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A COMPARISON BY SEX OF THE ENERGY COST OF WALKING

by
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of the requirements for the degree of
Doctor of Education
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CHAPTER I

INTRODUCTION

Statement of the Problem

Over the last half century, many researchers have measured the metabolic cost of the physical activity of men and women walking. The author of this investigation had the opportunity to contribute to a study (19) where the metabolic cost of walking was measured as a standard procedure. The results of the above-mentioned study showed a difference in the energy cost of male and female subjects. For a possible explanation of this difference, the work of other researchers was studied. A review of the literature showed no clear explanation for a difference in energy cost of males and females.

As a result of the experience gained from reviewing the literature and from other experiments, this researcher designed the present study in which the variables of height, weight, age, temperature, humidity and friction were controlled. The purpose of this study, therefore, was to compare the energy cost of males and females walking by assessing the oxygen consumption. In addition, the relationship of oxygen consumption to fat free mass, body weight, leg length and stride frequency were also determined.

Need for the Study

Taylor stated, "Since all physical activity is eventually paid for by the utilization of oxygen in the oxidation of food stuffs, the relationship betwen oxygen consumption and physical activity is of first importance in the understanding of physical activity," (37:126). Most oxygen consumption and related energy cost studies dealt predominantly with male subjects. So far as we know it would be presumptuous to assume the energy cost of females to be equal to the energy cost of males. Therefore, comparative studies of the energy cost of females and males are necessary so that physical educators can better understand physical activity.

Some comparisons of the energy cost of males and females walking have been done. However, for various reasons there seemed to be no consensus of agreement in previous comparisons. To begin with, in earlier investigations the tendency was to make extensive studies on one or two subjects. In recent work, stimulated by the greater convenience of modern technique, measurements have been done on a larger number of subjects. Yet, few papers reported repeated observations on the same subjects at or about the same speed of walking. Also such variables as temperature, humidity, shoe weight and friction were often overlooked. Due to differences in the age and race distributions, many studies reported in the literature were not comparable in respect to sex. Still another reason for the lack of agreement among researchers was the use of different terms to express energy cost and

speed. Finally, researchers used vague terms to describe body weight and height.

The third reason for this study was the practical importance of obtaining precise information about the energy cost of different types of physical activity. Astrand stated, "Such information is essential as a basis for an intelligent and fair administration of any rationing program in case of war or other emergencies. It is also of interest in connection with the discussion of the cost of living, especially in underdeveloped areas where economy and food availability are greatly restricted," (3:433).

Delimitation of the Study

Subjects. The subjects used in this investigation were twelve college women and twelve college men, students of Ball State University, who volunteered to act as subjects. All subjects were Caucasians between the ages of 19 and 21 years. An effort was made to select groups of men and women subjects with the same mean and range of height and weight.

General criteria which had to be met by the twenty-four subjects for inclusion in the study were: (1) freedom from fear of the water in a swimming situation, and (2) freedom from physical disabilities which might affect the results of the experiments.

Order of Experiments. The order in which the measurements were made was dictated by the tight schedule of the Laboratory and by the subject's availability. The body

density measurement was made in the morning between seven and eight o'clock. The energy cost measurement was made in the evening and within one week of the body density measurement.

Definition of Terms

Bitrochanteric width is the horizontal distance between the most lateral projections of the right and left greater trochanters.

Energy cost ($\dot{V}o_2$) is the total oxygen consumption per minute, calculated from the ventilation minute volume and analysis of expired gas.

Fat free mass is the weight of the body minus the weight of the body fat.

Functional leg length is the perpendicular distance between the greater trochanter and the sole of the foot.

Leg length is the measured distance along the long bones of the leg (eliminating leg contour) between the greater trochanter and the sole of the foot.

Residual volume is the volume of air in the lungs and air passages at the end of a maximal expiration.

Stride frequency is the number of steps that were taken to cover 80 meters in one minute.

CHAPTER II

REVIEW OF LITERATURE

Basically, the energy cost researchers were in agreement on the relationship of energy cost to speed, grade, weight, friction and training. The research in the area of energy cost and age, some morphological characteristics, and sex difference was vague and limited in quantity.

Effects of Speed

Previous research on male and female subjects walking showed a curvilinear relationship between energy cost and speed.

Passmore and Durnin (53) summarized the data on energy expenditure during walking from five different laboratories in five different countries: England, Austria, United States, Germany and Italy. The agreement between laboratories was so good that any other data seemed unnecessary. The results showed that over a limited range of 3.0 to 6.5 Km/hr. (approximately 2-4 mph.) energy expenditure was linearly proportional to speed. At higher speeds (above 6.5 Km/hr.) energy expenditure increased at a faster rate.

McDonald (41) reported a curvilinear relationship of

heat output per kilogram of body weight to speed for males, and a linear relationship between speed and energy cost for females. The author stated that the range of spped of the female subjects was probably too small to demonstrate non-linearity. McDonald also suggested that the effects of weight on energy cost were independent of walking speed.

Bobbert (4), Henry (31), and Workman (62) all agreed that there was a curvilinear relationship between energy cost and speed.

Effects of Incline

In previous research the grade of walking and energy cost was expressed as a curvilinear relationship.

The most comprehensive treadmill study of grade walking was carried out by Margaria (53). Margaria studied the energy cost of walking up gradients of 0, 5, 15, and 25 per cent. On very steep inclines, and especially at slow speeds, energy expenditure was appreciably more than when walking on the level.

Keys, Brozek, Henschel, Michelson and Taylor (53) found the mean rate of energy expenditure of 16 healthy subjects, average weight 70.6 kg., walking at 5.6 Km/hr. up a 10 per cent incline, to be 8.9 Kcal/min. This point fell almost midway between the lines for the 5 and 15 per cent slopes suggested by Margaria.

Bobbert (4) observed that energy cost increased with the square of speed, both in level and grade walking, and that

energy cost increased curvilinearly with the geometric angle (in degrees). Therefore, Bobbert concluded that the only difference between level walking and grade walking was the amount of vertical work performed.

Workman (62) considered the oxygen consumption of grade walking as the excess of oxygen consumption over that observed walking on the level at the same speed. According to Workman, this excess should be, but was not, simply related to body weight. For 42 determinations on eight individuals, the excess $\dot{V}o_2$ of grade walking was related to the product of ground speed and grade.

McDonald (41) made a survey of the published data on the gross metabolic cost in Kcal/min. of walking at known speeds and at known gradients. The regression analysis of the total 206 observations on 59 men walking uphill yielded a curvilinear relationship.

Effects of Weight

Most authors presented excellent information regarding the energy expenditure of walking at given speeds and at given grades. However, the influence of body weight on energy cost was also an important variable. Many researchers of speed and grade energy cost studies assumed a linear relationship between energy cost and body weight. This assumption was probably valid, but there seemed to be little agreement as to the exact relationship between body weight and energy expenditure.

