during the two minute collection period."
5. The pulse rate and oxygen consumption were expressed in gross values.

Definition of Terms

Energy expenditure. The oxygen consumption in liters per minute.

Oxygen consumption. The gross amount of oxygen consumed in liters per minute.

Pulse rate. The gross number of heart beats per minute.

III. Review of Related Literature

Early Studies

In 1907 Benedict (6) reported that changes in the pulse rate could be correlated with changes in heat production in any one individual. Benedict and associates (7, 8, 9, 10) confirmed and extended his observation in later works, and suggested that the pulse rate might provide a practical and satisfactory way of measuring metabolism. Krogh and Lindhard (29) observed concomitant changes in pulse rate and oxygen consumption when they compared the physiological effects of lying, sitting, and standing. Murling and Greer (35) confirmed that the pulse rate and oxygen consumption were related.

Henderson and Prince (23) showed that in any one individual, one relation between pulse rate and oxygen consumption held good during rest and very light activity, and there was an abrupt transition to a second relation when activity was increased to exercise. The relation during exercise was found to be more constant and linear, though it in turn broke down at high levels of exertion.

Recent Studies

Taylor (40) found that heart rate and work load correlated .97 and .96 in two individuals. Later Erickson and associates (18) found a similar correlation for individuals working on a treadmill. Wahlund (41) added support to the theory that the heart rate is roughly a linear function of oxygen intake and work load. His figures for heart rate were in line with those advanced by other investigators. Astrand's (4) findings, based on his investigation of the heart rate and oxygen intake using 112 females and 115 males, agreed with Wahlund. Astrand expanded the theory that the relationship between heart rate and oxygen intake existed through the total range from minimum to maximum workloads. Anderson and co-workers (2), in a study of young male Arctic Indians, substantiated the linear relationship between heart rate and metabolic rate during the muscular exercise in an apparent "steady state." Berggren and Christensen (11) using "trained" subjects corroborated the findings of Astrand (4), and Wahlund (41), and suggested that the heart rate during work ought to give rather dependable information about metabolic rate.

Brouha and Radford (24) explained the linear relationship between pulse rate and oxygen consumption by stating:

The total oxygen consumption equals the product of the heart rate times the stroke volume times the mean arteriovenous oxygen difference. At an oxygen consumption greater than one liter per minute the arteriovenous oxygen difference and the stroke volume are reasonably constant for any given subject, although considerable differences exist between individuals in their absolute levels. This constancy accounts for the direct relation found between heart rate and cardiac output or oxygen consumption during exercise at moderate ambient temperature.

Predicting of Oxygen Consumption

Karpovich (25) suggested that pulse rate could be used to predict oxygen consumption. His research concluded that there was a linear relationship between the oxygen consumed and the pulse rate. He felt there should be an individual table made for each experimental subject.

Booyens and Hervey (14) established the relation between pulse rate and metabolic rate for six subjects by a standard technique (bicycle ergometer) over the range of activity from lying still to moderate exertion. The same subjects then performed selected activities. The examiners concluded that while a subject is lying, sitting, and standing still the pulse rate is too variable to be useful for measuring metabolic rate. During muscular work, however, there was a consistent relation and with certain qualifications, it could provide a practical method of measuring metabolic rate.

Malhotra, Sen Gupta, and Rai (33) conducted a similar study with Indian soldiers. They made individual tables relating pulse rate and energy expenditure while doing standard tasks on a bicycle ergometer. In order to estimate the error of using pulse rate for measuring energy expenditure the same subjects were given various field tasks such as marching, running, walking, and hammering. Their per cent error for predicting ranged from .6 per cent to 7 per cent for seven subjects. The investigators concluded that it was possible to estimate the energy expenditure by measuring the pulse count for most of the normal activities.

Brouha and Maxfield (15) found in their tests with a magnetic ergometer and varying temperatures that the heart rate held a linear relation to oxygen consumption until the temperature was increased to ninety-one degrees Fahrenheit.

Bobbert (12) observed that heart rate increased linearly with energy expenditure when he tested six subjects with various work loads while hand cranking, cycling, and walking on a treadmill. Collet and Liljestrand (16) though, observed higher heart rates in cranking than in cycling and walking with the same levels of oxygen consumption. According to Asmussen and Nielsen (3) such discrepenacies can be explained by the difference in working posture. The influence of the pattern of movements was demonstrated by the fact that in swimming, Liljestrand and Lindhard (30) observed high pulse rates relative to oxygen consumption.

Hansen and Maggio (22) used phasic work as the base and added static work. They found that the pulse increased when static work began and remained at that level until the static work ended. The heart rate increased eight to eleven beats per minute more than was predicted by the dynamic exercise oxygen consumption data.

Paulsen and Asmussen (37) used two different activities for calibration in order to predict energy consumption from pulse rate. They had a high degree of efficiency using this method. They found that the arm work resulted in higher pulse rates than the leg work.

Sharkey (39) found that prediction of oxygen consumption based on phasic exercise data tends to over-estimate the oxygen uptake in static effort. The static pulse rate exceeded the phasic rate at an equivalent level of oxygen intake.

Research has pointed out that there is a relationship between pulse rate and oxygen consumption. It has indicated a need for further study of pulse rate as a predictor of oxygen consumption.

CHAPTER II

PROCEDURE OF THE STUDY

I. The Subjects

Four male students at the University of Montana at Missoula were used as subjects. The subjects were oriented to the purpose and procedure of the study. They were given an explanation of metabolic rate, and common methods of its determination. They were then pre-trained in treadmill walking and given experience in using the air collection equipment during the training period. The physical characteristics of the subjects are shown in Table I.

TABLE I

PHYSICAL CHARACTERISTICS OF THE SUBJECTS

Subjects	Height in inches	Weight in pounds	Age in years
L.P.	71.5	193	22
B.B.	70.0	177	22
R.S.	73.0	185	21
J.L.	70.5	200	25
MEANS	71.25	188.75	22.5

At the conclusion of a period of treadmill testing the subjects were then trained in riding the bicycle ergometer, hand cranking the bicycle ergometer, and walking on the treadmill while carrying a weight in their hands (with their arms flexed so that the lower arms were at right angles to the body).

II. Equipment and Apparatus

Treadmill

The walking surface of the treadmill was a continuous belt eight feet long and three feet wide. It was made of Goodyear wedge grip rubber and revolved on two 8.5 inch end rollers with forty-two 1.9 inch bed rollers between them. The smaller rollers furnished support for the walking surface.

The speed and elevation of the treadmill were controlled manually. The speed was held at a constant rate of three and one half miles per hour. The angle of elevation was set by a hand cranked winch located at the front of the machine. A dial located on the side of the treadmill indicated the per cent of grade. A diagram of the treadmill is shown in Appendix A.