Mahadeva, Passmore and Woolf (42) measured fifty subjects walking under standard conditions at 4.8 Km/hr. (3 mph.). Mahadeva (42) reported the relationship between the body weight and energy expenditure during walking as $c = 0.047W + 1.024$ where c was energy expenditure in kilocalories per minute.

In a more recent study, Malhotra (44) measured the energy expenditures of marching rifle drill, parading, physical training, bayonet fighting, cycling, sitting, and standing of a group of male subjects. Malhotra included basal values in expressing energy expenditures. The energy expenditures in terms of kilocalories per minute for different exercises were plotted against the body weight of the different subjects. For almost all tasks there was a linear or curvilinear relationship between energy expenditures for tasks in which the whole body is involved. It was surprising to Malhotra to find the same type of relationship for cycle riding, where only thigh and leg muscles take part. Malhotra explained that in adults, where the weight of the limbs is proportional to body weight, the net energy expenditure due to movement of legs and arms may be proportional to the entire body weight. The relationship between the body weight and the energy expenditure during walking was 0.058W. Malhotra stated that the difference between his values and Mahadeva's values may have been due to the greater swing of arms during military marching as compared with ordinary-walking, as well

as to the speed of walking.

Workman (62) stated that no energy cost prediction equation has been produced that was not invalid in some part of its range. Workman developed an equation to predict the energy cost of treadmill walking. He rationalized that oxygen consumption per step would be related to body weight, and the number of steps per minute would be a reciprocal function of height.

$$\dot{V}O_2 \text{ (level walking)} = \frac{\text{height (in)}}{0.0136 \text{ height} - 0.375} (1.92x^{0.176} - 1.445)$$

$$\cdot \text{body weight (lb)} \cdot (0.85x^2 - 3.94x + 9.66) (10^{-5})$$

x = speed (mph)

The predicting power of this equation was tested against his unpublished data on oxygen consumption of normal subjects, walking on the treadmill at various speeds and grades. For 84 determinations the correlation coefficient between measured and predicted $\dot{V}O_2$ was: $r = +0.935$.

Effects of Temperature, Training, Friction and Shoe Weight

Other factors found to influence the energy cost of walking were: (1) temperature, (2) training, (3) friction, and (4) shoe weight.

Several authors (21, 43, 50, 54) agreed that over a limited range of temperature the effects of temperature on the metabolic cost of work was very small. Extreme heat and extreme cold did affect the energy cost of work (10, 35).

Erickson (25), Cotes (13) and Taylor (37:133) reported a very slight decrease of energy expenditure in walking after

repeated performances of an experiment. The explanation given was that training resulted in better coordination of movements and, in this way, caused a slightly higher efficiency.

Passmore (53) and Daniels (4) related that the type of surface may have had a slight effect on the energy cost of walking. Passmore (53) pointed out that unless the surface was markedly rough the effect would probably not exceed 10 per cent more than walking on a flat surface.

According to Passmore (53) and Robinson (57), the oxygen consumption per kilogram was slightly higher if heavy shoes were worn.

Effects of Age, Morphology and Sex

Although there seemed to be general agreement among researchers that the previously mentioned factors did influence the energy cost of walking, there also seemed to be a group of factors in which there was little or no agreement as to their influence on the energy cost of walking. These factors were age, morphology and sex.

Age. The available literature on the effect of age on the energy cost of walking was controversial. Two authors, Adams (1) and Mahadeva (42) reported that age did not materially influence energy expenditure. Adams (1) stated that age had no effect on energy expenditure if the latter was divided by total body weight.

However, in two other studies, differences between the

energy expenditure of older and younger men performing the same tests were found. Both Grimby and Scalerhelm, reported by Adams (1), and Durnin and Mikulicic, reported by Durnin (22). found significantly higher oxygen consumption per kilogram for the group of older men.

Morphology. Studies on the influence of structural characteristics on the energy cost of walking were limited in number. Surface area was the only morphological factor which was studied by more than one person in its relationship to energy cost. Other factors were either not substantiated or not studied in relationship to energy cost.

Durnin (22) and Rasch (56) both concluded that surface area was no more useful as a standard unit of reference than was gross body weight.

Workman (62) considered oxygen consumption per step to be related to body weight, and the number of steps per minute related inversely to height. Dean (15) and Booyens (5) both considered leg length-stride length ratios, but did not statistically relate the leg length or stride length to energy cost.

Cotes (13) reported that he considered step frequency to have a fundamental role in the ergonomics of walking and that variations, such as pelvic shape, may account for variations in the step frequency-energy cost relationship.

Miller (46) concluded that the prediction values of anthropometric factors other than body weight were due

largely to their respective correlation with body weight, a finding that was substantiated by the partial correlations analysis in this study.

Sex. A limited number of studies were conducted on the energy cost of males and females walking. Such factors as age, temperature, weight of shoe, and weight were not considered in the experimental design. One study (41) used only the available energy cost values from the literature. There were basically five studies which dealt specifically with the energy cost of walking of male and female subjects. Of the five, two studies (23, 42) related that there was no difference in the energy cost of males and females, and two studies (5, 41) reported that there was a difference in the energy cost of male and female subjects. The one remaining study (13) reported a lower, but not significantly lower, energy cost for female subjects.

In a survey of the published data McDonald (41) found two regression equations best described the relationship between heat output per kilogram and speed. One equation may be fitted to the data for both women and men, but such an equation fits the data significantly less well (P 0.001) than the separate equations for men and women. McDonald concluded that there was a difference in the cost of walking between the sexes.

As a check on the reliability of the above conclusion, McDonald compared the heat output per body weight of male and female subjects at fixed speeds. The results were in good

agreement with those from the overall analysis. At each speed the estimated regression coefficient of $\log_{10}$Kcal on weight was greater for women than for men. McDonald concluded that $\log_{10}$Kcal increased more rapidly with weight for women than for men. Therefore, in estimating sex differences weight must be considered as well as speed. On the average, McDonald found that the energy expenditure was 12 per cent greater for a man than for a woman of the same weight walking at the same speed.

Booyens and Keatinge (5) measured the energy expenditure as related to frequency and length of stride of ten men and ten women while walking on a straight outdoor level track. These authors found that women expended significantly less energy per unit body weight than men at both speeds, (5.47 Km/hr. and 6.44 Km/hr.), and that women increased their walking speed mainly by increasing their frequency of stride. The smaller expenditure of energy of women was associated with their relatively short strides, and it was suggested that their lower expenditures were due to the smaller amount of work they performed in lifting the body vertically.

Cotes (13) also observed that in walking energy expenditure per kilogram of body weight was lower, but not significantly lower, in women than in men.

Durnin and Namyslowski (23), Mahadeva (42), Astrand (2) and Adams (1) observed no difference between men and women while walking or riding a bicycle.