Bicycle Ergometer

The bicycle ergometer was of the friction type. It was mounted on a wooden frame that stabilized it. The rubber mounted on the outside of the rim of the wheel was removed. The rim was lined with water proof adhesive tape to provide a smooth surface. A one inch wide belt made of webbing material holding a weight on one end, was passed over the bicycle wheel, and was connected to a spring scale that was mounted on the wooden frame just below the pedal assembly (Figure 1). The belt and weight acted as a brake that provided 6200 foot-pounds per minute of resistance while cycling and 2000 foot-pounds per minute of resistance while hand cranking.

Radio-Electrocardiograph

The Telemedics RKG 100 Radio-Electrocardiograph system, a fully integrated electronic system, obtained consistent and reproducible results over a wide variety of exercise and work conditions. The system consisted of specially designed disposable electrodes which easily adhered to the subjects's skin, a ten ounce pocket sized battery operated radio transmitter which could be placed in the subject's pocket, and a portable desk model radio receiver which forwarded the characteristic EKG waves to conventional recording equipment (Figure 2).

The radio transmitter. The frequency modulated radio transmitter was approximately one inch thick by three inches wide by four inches high and weighed ten ounces including the batteries. Heart signals from the electrodes were carried by thin flexible wires of the subject's cable to the transmitter where they were amplified and transmitted from an antenna included within the unit.

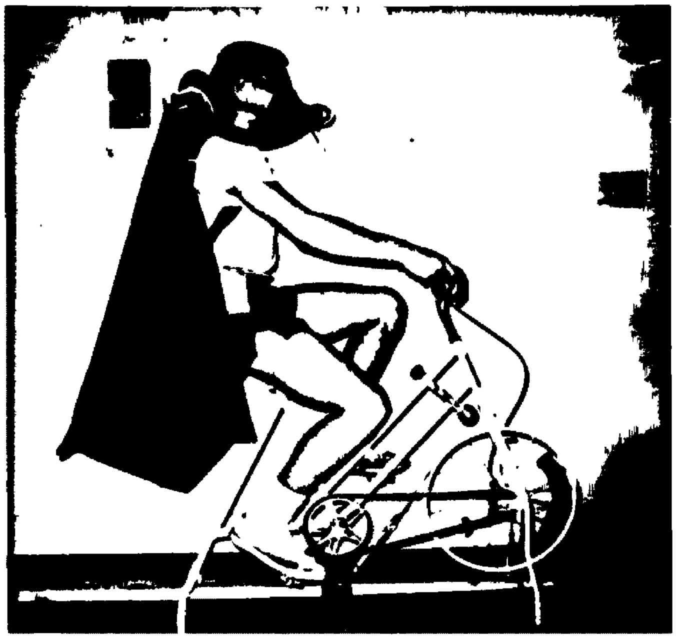

Figure 1. Bicycle Ergometer

Figure 2. Radio-Electrocardiograph

The electrodes. The electrodes consisted of a patch type adhesive bandage with an electrode paste reservoir, a metallic screen, and a contact snap fastener. In order to minimize muscle noise, the two electrodes were placed at the right and left fifth rib, slightly forward of the mid-axillary line (Figure 3).

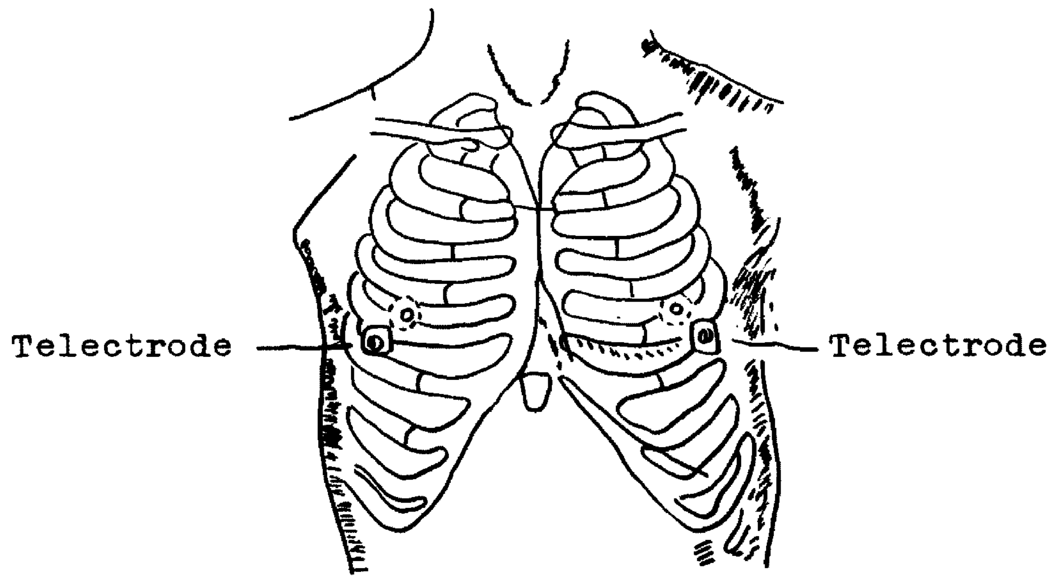

Figure 3. Electrode Positioning

The radio receiver. The desk model receiver was operated from a standard 115 volt 60 cycle power line. It was equipped with a channel selector switch which channeled the EKG signal to a recording instrument.

The recording instrument. The Telemedics Cardiotac 400R electrocardiograph was equipped with a meter that continually indicated the average heart rate in beats per minute. The peaks of the amplified heart complex (EKG) were translated into distinct "beeps." A volume control permitted setting the audible level. A recording mechanism was in operation, feeding chart paper and providing a permanent record of the heart beats during the exercise.

Air Collection, Sampling, and Measurement Equipment

Air collection equipment. The open circuit method for the collection of expired air was used because of its accuracy and adaptability to the problem. The subject wore a special face mask which fit over his nose and mouth. An automatic one-way valve was connected to the face mask so that the subject inhaled atmospheric air while his expired air went into a rubber tube. This rubber tube was in turn connected to a two-way valve which directed the air out into the atmosphere or into the Douglas bag which the subject carried on his back. Figure 4 illustrates the pack carrier, Douglas bag, and face mask as assembled for the tests.

Sampling equipment. The expired air samples were collected from the gas in the Douglas bag over mercury into Baily bottles and then labelled (Figure 5). The gas analysis was performed following the collection of the sample.

Measurement equipment. A 600 liter chain compensated gasometer was used to draw the expired air out of the Douglas bags. A meter stick attached to the gasometer indicated the height that the gasometer bell rose while the expired air was being collected from the Douglas bag. The volume of the

Figure 4. Air Collection Apparatus

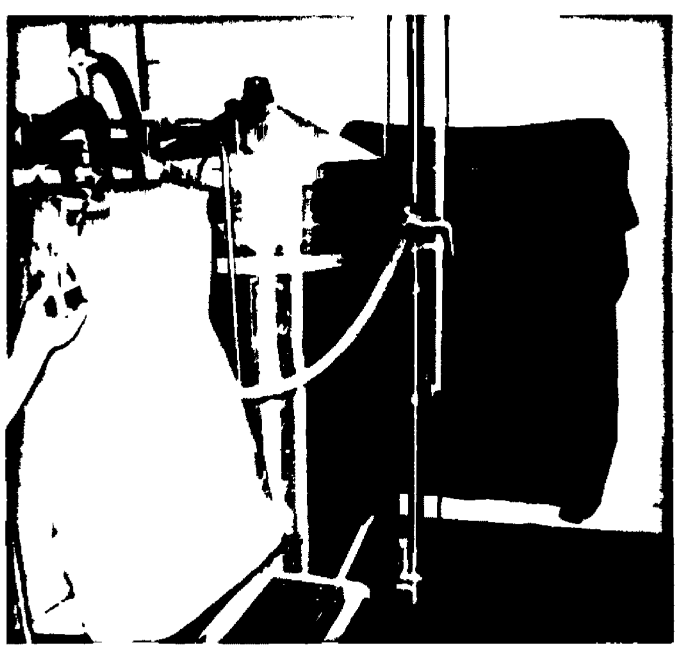

Figure 5. Air Sampling and Measuring Equipment

The volume of the expired air was obtained by multiplying the number of centimeters rise times the gasometer conversion factor which was 5.158 liters per centimeter. The expired air was mixed by an electric fan located within the gasometer bell. The temperature of the expired air was obtained from a thermometer which was located within the gasometer bell (Figure 5).

Gas Analysis

The Scholander method of gas analysis was used to determine the percentage of oxygen and carbon dioxide in the expired air samples. The principles of this method were reported by Scholander (38):

> A gas sample is introduced into a reaction chamber connected to a micrometer burette and is balanced by means of an indicator drop in a capillary against a compensating chamber. Absorbing fluids for carbon dioxide and oxygen can be tilted into the reaction chamber without causing any change in the total liquid content of the system. During absorption of gas, mercury is delivered into the reaction chamber from the micrometer burette so as to maintain the balance of the gas against the compensating chamber. Volumes are read in terms of micrometer divisions. The rinsing fluids and absorbents are accurately adjusted to have the same vapor tension.

III. Computation of Oxygen Consumption

The formulas used to compute oxygen consumption were those provided by Consolazio, Johnson, and Pecora (17). Oxygen consumption was expressed as the liters per minute consumed. The following indirect method of measurement was employed in the computation of oxygen consumption and energy expenditure:

1. The volume of the gas collected during each experimental period was converted to Standard Temperature and Pressure Dry (STPD) by multiplying the measured volume by a correction factor obtained from charts prepared by Consolazio, Johnson, and Pecora (17). The magnitude of the factor was dependent on the atmospheric pressure and the temperature of the gas at the time the gas volume was measured. The barometric pressure was recorded from an aneroid barometer located within the laboratory.
2. The per cent of nitrogen in the sample was obtained by adding the per cent of carbon dioxide and oxygen and subtracting the total from 100 per cent.
3. The volume of air expired per minute was computed according to the formula:

   $$\text{V air/min.} = \frac{\text{Volume collected (corrected to STPD)}}{\text{Collection time}}$$

4. The true oxygen consumption was obtained from charts prepared by Consolazio, Johnson, and Pecora (17). The formula for computing true oxygen is as follows:

   True oxygen = Per cent nitrogen in expired air x 0.265 - per cent oxygen in expired air

5. The volume of oxygen consumed per minute was determined by the formula:

$$VO_2/\text{min.} = \frac{\text{Vol. exp. air/min.}}{100} \times \text{true oxygen}$$

IV. Experimental Procedure

The testing was conducted during the Winter Quarter 1965 in the Human Performance Laboratory of the University of Montana. Each subject was oriented to the complete study. The importance of their cooperation was stressed. The subjects were introduced to the factors that would affect the results of their tests. They were asked to get a good nights rest before their test, and to report for testing in the post absorptive state. The tests were all conducted early in the morning, and each subject was tested at approximately the same time each testing day.

Prior to the collection of data, each subject was required to participate in one practice trial for each activity. During the practice trials all the procedures of an experimental trial were performed. A testing period lasted for forty minutes. Each subject reported to the laboratory for only one testing period in a day.

V. Description of Selected Tasks

Bicycle Ergometer

The subjects pedaled the bicycle ergometer (Figure 1) at a rate that caused the wheel to make ninety-two revolutions per minute. A metronome was placed in front of the ergometer and adjusted to help the subject maintain a steady pace of ninety-two revolutions per minute.

Treadmill

The subjects walked on a treadmill set at six different grades. The treadmill was operated consistently at three and one-half miles per hour. The random sequence of the grades in which each subject walked on the treadmill was determined from a table of random numbers provided by Walker and Lev (42). Table II shows the order of the grades on the treadmill for each subject.

TABLE II

SEQUENCE OF TREADMILL GRADES

Subjects	1st day	2nd day	3rd day	4th day	5th day	6th day
L.P.	1	4	5	3	6	2
B.B.	2	4	1	3	6	5
R.S.	2	3	6	4	5	1
J.L.	4	2	1	6	5	3

1 = 0% grade 3 = 6% grade 5 = 10% grade
2 = 4% grade 4 = 8% grade 6 = 12% grade

Hand Cranking

The bicycle ergometer was mounted on a table (Figure 6). The subject sat on a stool and reached forward to crank

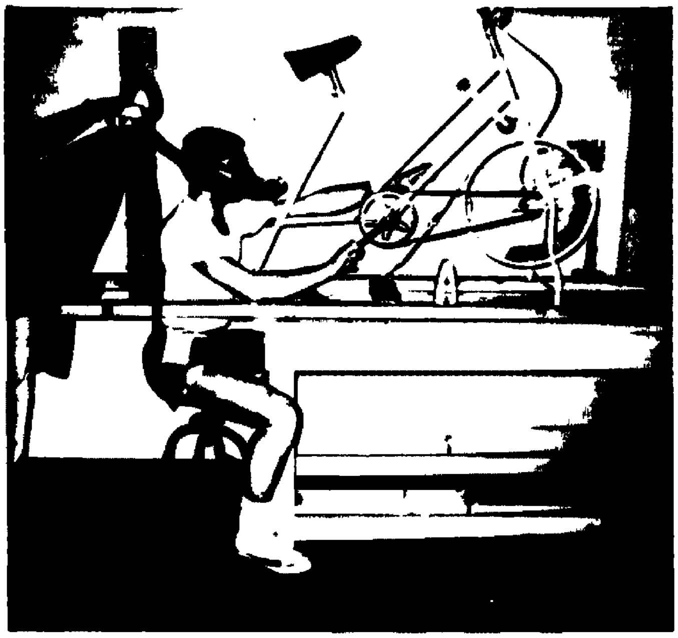

Figure 6. Hand Cranking the Bicycle Ergometer

Figure 7. Treadmill Walking and Static Contraction

the pedals. The metronome was used to help the subject keep an even pace on ninety-two revolutions per minute.