Durnin and Namyslowski (23) measured variations in energy expenditure of ten men and ten women in four standardized activities. These activities were lying, sitting, walking on a treadmill on the level at 5.2 Km/hr., and walking on an incline up a ten per cent gradient at 4.3 Km/hr. No sex differences in energy expenditure per kilogram of body weight was found. If age is a factor in energy expenditure, it should be noted that the range of age for the men was 21 to 39 years and was 18 to 24 years for the women. The mean values were 25.4 years for men and 20.1 years for women.

CHAPTER III

PROCEDURE

Subjects

The subjects used in this study were twelve college women and twelve college men, students of Ball State University, who were asked to volunteer. An effort was made to select groups of men and women subjects with the same mean and range of height, weight and age.

Body Density Procedures

The body density was determined by weighing the subject in air and underwater. The underwater weight was corrected for the residual air volume in the lungs and the appropriate calculations were made to determine the percentage of fat free body mass.

Underwater Weighing. The subject was instructed to report to the pool in a fasting state and to empty his bladder before weighing. The weight in air was obtained to within 50 grams. The underwater weighing was performed in the deep end of a swimming pool. Suspended over the pool was a post mortem scale, graduated to 10 grams and a 9 kilogram capacity. A rope was attached to the wire leading from the scale.

Holding on to the side of the pool with the water at neck level, the subject was instructed to take three or four

normal breaths and after the last breath to empty his lungs completely. This expiration was completed before or after he submerged. The subject was instructed to grasp the rope with an index finger and to slowly let go of the side of the pool. When he was completely submerged, he suspended himself gently on the rope. The subjects were given a few practice trials until they were able to do this with little oscillation of the pointer. Three or four trials were usually enough to obtain a "good" reading (within $\pm$ 50 g). Three good readings were recorded with the mean representing the subject's underwater weight. The temperature of the water was taken at the time of weighing.

It was necessary to attach a "sinker" (a 10 lbs. lead weight) to some of the subjects in order to submerge them. This was necessary for twelve of the female subjects and three of the male subjects. In such instances, the underwater weight of the sinker was subtracted from the gross underwater weight of the subject plus the sinker, giving the subject's true underwater weight.

Residual Volume Procedure

The residual lung volume was measured by the method described by Myhre (49). The breathing apparatus used in making this measurement is described in Appendix A. The apparatus was tested for tight connections. The system was flushed with about 15 liters of oxygen, three times, before each experiment. During the flushing period, the subject

was seated in a chair. The subject was instructed to put on the nose clips and insert the mouthpiece. The breathing valve was adjusted so that the subject was breathing room air through the open side of the cock. After acquainting him with the whole procedure, the subject was instructed to make a maximum expiration, signalling with his hand when his lungs were completely emptied. The cock was then quickly turned 90° and the subject was instructed to begin breathing. The investigator regulated the flow of oxygen from the cylinder to the 5-liter anesthesia bag so as to maintain a partial inflation throughout the collection period. Before the end of the seven minutes, a syringe was attached to the sampling outlet located on the expiration side of the breathing valve. Near the end of about seven minutes the subject was instructed to repeat the maximal expiration procedure followed at the beginning of the experiment. The syringe was flushed three times and the alveolar sample was drawn towards the end of his expiration. When the subject had fully emptied his lungs, he signaled with his hand and the investigator turned the valve of the cock 90° allowing the subject to breathe room air once more. He was then disconnected from the mouthpiece and the nose clip was removed.

After mixing the expired gas in the meteorological balloon the gas was analyzed on the Beckman Analyzer. The volume of expired gas was metered by the Parkinson-Cowan CD4 Gasometer. The alveolar gas sample was analyzed on the Van Slyke monometric apparatus following the method described

in Appendix A.

Calculation of Body Fat

The body density (D_B) was estimated from the equation by Keys and Brozek (38) as follows:

$$D_B = \frac{MA}{\left(\frac{MA - M'_W}{D_W}\right) - V_R}$$

where MA = weight in air, kilograms

M'_W = apparent weight in water, kilograms

D_W = density of water at pool temperature

V_R = residual volume, liters at BTPS

The percentage of body fat was estimated from body density using the equation developed by Keys and Brozek (38), and later reconstructed by Brozek et al (7).

$$\text{Per Cent Fat} = 100 \left[\left(\frac{4.570}{D_B}\right) - \left(4.142\right)\right]$$

Energy Cost Procedures

Indirect open-circuit calorimetry was employed to measure the energy expenditure at rest and during exercise. A Collins J valve and a Collins 120 liter Chain-Compensated Gasometer were used to collect the resting samples. The Douglas Bag method with a Collins Triple J valve was utilized to determine the oxygen requirements for each subject during exercise. The volumes of expired air for the exercise samples

were metered by a Parkinson Cowan CD-4 gasometer.

A five hundred milliliter sample of exercise gas was taken directly from the meteorological balloon. The sample was analyzed for the per cent of oxygen and carbon dioxide by the Beckman LBI and E_2 gas analyzers. The expired air in the balloon was then metered for volume and temperature. The controlled environmental conditions of the laboratory consisted of a temperature between 24° and 26° C and a relative humidity of 50 per cent.

Standing energy cost was measured while the subject stood for six minutes. The expired air was collected for three minutes at the end of the standing period.

Exercise energy cost was measured while the subject walked at 80 meters per minute up a seven per cent grade for ten minutes. Speed and grade were calibrated with the subject on the treadmill.

The subjects were given approximately two minutes of practice at the intended speed and grade. Gas samples were collected for the last three minutes of each walk.

At the beginning of each walk the subject was instructed to straddle the treadmill, and at a given signal to start the walk. After walking six minutes the subject applied the mouthpiece and noseclips. The valve to the meteorological balloon remained closed in order to wash out the dead space in the connecting hose. At the seventh minute of exercise the collection of the expired air began and continued for

three minutes.

All subjects walked in shirts and shorts and without shoes. Body weight was measured before each exercise period in walking clothes, again meaning shirts, shorts, and without shoes.

The subjects repeated the energy cost test within one week of the original test.

Stride Frequency and Stride Length Procedure

The average stride frequency per minute and stride length were computed from four counts of strides at intervals of 30 seconds. Stride counts took place during the 4th, 5th, 6th, and 7th minute of each walk.

Leg Length and Bitrochanter Width

Leg length was determined by measuring the distance from the greater trochanter to the sole of the foot. During this measurement the subject was in a supine position with the ankle at 90°. A steel measuring tape was placed at the side of the subject. The tape was adjusted so that the beginning of the tape was parallel to the sole of the foot. A wooden 90° angle was placed parallel to the greater trochanter of the left femur of the subject and on the steel tape marking the length of the leg.

The bitrochanter width was determined by measuring the distance between the trochanters. The subjects wore nylon swimming suits for these measurements. The 90° angle of an

architecture "T" was placed on the subject's right greater trochanter and a clear plastic angle was placed on the T and on the left trochanter. Distance between the right angle of the T and the plastic angle was recorded as the bitrochanter width. Three readings were recorded with the mean representing the bitrochanter width.