Static Contraction and Treadmill Walking

The subject walked on the treadmill holding a twenty-three pound dumbbell in his hands (Figure 7). The weight was held so that the lower arms were at right angles to the body. The slope of the treadmill was two per cent, and the speed was three and one-half miles per hour.

VI. Conduct of Experimental Trials

The subject filled out a checklist (Appendix B) on which they described their last exercise, food, drink, and hours of sleep. Body weight, oral temperatures, and resting heart rate were also measured each day.

Accurate record was kept of room temperature, relative humidity, and barometric pressure at the time of each test.

After the subject finished with his personal data, the electrodes were fastened to his chest and the radio-cardiograph transmitter mounted on his waist. The pack carrier with the Douglas bag was placed on his back. The subject sat quietly and his radial pulse was taken for fifteen seconds at one minute intervals until it was the same for two consecutive times and agreed with the indicator needle of the radio-electrocardiograph. The face mask was then adjusted to the subject's face and he began work immediately.

At the conclusion of five minutes of work, the two-way valve was turned directing the expired air into the Douglas bag. The subject worked for two more minutes and the expired gas was collected. At the conclusion of the collection period the subject stopped work.

The Douglas bag was then disconnected from the air collection apparatus and a sample, which was later analyzed in the laboratory, was taken over mercury into Baily bottles and labeled. The air in the bag was then drawn into a gasometer to determine the total volume of expired air. The temperature of the expired air was read from a thermometer in the bell of the gasometer.

CHAPTER III

ANALYSIS AND DISCUSSION OF RESULTS

I. Analysis of Results

The data which was collected from the subjects while walking on the treadmill at different angles is shown in Appendix C, while the data collected from the subjects while doing the selected tasks is shown in Appendix D. The metabolic rates were expressed in liters of oxygen consumed per minute, and the heart rates are expressed in beats per minute.

Gross values were used in both the oxygen consumption per minute and heart beats per minute. Bobbert (12) had so much variability in the resting levels of his subjects that he concluded that a preliminary period of thirty minutes was not satisfactory for bringing the subjects into a definite resting condition. In this study the subject rested for fifteen minutes, and the resting values were not subtracted from the data obtained during exercise.

Method of Predicting Oxygen Consumption

The data collected for each subject while walking on the treadmill at six different angles was used to derive a regression line relating the subject's oxygen consumption per minute with his heart rate per minute. Each regression line and correlation coefficient was determined by the method dexcribed by Alder and Roessler (1):

1. The line $Y_e = a + bX$ which has been fitted to a set of n points (X,Y) by the method of least squares is called the <u>line of regression of Y on X or the line of prediction for Y</u>.
2. b was determined from the following equation:

   $$b + \frac{\Sigma XY - n\overline{XY}}{\Sigma X^2 - n\overline{X}^2}$$

   X = pulse rates of subjects in trial tests

   Y = oxygen consumption in liters per minute while doing trial tests on the treadmill

   $\overline{X}$ = sum of pulse rates divided by the number of trials tests

   $\overline{Y}$ = sum of liters of oxygen consumed divided by the number of trial tests
3. a was determined from the following equation:

   $$a = \overline{Y} - b\overline{X}$$
4. In order to graph the line of regression the Y_e value was determined for the two extreme X-values. The two Y_e values were then connected by a straight line.
5. The correlation coefficient for oxygen consumption and pulse rate was determined from the following equation:

   $$r = \frac{\Sigma XY - n\overline{XY}}{\sqrt{(\Sigma X^2 - n\overline{X}^2)(\Sigma Y^2 - n\overline{Y}^2)}}$$

The regression lines for the four subjects are shown in Figure 8. The predicted Y_e values for each subject and the per cent error of each predicted Y_e value are shown in