Foot Width

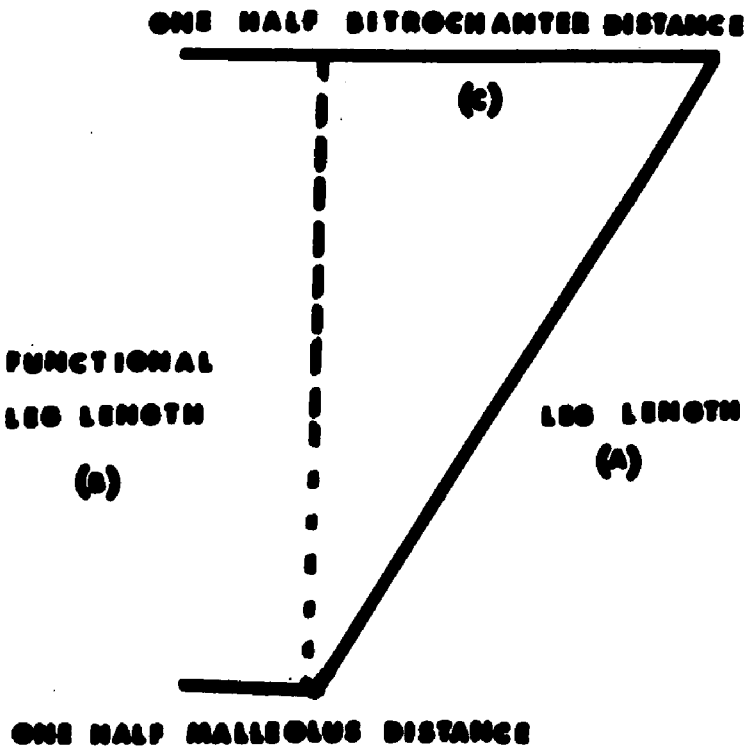
A piece of white construction paper twenty inches wide and seven feet long was utilized to record the subject's foot impression. The paper was placed on the treadmill while the subject was walking at 80 m/min up a 7 per cent grade. The impressions were made by a combination of moisture and dust on the subject's feet. The subject then stepped off of the treadmill and placed his foot on the impressions while an outline of the foot was drawn. The location of the right lateral malleolus and the location of the left lateral malleolus were marked on the foot impression outline.

A line parallel to the direction of movement and bisecting the left lateral malleolus was drawn. The horizontal distance between this line and the right lateral malleolus was measured. Three readings were recorded with the mean representing the horizontal distance.

Calculation of Functional Leg Length

The functional leg length was determined from a right triangle. Side (a) of the triangle was the length of the subject's leg; side (c) was one half of the greater trochanter

FIGURE 1
FUNCTIONAL LEG LENGTH ILLUSTRATION



width minus one half of the lateral malleolus foot impression marked distance, and side (b) was the length of the functional leg. Figure 1. The following formula (30:44) was used:

$$b = \sqrt{(a - c)(a + c)}$$

Statistical Treatment

Correlation. The linear relationship between two sets of measures may be expressed by the product-moment coefficient of correlation, designated by the letter r. Garrett (28:125) stated that "the product-moment coefficient of correlation may be thought of essentially as that ratio which expresses the extent to which changes in one variable are accompanied by or are dependent upon change in a second variable."

Energy cost (L/min) and the following variables were correlated: total body weight, leg length, stride frequency, bitrochanter width, and fat free body mass.

Regression Equations. Regression lines were drawn to represent the change in the mean value of Y over the given range of X (28:132).

Regression equations for the Y energy cost (L/min) and the following X variables were computed: total body weight, resting energy cost, and fat free body mass.

t-test. A t-test was employed to compare the energy cost of male subjects in this investigation to the energy cost of female subjects.

The male and female subjects in the investigation

were compared on the basis of the following variables: Gross $\dot{V}o_2$ L/min, Net $\dot{V}o_2$ L/min, $\dot{V}o_2$ ml/min.kg of total body weight, and $\dot{V}o_2$ ml/min.kg of fat free body mass.

CHAPTER IV

RESULTS

Characteristics of Subjects

Age, Height and Weight. The subjects in this investigation were selected on the basis of their age, height and weight. The mean age of the male subjects was 20.76 years, and the mean age of the female subjects was 20.03 years. The male subjects were 0.73 years older than the female subjects.

The female subjects were 0.5 centimeters taller than the male subjects. The standard deviation of the height of the male subjects was 2.65. The standard deviation of the height of the female subjects was 3.09. The mean height of the male and female subjects was 169.6 and 170.1 respectively.

The mean body weight of the male and female subjects was 65.92 kilograms and 65.35 kilograms. The body weight standard deviation was 4.34 for the male subjects and 6.65 for the female subjects. The male subjects weighed 0.57 kilograms more than the female subjects. Appendix B presents the individual values for age, height and weight.

Underwater Weight, Residual Volume, Body Density and Fat Free Mass. The underwater weighing technique, based on the Archimedean Principle to determine body density, was utilized in this investigation. The density of the whole

body is the ratio of the total weight of the body to the total body volume. The body density measurements were corrected for residual lung volume. From the density measurements an estimate of the fat free body mass was derived. Table 1 presents the underwater weight, residual lung volume, body density and fat free body mass values of the male and female subjects. The individual values of underwater weight, residual volume, body density and fat free mass are presented in Appendix B.

TABLE 1

MEAN UNDERWATER WEIGHT, RESIDUAL VOLUME, BODY DENSITY AND FAT FREE BODY MASS VALUES OF MALE AND FEMALE SUBJECTS

	Underwater Weight (kg)	Residual Lung Volume (L)	Body Density (g/cc)	Fat Free Mass (kg)
Male subjects				
Mean	3.35	1.53	1.07	57.11
SD	1.00	.19	.02	3.91
N 12				
Female subjects				
Mean	1.87	1.39	1.04	50.42
SD	.82	.26	.01	6.17
N 12				

The mean underwater weight for the male subjects was 3.35 kilograms and the standard deviation was 1.00. The mean underwater weight for the female subjects was 1.87 kilograms with a standard deviation of 0.82.

The mean residual lung volume for the male subjects was 1.53 liters and the standard deviation was 0.19. The mean

residual lung volume for the female subjects was 1.39 liters and the standard deviation was 0.26.

The mean body density for male and female subjects was 1.07 g/cc and 1.04 g/cc respectively. The standard deviations were .02 for the male subjects and .01 for the female subjects.

The mean fat free body mass of the male subjects was 6.69 kilograms greater than that of the female subjects. As evaluated by a t-test the observed difference was statistically significant at the .01 level with 22 degrees of freedom ($t = 3.17$).

Leg Length, Functional Leg Length and Stride Frequency. The mean leg length of the male subjects was 85.95 centimeters; the mean leg length for the female subjects was 90.44 centimeters. The standard deviation for the male and female subjects was 2.59 and 3.15 respectively.

The mean functional leg length for the male subjects was 85.36 centimeters with a standard deviation of 2.61. The mean functional leg length for the female subjects was 89.78 centimeters with a standard deviation of 3.14. The difference between means of the leg length and the functional leg length was 0.59 centimeters and 0.66 centimeters for the male and female subjects.