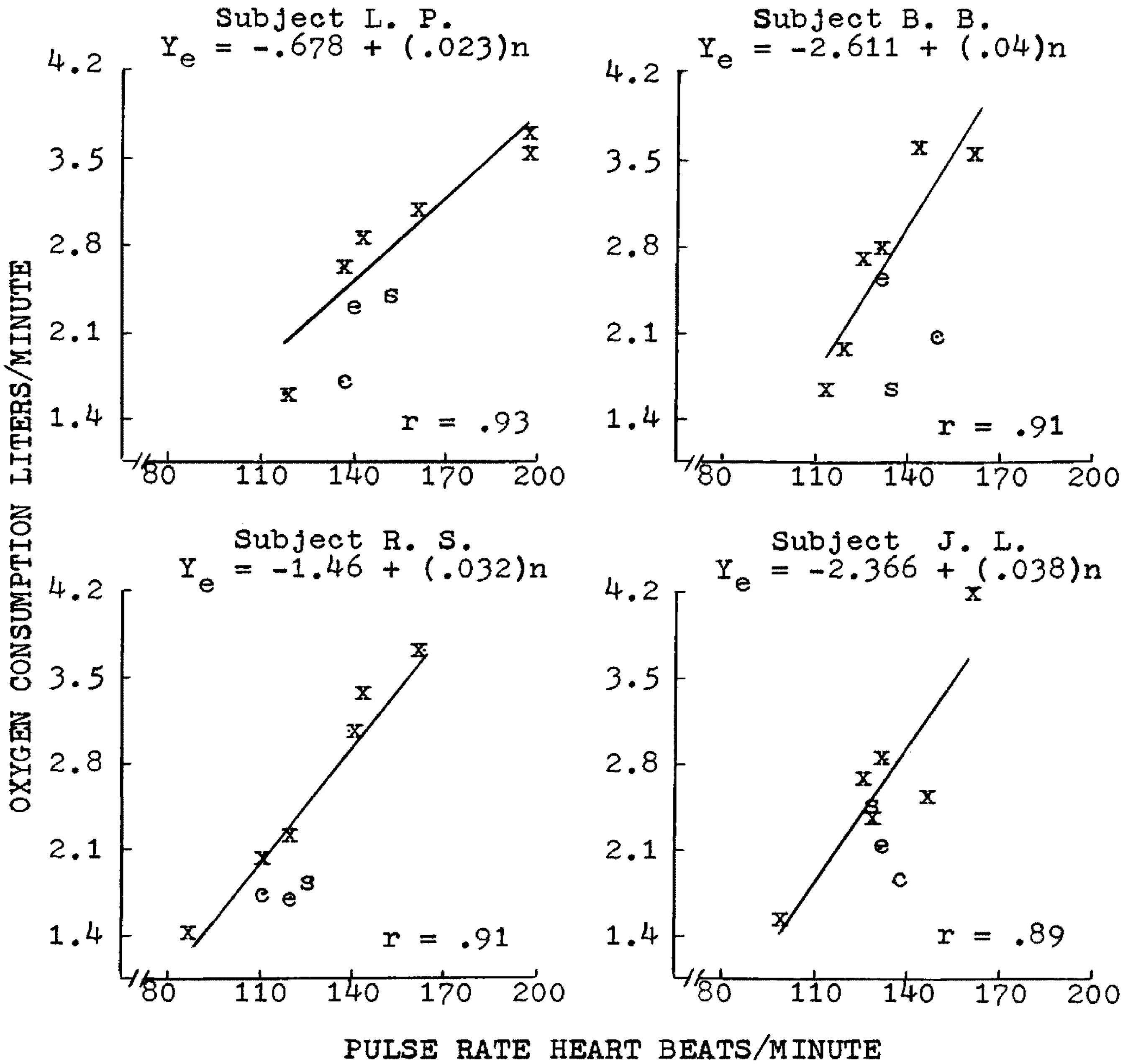

FIGURE 8. REGRESSION LINES

x = actual oxygen consumption for treadmill slopes
c = actual oxygen consumption for hand cranking
e = actual oxygen consumption for cycling
s = actual oxygen consumption for treadmill and static contraction
Y_e = predicted oxygen consumption in regression equation
n = pulse rate in regression equation
r = coefficient of correlation for oxygen consumption and pulse rate

Tables III, IV, V, and VI. The predicted values were calculated by means of the regression equations.

Method of Analysis

The data was analyzed by finding the difference between the predicted oxygen consumption during the tests and the actual oxygen consumption, and determining the per cent of error of each prediction.

The mean of the per cent error of each activity was tested by the one-way analysis of variance. The hypothesis tested was that there were no differences between the means of the per cent error of each activity.

Comparison of Predicted and Actual Oxygen Consumption

The prediction of oxygen consumption showed less error for each subject when the subjects walked on the treadmill at a 6 per cent slope. The per cent error varied from 5.05 per cent to 11.64 per cent and had a mean of 7.89 per cent (Table III).

TABLE III

TREADMILL WALKING AT A 6 PER CENT SLOPE

Subjects	Heart Rate	Predicted Oxygen Consumption	Actual Oxygen Consumption	Per Cent Error
L.P.	138	2.496	2.622	5.05
B.B.	125	2.389	2.667	11.64
R.S.	120	2.380	2.249	5.50
J.L.	130	2.574	2.333	9.36
Means	128.25	2.460	2.468	7.89

In two cases the prediction of oxygen consumption while cycling on the bicycle ergometer had less than 8.23 per cent error. One subject had a difference between predicted and actual oxygen consumption that resulted in a 29.54 per cent error. The mean of the per cent errors for cycling on the bicycle ergometer was 15.83 per cent (Table IV).

TABLE IV

CYCLING ON THE BICYCLE ERGOMETER

Subjects	Heart Rate	Predicted Oxygen Consumption	Actual Oxygen Consumption	Per cent Error
L.P.	143	2.611	2.396	8.23
B.B.	134	2.749	2.576	6.29
R.S.	120	2.380	1.677	29.54
J.L.	132	2.650	2.139	19.28
Means	132.25	2.598	2.197	15.83

When the subject sat on a stool and hand cranked the bicycle ergometer, the per cent error for predicted oxygen consumption ranged from 21.43 per cent to 36.38 per cent, and had a mean of 29.75 per cent (Table V).

Treadmill walking on a 2 per cent slope, while the subject carried a twenty-three pound dumbbell in his hands, caused a variance in the per cent of error in prediction of oxygen consumption from a low of 7.03 per cent to a high of 38.83 per cent, and had a mean of 21.93 per cent (Table VI).

TABLE V

HAND CRANKING THE BICYCLE ERGOMETER

Subjects	Heart Rate	Predicted Oxygen Consumption	Actual Oxygen Consumption	Per Cent Error
L.P.	137	2.473	1.754	29.07
B.B.	150	3.389	2.156	36.38
R.S.	113	2.156	1.694	21.43
J.L.	135	2.764	1.876	32.13
Means	135.75	2.696	1.870	29.75

TABLE VI

TREADMILL WALKING AND STATIC CONTRACTION

Subjects	Heart Rate	Predicted Oxygen Consumption	Actual Oxygen Consumption	Per Cent Error
L.P.	150	2.772	2.452	11.54
B.B.	133	2.709	1.657	38.83
R.S.	127	2.604	1.815	30.30
J.L.	130	2.574	2.393	7.03
Means	135	2.665	2.079	21.93

There was a range in the means of the per cent error of prediction from a low of 7.89 per cent for treadmill walking to a high of 29.75 per cent for hand cranking, although no significant F ration was shown for the differences between the means of the per cent error of prediction for each of the selected activities (Table VII).

TABLE VII

ANALYSIS OF VARIANCE FOR PER CENT ERROR OF PREDICTIONS

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F ratio
Trials	1030.35	3	343.45	3.216 N.S.
Subjects	241.10	3	80.37	.753
Interaction	961.13	9	106.79	
Total	2232.60	15	$F_{.95}$ (3,9) = 3.86	

II. Discussion of Results

The results of the study suggested that the more related the selected task was to the activity that was used to develop the regression equation, the more accurate was the prediction. Although the means of the per cent error of the test conditions were different (7.89 per cent for treadmill walking to 29.75 per cent for cranking) they were not significantly different at the .05 level of confidence. Inspection of the variability within a specific treatment suggests the reason for the non-significant difference.

The regression equation was developed from the data collected while the subject walked on the treadmill adjusted to slopes varying in steepness.

The predictions resulting in the lowest per cent error were those made from the pulse rates while the subject walked on the treadmill adjusted to a 6 per cent slope. Predictions made from the pulse rate while the subjects cycled on the bicycle ergometer were close for two subjects, but resulted in a 29.54 per cent error in prediction for one subjects. According to the findings of Lundgren (31), the increase in pulse while cycling may have been due to fatigue.

The heart rate in the cycling, hand cranking, and treadmill walking with arms in a static contraction indicated a greater oxygen consumption than there actually was. This held true in every case. Figure 8 readily shows the over prediction. Müller (34) experienced the same result. He found that arm work gave a higher pulse rate for equal metabolism than did leg work. Poulsen and Asmussen (37), upon finding the same result, thought the pulse rate while sitting or standing with the legs more or less passive was increased because of the hydrostatic effect of the position on the circulation.

The higher prediction of oxygen consumption than actually was consumed for the selected task of walking on the treadmill while statically holding a weight is in agreement with the findings of Hansen and Maggio (22). Sharkey (39) found the same result and felt the greater response of the heart in static effort was the result of the throttling effect of the static contraction on the blood vessels of the contracting muscles.

Figure 9 indicates the linear relationship between pulse rate and oxygen consumption while walking on the treadmill adjusted to varying slopes. The result was in agreement with most of the similar studies. There was one trial in which the pulse rate did not increase with an increase in treadmill slope, also on one trial an increase in pulse rate was accompanied by a reduction in oxygen consumption. This suggests agreement with the training effect found in the studies conducted by Krogh and Lindhard (29) and Booyens and Hervey (14).

CHAPTER IV

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

I. Summary

The purpose of the study was to determine the usefulness of the pulse rate as a predictor of energy cost while doing selected laboratory tasks involving different muscle groups in static and phasic contractions. The pulse was counted by a radio-electrocardiograph. The oxygen consumption was measured by collecting the expired gas, analyzing the oxygen and carbon dioxide content of the expired gas, and measuring the volume of the collected gas.

The prediction of oxygen consumption was done by developing a regression equation for each subject. The regression equations and lines were developed from the data collected for each subject while he walked on the treadmill at six different per cent grades. The subjects then did the three selected tasks. The tasks were cycling on the bicycle ergometer, hand cranking the bicycle ergometer, and walking on the treadmill with arms in a static contraction. The oxygen consumption was predicted for each task from the subject's heart rate during the collection period. The gas collected was analyzed and the volume measured to determine the actual oxygen consumed. A per cent of error for each prediction was determined. The means of the per cent error for each of the selected tasks were determined. In addition to the three selected tasks, the data collected while the subjects walked on the treadmill at a 6 per cent grade was treated in the same manner. A one-way analysis of variance test was used to test the hypothesis that there were no differences between the means of the per cent error of each activity. The analysis of variance test indicated there were no significant differences in the means.

When the subjects walked on the treadmill, their increase in pulse was generally accompanied by an increase in oxygen consumption (Figure 9 and Appendix C). It was also noted that pulse rate increased or decreased as the grade of the treadmill was increased or decreased.

The pulse rate tended to over-estimate the oxygen consumption while hand cranking the bicycle ergometer and while walking on the treadmill with the arms statically contracted. There was a large variation in the per cent error of prediction for the task of cycling on the bicycle ergometer.

Walking on a treadmill at a 6 per cent grade provided the prediction with the lowest mean for per cent of error. This would be expected since this data was a portion of that used to develop the regression equation. If the standard of 10 per cent error was used as the mean limit acceptable, it would be concluded that the pulse rate--oxygen consumption relationship should only be used to predict for activities closely related to the exercise used to derive the prediction equation.

II. Conclusions

The results of the study pointed out the following conclusions:

1. There is a linear relation between pulse rate and oxygen consumption.
2. Pulse rate can be a useful predictor of metabolic rate.
3. A static contraction while doing phasic work, hand cranking and pedaling the bicycle ergometer caused the pulse rate to increase higher for an equal oxygen intake than for treadmill walking.
4. Data for a regression equation and line should be collected from an activity very similar to the activity in which predictions are to be made.

III. Recommendations

The findings of this study indicate that the pulse rate can be a useful predictor of energy cost. The results of the study showed great variation in the heart rate in relation to oxygen consumption when different large muscle groups were used in phasic and static work. The results of the study have indicated the following recommendations:

1. Further research should be conducted where predictions are made while doing tasks very similar to the ones that provided the data for the regression lines.

2. More research needs to be done to investigate the relationship of pulse rate to oxygen consumption while doing static muscular work.
3. Studies are needed to examine the prediction of oxygen consumption for muscular work involving a combination of phasic and static contraction. Regression lines should be formed from similar tasks.

SELECTED BIBLIOGRAPHY

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1. Alder, Henry L., and Edward B. Roessler. Introduction to Probability and Statistics. San Francisco: W. H. Freeman and Co., 1962.

2. Anderson, K., A. Bolstad, V. Llyning, and L. Irving. "Physical Fitness of Arctic Indians," Journal of Applied Physiology, 15:645-648, July, 1960.

3. Asmussen E., and M. Nielsen. Acta Physiologia Scandanavia, 12:171, 1946. Cited by Kozar (Ref. 27).

4. Astrand, P. O. Experimental Studies of Working Capacity in Relation to Sex and Age. Copenhagen: Munksgaard, 1952. Cited by Kozar (Ref. 27).

5. Astrand, P. O. and B. Saltin. "Maximal Oxygen Uptake and Heart Rate in Various Thpes of Muscular Activity," Journal of Applied Physiology, 16:977-981, November, 1961.

6. Benedict, F. G. "The Influence of Inanition on Metabolism," Carnegie Institute, Washington Publication No. 77. 1907.

7. Benedict, F. G. "The Metabolism and Energy Transformations of Healthy Man During Rest," Carneigie Institute, Washington Publication No. 126. 1910.

8. Benedict, F. G. "Muscular Work," Carneigie Institute, Washington Publication No. 187. 1913.

9. Benedict, F. G. "The Gaseous Metabolism of Infants," Carnegie Institute, Washington Publication No. 201. 1914.

10. Benedict, F. G. "A Study of Prolonged Fasting," Carnegie Institute, Washington Publication No. 203. 1915.

11. Berggren, G. and E. H. Christensen. "Heart rate and Body Temperature as Indices of Metabolic rate During Work," Arbeitsphysiologie, 14:225-260, 1950. Cited by Kozar (Ref. 27).

12. Bobbert A. C. "Physiological Comparisons of Three Types of Ergometry," Journal of Applied Physiology, 15: 1007-1015, November, 1960.

13. Boothby, W. M. "A Determination of the Circulation Rate in Man at Rest and at Work," American Journal Of Physiology, 37:383-416, May, 1915.

14. Booyens, J. and G. R. Hervey. "The Pulse Rate as a Means of Measuring Metabolic Rate in Man," Canadian Journal of Biochemistry and Physiology, 38:1301-1309, November, 1960.

15. Brouha, L. and M. E. Maxfield. "Practical Evaluation of Strain in Muscular Work and Heat Exposure by Heart Rate Recovery Curves," Ergonomics, 5:86-91, January, 1962.