The mean stride frequency for the female subjects was 119.4 strides per minute and the mean stride frequency for the male subjects was 117.7 strides per minute. Individual values for leg length, functional leg length and stride frequency are presented in Appendix B.

Bitrochanter Width and Malleolus Width. The male subjects had a smaller bitrochanter width than the female subjects. The mean values for the male and female subjects were 32.52 centimeters and 34.27 centimeters respectively. The standard deviations for the male and female subjects were 2.48 and 1.24 respectively. The difference between the two means was significant at the .05 level.

The measured distance between the right and left lateral malleolus of the male subjects was 13.02 centimeters. The standard deviation was 3.93. The lateral malleolus perpendicular distance for the female subjects was 12.53 centimeters with a standard deviation of 3.32. Appendix B presents the individual bitrochanter widths and the lateral malleolus distances.

Reliability

All subjects repeated the energy cost test within one week of the original test. The energy cost test-retest reliability coefficient was r = 0.90. The mean value for the first test was 1.56 $\dot{V}O_2$ L/min. The retest mean value was 1.52 $\dot{V}O_2$ L/min. The retest energy cost value was 0.04 L/min. less than the first test energy cost value. The single group method for determining the difference between two correlated means revealed a significant difference between test one and test two (t = 4.17).

TABLE 2

COMPARISON OF OXYGEN CONSUMPTION ($\dot{V}O_2$ L/MIN) BETWEEN THE TWO EXERCISE PERIODS

	$Walk_1$	$Walk_2$	Mean	t
Mean	1.56	1.52	1.54	4.17*
SE	.028	.024	.026	
N 24				

*Significant at the .01 level with 46 degrees of freedom.

Sex Difference in Energy Cost

The mean energy cost values for walking at 80 m/min up a 7 per cent grade for the male and female subjects in this investigation were 1.57 L/min and 1.50 L/min respectively. The standard deviations of the sample were 0.11 for the male subjects and 0.14 for the female subjects. The difference between the means was 0.07 L/min and the t was 1.29 which was not significant at the .05 level. Appendix C lists the individual values for energy cost.

The resting oxygen consumption was determined while the subjects stood for approximately six minutes prior to the two exercise periods. The mean of the two separate energy cost determinations for rest and exercise was computed. The net oxygen consumption was determined by subtracting the resting $\dot{V}O_2$ from the exercise $\dot{V}O_2$.

The mean value for the male subjects in terms of net oxygen consumption was 1.22 L/min, and the standard deviation was 0.082. The mean net oxygen consumption value for the female subjects was 1.20 L/min with a standard deviation of 0.121. The difference between the means of the male and female subjects was 0.02 L/min. The results of the t-test were not significant at the .05 level.

The mean energy cost per kilogram of fat free mass for the male subjects was 27.33 ml/kg.min. The difference between the groups was 2.73 ml/min (FFM) kg and there was no significant difference between the two groups at the .01 level. However, the t-test results were significant at the .05 level.

The mean energy cost per kilogram of body weight of the clothed female subjects was 22.58 ml/min.kg and the standard deviation of the sample was 0.81. The mean and the standard deviation for the clothed male subjects were 23.49 ml/min.kg and 0.78 respectively. The difference between the means was 0.91 ml/min.kg. A t-test with 22 degrees of freedom showed no significant difference between the two groups at the .01 level, and a significant difference at the .025 level. Table 3 presents the energy cost mean values and the t-test results. Individual data on energy cost is presented in Appendix C.

Relationship of Selected Factors and Energy Cost

Nude body weight, leg length, fat free body weight,

TABLE 3

SUMMARY OF t-TESTS OF ENERGY COST, NET ENERGY COST, ENERGY COST PER FAT FREE MASS AND ENERGY COST PER BODY WEIGHT

Variables	Male Mean	SE	Female Mean	SE	Mean Difference	t
$\dot{V}O_2$ L/min	1.57	0.031	1.50	0.040	0.07	1.29
Net $\dot{V}O_2$ L/min	1.22	0.022	1.20	0.035	0.02	0.64
$\dot{V}O_2$ ml/kg min fat free mass	27.33	0.637	30.06	1.030	-2.73	2.25[a]
$\dot{V}O_2$ ml/kg min total body weight	23.49	0.227	22.58	0.234	0.91	2.80[b]
N = 24						

[a]Significant at the .05 level with 22 degrees of freedom

[b]Significant at the .025 level with 22 degrees of freedom

stride frequency and bitrochanter width were correlated with energy cost (L/min). Table 4.

TABLE 4

SUMMARY OF CORRELATIONS OF ENERGY COST AND OTHER VARIABLES

Correlation of Energy Cost L/min and Variables	Correlation (r) for male subjects	Correlation (r) for female subjects	Correlation (r) for all subjects
Nude Body Weight	0.76[a]	0.77[a]	0.70[b]
Leg Length	-0.10	0.42	0.00
Fat Free Body Weight	0.28	0.45	0.46[c]
Stride Frequency	0.15	-0.09	-0.04
Bitrochanter Width	-0.23	0.50	-0.07

[a]Significant at the .01 level with 10 degrees of freedom.
[b]Significant at the .01 level with 22 degrees of freedom.
[c]Significant at the .05 level with 22 degrees of freedom.

The highest correlation, of the five factors correlated with energy cost, was the body weight-energy cost correlation. The correlation coefficients of the males, females and total group were $r = 0.76$, $r = 0.77$ and $r = 0.70$. All three correlation coefficients were significant at the .01 level with 10, 10, and 22 degrees of freedom respectively.

The relationship of leg length to energy cost correlation coefficients were $r = -0.10$, $r = 0.42$ and $r = 0.00$ for the male subjects, female subjects and the total group. None

of these correlation was significant with the corresponding degrees of freedom at the .05 level.

A product moment correlation was employed to describe the relationship between the energy cost of walking and fat free body mass. The correlation for the total twenty-four subjects was r = 0.46. This correlation was significant at the .05 level and not significant at the .01 level. The correlation for the male subjects alone was r = 0.28 and for the female subjects alone the correlation was r = 0.45. A z test of significance was employed to test the difference between the male and female energy cost, fat free mass correlations. The z score was not significant at the .05 level.

Stride frequency and bitrochanter width correlations with energy cost were not significant. For the total group (both male and female subjects) the relationship of energy cost and these two factors was very low and negative.