16. Collet, M. E. and G. Liljestrand. Skandanavian Archives of Physiology, 45:29, 1924. Cited by Bobbert (Ref. 12).

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

18. Erickson, L. E., E. Simonsen, H. L. Taylor, H. Alexander and A. Keys. "The Energy Cost of Horizontal and Grade Walking on Motor-Driven Treadmill," American Journal of Physiology, 145:391-401, November, 1945.

19. Fletcher, J. G. "Maximal Work Production in Man," Journal of Applied Physiology, 15:764-768, September 1960.

20. Garrett, Henry E. Statistics in Psychology and Education. New York: David McKay Company, Inc., 1958.

21. Goldman, R. F. and P. F. Iampietro. "Energy Cost of Loan Carriage," Journal of Applied Physiology,

22. Hansen, O. H. and M. Maggio. "Static Work and Heart Rate," Intrationale Zeitschrift Für Angewandte Physiologie Einschliesslich Arbeitsphysiologie, 18:242-247, 1960. Cited by Sharkey (Ref. 39).

23. Henderson, V. and A. L. Prince. "Oxygen Pulse and Systolic Discharge," American Journal of Physiology, 35:106-108, August-November, 1914.

24. Johnson, Warren R. Science and Medicine of Exercise and Sports. New York: Harper and Brothers, 1960.

25. Karpovich, Peter V. Physiology of Muscular Activity. Fifth Edition. Philadelphis: W. B. Saunders Co., 1959.

26. Knuttgens, Howard G. "Oxygen Uptake and Pulse Rate While Running With Undetermined Stride Lengths at Different Speeds," Acta Physiological Scandanavica, 52:366-371, July-August, 1961.

27. Kozar, Andrew J. "A Study of Telemtered Heart Rate During Sports Participation of Young Adult Men," Doctorate Dissertation, University of Michigan, Ann Arbor, 1961.

28. Kozar, Andrew J. "Anticipatory Heart Rate in Rope Climbing," Ergonomics, 3:312, July, 1964.

29. Krogh, A. and J. Lindhard. Journal of Physiology, 51:182, 1917. Cited by Booyens and Hervey (Ref. 14).

30. Liljestrand, G. and J. Lindhard. Skandanavian Archives of Physiology, 39:64, 1920. Cited by Bobbert (Ref. 12).

31. Lundgren, N. P. "The Physiological Effects of Time Schedule Work on Lumber Workers," Acta Physiological Scandanavia, 5:137, 1947.

32. Malhotra, M. S., S. S. Ramaswamy, S. N. Ray and T. N. Shrivastov. "Minute Ventilation as a Measure of Energy Expenditure During Exercise," Journal of Applied Physiology, 17:775-779, September, 1962.

33. Malhotra, M. S. J. Sen Gupta and R. M. Rai. "Pulse Count as a Measure of Energy Expenditure," Journal of Applied Physiology, 18:994-996, September, 1963.

34. Müller, E. A. "Die Pulsyahe als Kennzeichen für Staffanstausch und Ermudbarkeit des Arbeitenden Muskels," Arbeitsphysiologie, 12:92-104, 1942. Cited By Sharkey (Ref. 39).

35. Murlin, J. R. and J. R. Greer. "The Relation of Heart Action to the Respiratory Metabolism," American Journal of Physiology, 33:253-282, January, 1914.

36. Passmore, R. and J. V. Durnin. "Human Energy Expenditure," Physiological Reviews, 35:802, October, 1955.

37. Poulsen, E. and E. Asmussen. "Energy Requirements of Practical Jobs from Pulse Increase and Ergometer Test," Ergonomics, 5:33-36, January, 1962.

38. Schollander, P. F. "Analyzer for Accurate Estimation of Repiratory Gases in ONe-Half Cubic Centimeter Samples," The Journal of Biological Chemistry, 167:1-15, January, 1947.

39. Sharkey, Brian J. "Comparison of Selected Physiological Relationships in Static and Phasic Exercise." Paper read at annual Convention of American Association for Health, Physical Education and Recreation, Dallas, March 19, 1965.

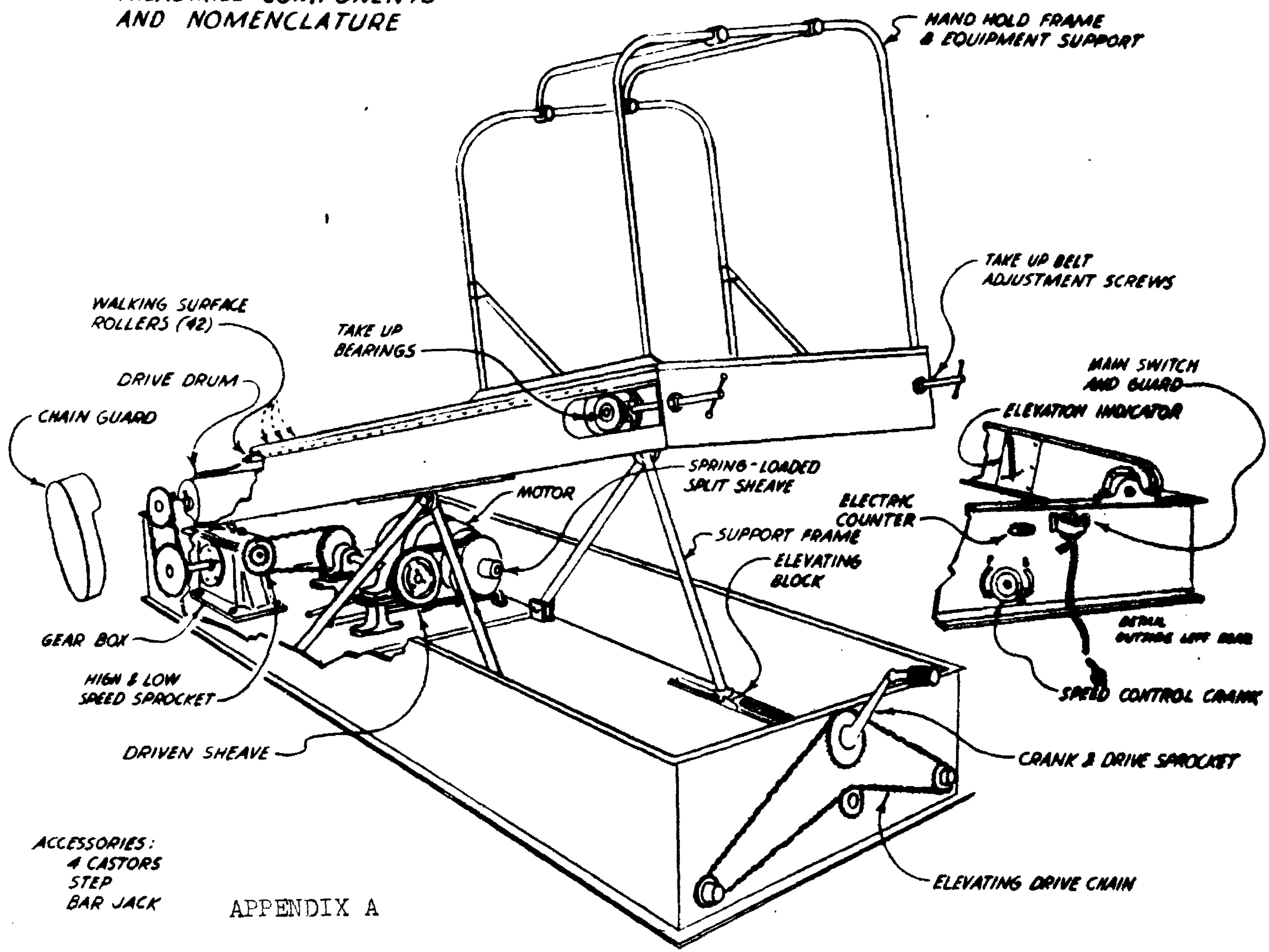
40. Taylor, C. "Studies in Exercise Phsyiology," American Journal of Physiology, 135:27-42, December, 1941.