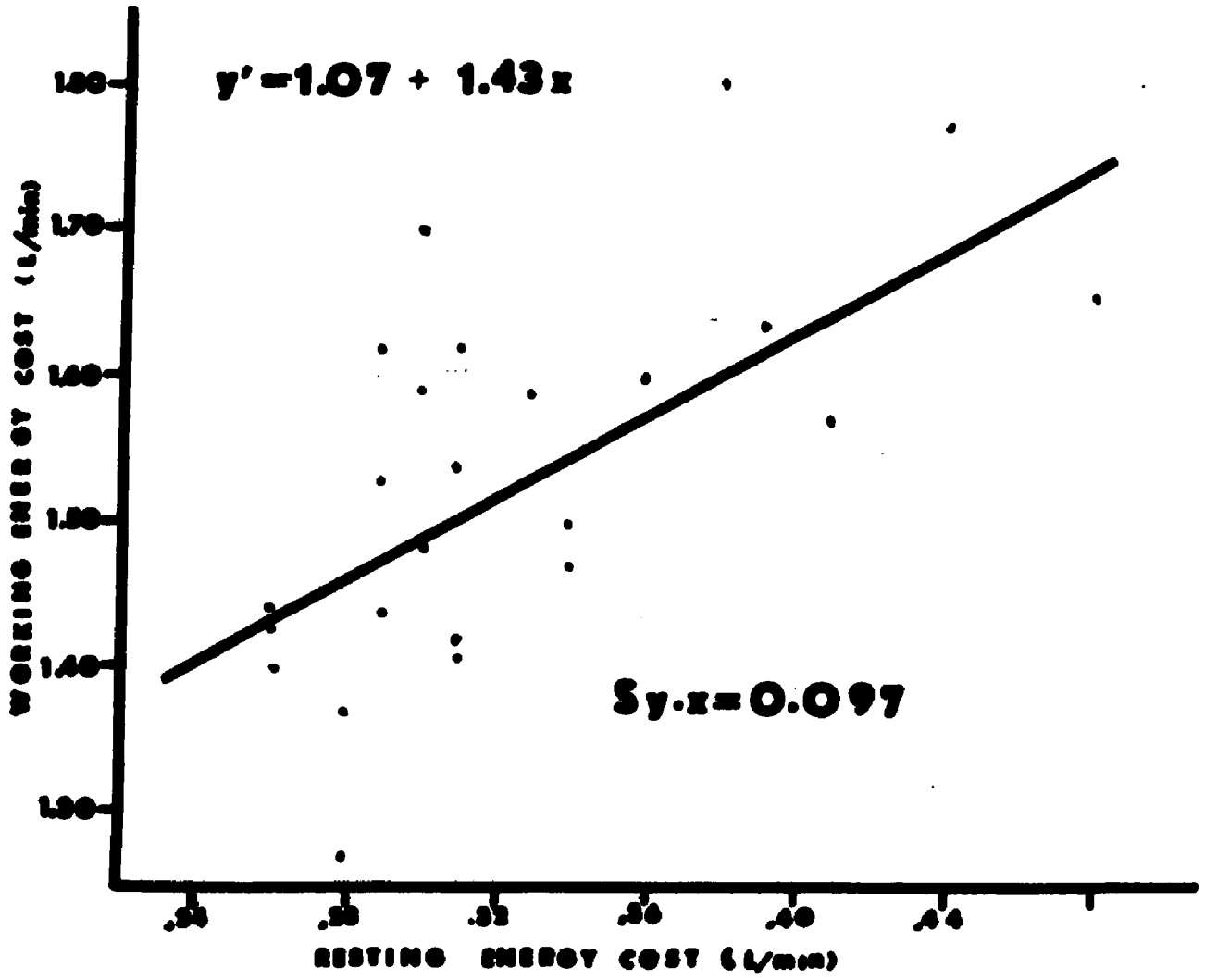
Energy Cost Relationship to Resting Energy Cost, Fat Free Body Weight, and Body Weight

Regression equations were computed to show the inter-relationship between energy cost (L/min) and the following three other variables: resting energy cost (L/min), fat free body weight (kg), and gross body weight (kg).

The linear regression equation in Figure 2 describes the relationship between working energy cost (L/min) and resting energy cost (L/min). The correlation coefficient for the two variables was r = 0.64 and the standard deviation

FIGURE 2

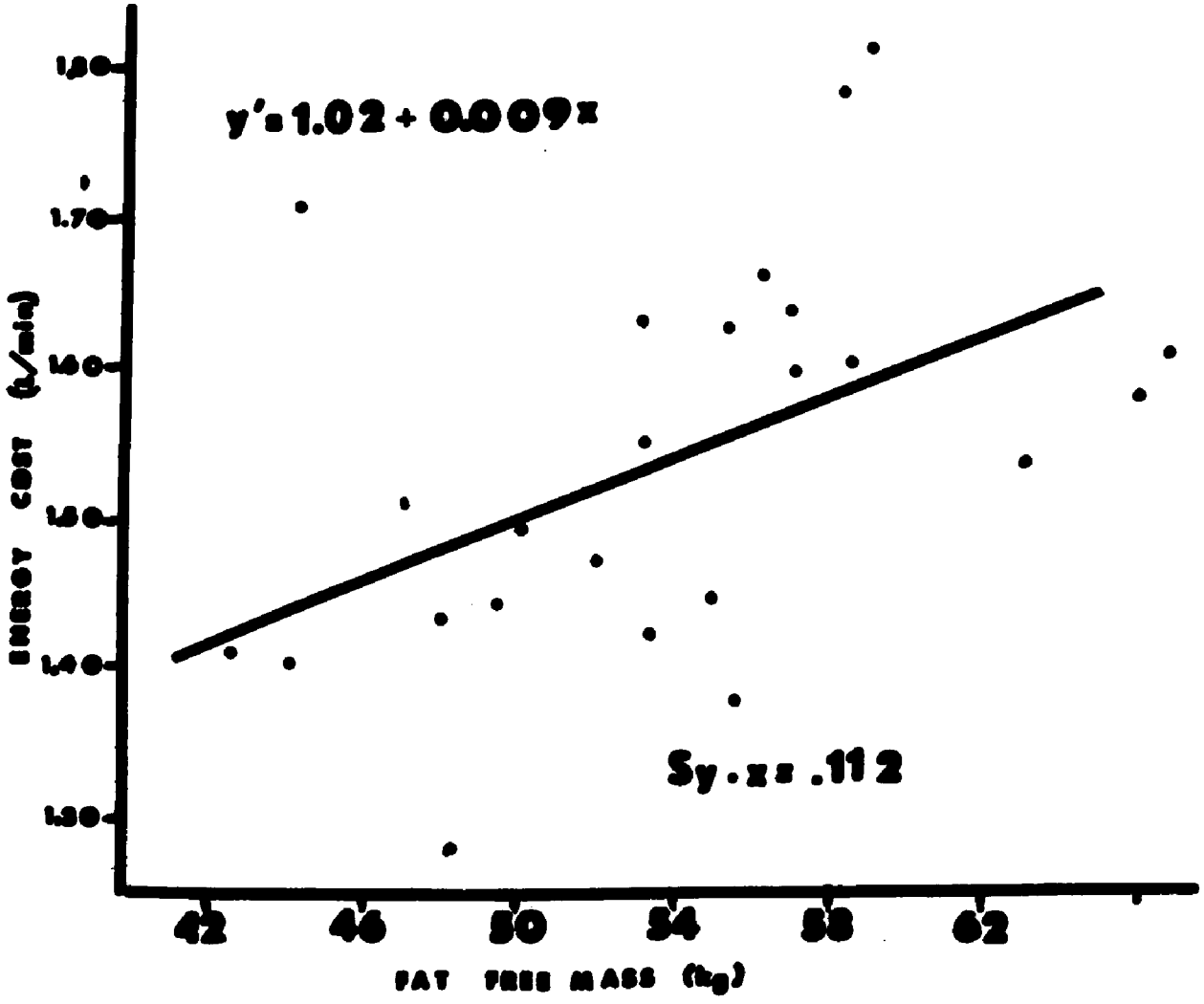
WORKING AND RESTING ENERGY COST



N = 24

FIGURE 3

ENERGY COST AND FAT FREE MASS



N = 24

of x•y was 0.097. The regression was evaluated by a t-test. The regression was significant at the .01 level with 22 degrees of freedom. Linearity was assumed.

The fat free mass regression equation, Figure 3, was also significant at the .01 level and linearity was assumed. The correlation was r = 0.46.

The interrelationship between body weight including clothing and energy cost can be described by the regression line in Figure 4. The standard deviation of x•y was 0.07, and the correlation was r = 0.82. The regression was significant at the .01 level and linearity was assumed.

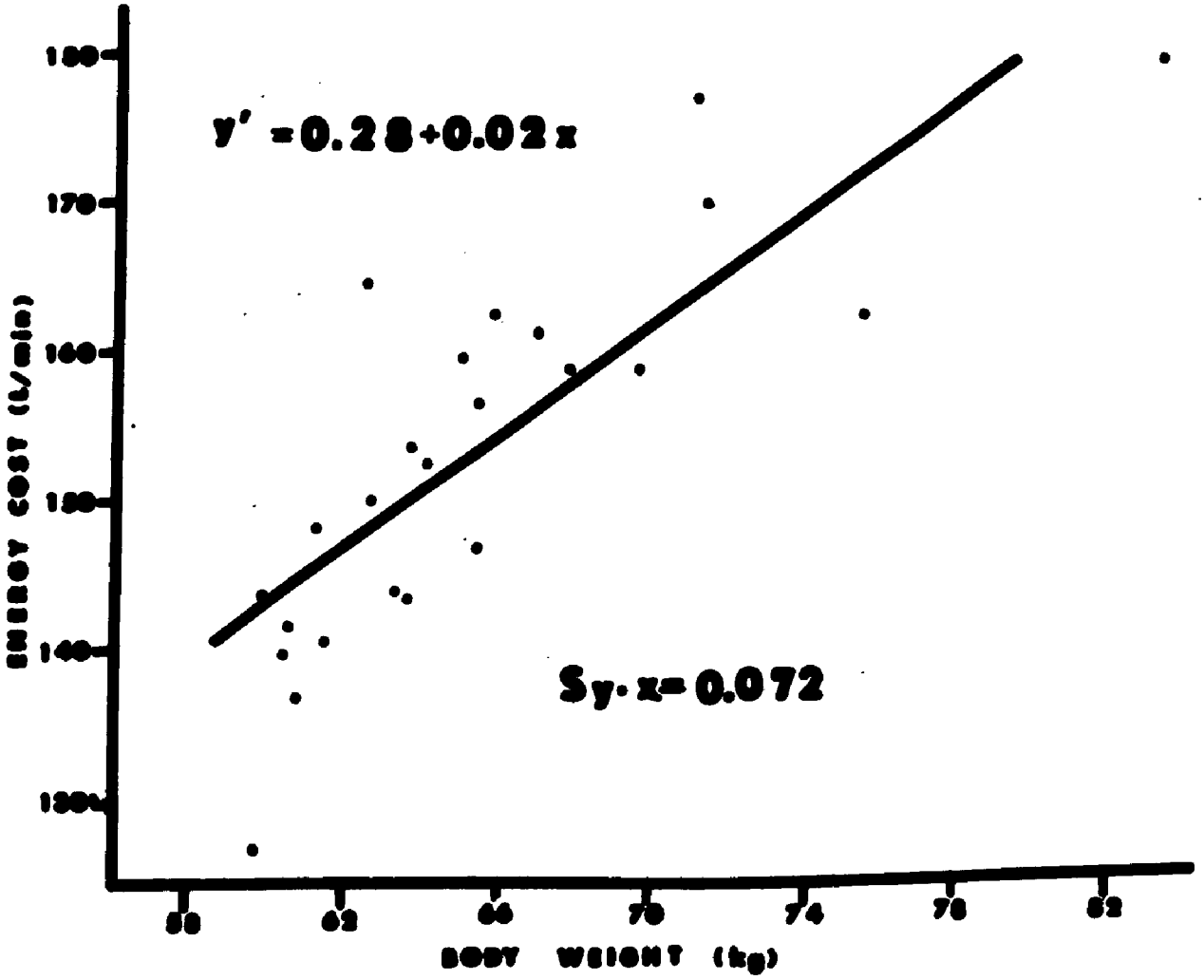
Stride Length, Leg Length Ratios

The stride length, leg length ratio was computed by dividing the stride length by the leg length. Appendix B. The mean ratio for the male subjects was 0.792 and the mean ratio for the female subjects was 0.741. The male subjects took longer strides per leg length than the female subjects.

The mean ratio of stride length to functional leg length was 0.798 and 0.754 for the male and female subjects. The mean ratios of stride length to measured leg length (stated above) were 0.792 and 0.741 for the male and female subjects. The difference between the male and female ratios for functional leg length was 0.044; the difference between the male and female ratios for measured leg length was 0.051. The difference between the two ratios was tested with a t-test and a t of 0.86 was obtained which was not significant at the .05 level.

FIGURE 4

ENERGY COST AND TOTAL BODY WEIGHT



N = 24

CHAPTER V

DISCUSSION AND CONCLUSIONS

Discussion

The primary question answered in this investigation was whether there was a difference in the oxygen consumption of males and females walking up a 7 per cent grade at 80 meters per minute. The energy cost was measured in units of oxygen consumption (L/min), net oxygen consumption (L/min), oxygen consumption per fat free mass (ml/kg.min) and oxygen consumption per body weight (ml/kg.min).

Results varied. To begin with, the energy cost values for oxygen consumption (L/min) and net oxygen consumption (L/min) did not distinguish male subjects from female subjects of approximately the same weight. But, when oxygen consumption per unit of fat free mass and body weight were considered, an increasing difference evolved. The male subjects had a higher energy cost per unit of body weight and a lower energy cost per unit of fat free mass than the female subjects. The effect of dividing energy cost (L/min) by body weight and fat free mass may have caused some of the discrepancies in the energy cost literature. Both McDonald (41) and Booyens (5) found a difference in energy cost per body weight to distinguish males from females. Other researchers

(23, 42) who found no difference in the energy cost of male and female subjects also divided by body weight. Various reasons, shoe weight, age and race, may have contributed to errors in their energy cost data. In addition, the effects of training may have contributed to errors in the energy cost literature. In this investigation the oxygen consumption (L/min) values for the first walking test were significantly higher than the oxygen consumption (L/min) values of the second walking test. Taylor (37:133) reported that repeated bouts of walking on a treadmill resulted in an improvement in the oxygen cost of walking.