41. Wahlund, H. "Determinations of Physical Working Capacity," Acta Medica Scandanavica, Supplement, 215:5-77, 1948. Cited by Kozar (ref. 27).

42. Walker, Helen M. and Joseph Lev. Statistical Inference. New YOrk: Holt and Co. , 1953.

APPENDIX

TREADMILL COMPONENTS AND NOMENCLATURE



ACCESSORIES:
4 CASTORS
STEP
BAR JACK

APPENDIX A

APPENDIX B

HUMAN PERFORMANCE LABORATORY

Subject________________ Date____________Treatment___________

Control Data: Rm Temp_____Bar Pr____Rel Hum____Oral Temp___

Bdy Wt____Ht___Resting Pulse ____ ____ ____ ____Bl Pr_______

Last food______Drink(not H_2O)_______Hrs Slp_____Last Ex_____

Other ____

Experimental Data:

____

____

____

____

Ventilation: Gasometer factor (GF)_________Meter factor_____
Conversion factor (derived from bar pr and temp of gas) - CF

Post

____-____=____ x GF =____ x CF = _____/min. = ____VR (L/min.)
____ ____ ____ ____ _____ ____
____ ____ ____ ____ _____ ____

Gas Analysis:

	T1	T2	$\bar{X}$	RO	T-O_2		VR			cO_2/min.
CO_2	______	______	______	______	______	x	______	=___	/100=	______
O_2	______	______	______	______	______	x	______	=___	/100=	______
	______	______	______	______	______		______	___		______
	______	______	______	______	______		______	___		______

Comments:

APPENDIX C

RAW DATA FOR TREADMILL WALKING AT SIX DIFFERENT ANGLES

Subjects	TS*	RT*	BP*	VR*	RQ*	TO_2*	O_2C*	PR*
L. P.	0%	24.5	680	26.22	.84	6.06	1.589	117
	4%	22	686	45.10	.89	6.52	2.941	142
	6%	25	680	39.43	.85	6.65	2.622	138
	8%	26	668	48.91	.93	6.45	3.155	160
	10%	18.5	683	69.18	1.03	5.26	3.638	195
	12%	21.4	685	64.33	1.00	5.86	3.769	195
B. B.	0%	18	687	32.99	.81	4.90	1.616	114
	4%	21	692	36.82	.84	5.36	1.973	118
	6%	23	685	51.79	.91	5.15	2.667	125
	8%	28	668	52.70	.91	5.26	2.772	132
	10%	18.5	683	70.81	.94	5.06	3.544	163
	12%	27	687	69.96	.88	5.15	3.603	144
R. S.	0%	25.5	686	23.93	.74	5.97	1.428	87
	4%	20	690	35.94	.84	5.54	1.991	112
	6%	25	681	40.32	.86	5.58	2.249	120
	8%	21	685	58.44	.94	5.14	3.003	140
	10%	26	689	63.90	.96	5.21	3.329	142
	12%	20	687	77.58	1.01	4.71	3.654	162
J. L.	0%	20.5	690	26.12	.78	5.86	1.530	99
	4%	23	685	43.19	.86	6.13	2.647	127
	6%	26	669	39.82	.88	6.00	2.333	130
	8%	23	684	44.62	.88	6.25	2.789	134
	10%	26	687	42.20	.87	6.08	2.565	148
	12%	26	689	77.55	.96	5.50	4.265	160

*TS = Treadmill Slope
*RT = Room Temperature (C°)
*BP = Barometric Pressure (mm. of Hg)
*VR = Ventilation Rate (liters/min.)
*RQ = Respiratory Quotient
*TO_2 = True Oxygen
*O_2C = Oxygen Consumption (Liters/min.)
*PR = Pulse Rate (Heart Beats/min.)

APPENDIX D

RAW DATA FOR SELECTED LABORATORY TASKS

Subjects	LT*	RT*	BP*	VR*	RQ*	TO_2*	O_2C*	PR*
L. P.	A*	22	675	43.09	.94	5.56	2.396	143
	B*	22	675	45.92	.94	4.82	1.754	137
	C*	20	684	35.79	.85	6.75	2.452	150
	D*	25	680	39.43	.85	6.65	2.622	138
B. B.	A	20	674	45.92	.85	5.61	2.576	134
	B	23	674	50.61	1.00	4.26	2.156	150
	C	19.5	682	39.64	1.06	4.18	1.657	133
	D	23	685	51.79	.91	5.15	2.667	125
R. S.	A	20	676	37.27	1.02	4.50	1.677	120
	B	23	667	33.54	.94	5.05	1.694	113
	C	20	676	41.82	1.16	4.34	1.815	127
	D	25	681	40.32	.86	5.58	2.249	120
J. L.	A	23	676	41.77	.91	5.12	2.139	132
	B	23	667	39.09	.93	5.80	1.876	135
	C	23.5	676	41.40	.92	5.78	2.393	130
	D	26	669	39.82	.88	5.99	2.333	130

*LT = Laboratory Tasks
*RT = Room Temperature (C^o)
*BP = Barometric Pressure (mm. of Hg)
*VR = Ventilation Rate
*RQ = Respiratory Quotient
*TO_2 = True Oxygen
*O_2C = Oxygen Consumption (Liters/min.)
*PR = Pulse Rate (Heart Beats/min.)
*A = Cycling on the Bicycle Ergometer
*B = Hand Cranking the Bicycle Ergometer
*C = Treadmill Walking and Static Contraction
*D = Treadmill Walking at a 6 per Cent Slope