In this investigation the relationship of energy cost to body weight improved when total body weight, including clothing, was considered. The fat free mass-energy cost correlation was lower than the nude body weight-energy cost correlation, and the nude body weight-energy cost correlation was slightly lower than the total body weight-energy cost correlation. There seemed to be little doubt that energy cost increased with increase in total body weight.

Rasch (56) reported a significant correlation for energy cost and calculated fat free mass. The use of anthropometrics to predict fat free mass, as Rasch used, may have interjected another possible error in energy cost studies. It was possible that the anthropometric measures reflected some portion of total body weight in estimating fat free mass.

It was possible that the bitrochanter width for the

female subjects also reflected body weight. In general the women with the greatest bitrochanter width also had the greatest weight. This was not true of the male subjects, and the correlation for the female subjects was much higher than the correlation for the male subjects.

This possibility of structural characteristics reflecting body weight may also explain the differences in the leg length correlations. Again the female subjects who were heavier had the longest leg length.

Stride frequency did not seem to have any influence on the energy cost of grade walking at 80 meters per minute. It may be that there was no stride frequency energy cost relationship.

The stride length-leg length ratio revealed that the female subjects took shorter strides per leg length than the males. Other researchers (13, 5) reported the same type of relationship.

The functional leg length-stride length ratio was derived for the purpose of equalizing the leg length-stride length ratios of the female and male subjects. However, the results of this investigation showed no appreciable difference between the two ratios, functional and measured. The reason for this may be that the women subjects took shorter steps per stride than the male subjects did, or that the measurement used in this study was not accurate enough to reflect a difference in the leg length-stride length ratios.

Conclusions

Within the limits of this investigation the following conclusions can be drawn:

1. In the physical activity of walking, a large proportion of energy was used to move the total body weight.
2. In the physical activity of walking, the energy cost of male and female subjects was not greatly influenced by leg length, stride frequency or bitrochanter width.
3. In the physical activity of walking, there was no significant difference in the oxygen consumption (L/min) of male and female subjects.
4. In the physical activity of walking, there was a significant difference in the oxygen consumption (ml/kg.min) per unit of body weight of male and female subjects.

Recommendations

The following suggestions were made for future research:

1. An investigation of the effects of shoe weight on the energy cost of male and female subjects.
2. An investigation of the effects of various environments on the energy cost of male and female subjects walking at 80 meters per minute.
3. An investigation of the effects of the degree of plantar flexion and of hip extension on the energy cost of walking.
4. An investigation of the effects of the amount of vertical movement of the center of gravity on the energy cost of male and female subjects.

REFERENCES

1. Adams, W. C. "Influence of Age, Sex, and Body Weight on the Energy Expenditure of Bicycle Riding." Journal of Applied Physiology. 22 (1967), 539-545.

2. Astrand, P. O. Experimental Studies of Physical Working Capacity in Relation to Sex and Age. Copenhagen: Munksgaard, 1952.

3. _____, and Rohahl, K. Textbook of Work Physiology. New York: McGraw-Hill Book Co., 1970.

4. Bobbert, A. C. "Energy Expenditure in Level and Grade Walking." Journal of Applied Physiology. 15 (1960), 1015-21.

5. Booyers, J., and Keatinge, W. R. "The Expenditure of Energy by Men and Women Walking." Journal of Applied Physiology. 138 (1957), 165-171.

6. Brouha, L., et al. "Physiological Reactions of Men and Women During Muscular Activity and Recovery in Various Environments." Journal of Applied Physiology. 16 (1960), 133-140.

7. Brozek, Josef. "Changes of Body Composition in Man During Maturity and Their Nutritional Implications." Federation Proceedings. 11 (1952), 784-793.

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

9. Cavagna, G. A., et al. "External Work in Walking." Journal of Applied Physiology. 18 (1963), 1-9.

10. Consolazio, C. Frank, et al. "Environmental Temperature and Energy Expenditure." Journal of Applied Physiology. 18 (1963), 65-68.

11. _____, et al. Physiological Measurements of Metabolic Function in Man. New York: McGraw-Hill Book Co. Inc., 1962.

12. Cotes, J. E., et al. Federation Process. 16 (1957), 25.

13. _____, and Meade, F. "The Energy Expenditure and Mechanical Energy Demand in Walking." Ergonomics. 3 (1960), 97-199.

14. Cullumbine, H. "Heat Production and Energy Requirements of Tropical People." Journal of Applied Physiology. 2 (1950), 640-653.

15. Dean, G. A. "An Analysis of the Energy Expenditure in Level and Grade Walking." Ergonomics. 8 (1965), 31-47.

16. Diem, Konrad (Ed.). Documents Geigy Scientific Tables, (6 Ed). New York: Geigy Pharmaceutical Division of Geigy Chemical Corporation, 1962.

17. Dill, David Bruce. "Estimation of Body Fat in Man." Scientific Problems of Physical Culture, Physical Culture Research Institute. Warsaw, Poland, 7 (1953), 251-256.

18. _____. "Oxygen Used in Horizontal and Grade Walking and Running on the Treadmill." Journal of Applied Physiology. 20 (1965), 19-22.

19. _____, et al. "Sweat Electrolytes in Desert Walks." Journal of Applied Physiology. 23 (1967), 746-751.

20. DuBois, E. F. "Energy Metabolism." Annual Review of Physiology. 16 (1954), 125-134.

21. Durnin, J. V. G. A., and Namyslowski, L. "The Oxygen Consumption Energy Expenditures and Efficience of Climbing with Loads at Low Altitudes." Journal of Physiology. 128 (1955), 294-309.

22. _____. "The Use of Surface Area and of Body Weight as Standard of Reference in Studies on Human Energy Expenditure." British Journal of Nutrition. 13 (1959), 68-71.

23. _____. "Individual Variations in the Energy Expenditure of Standardized Activities." Journal of Physiology. (London) 143 (1958), 573-578.

24. Edholm, O. G., et al. "Energy Expenditure and Food Intake of Individual Men." British Journal of Nutrition. 9 (1955), 286.

25. Erickson, L., et al. "The Energy Cost of Horizontal and Grade Walking on the Motor Driven Treadmill." American Journal of Physiology. 145 (1945), 391-401.

26. Falls, H. B. (Ed.). Exercise Physiology. New York: Academic Press, 1968.

27. Fenn, W. O. "Frictional and Kinetic Factors in the Work of Sprint Running." American Journal of Physiology. 92 (1930), 583-611.

28. Garrett, H., and Woodworth, R. Statistics in Psychology and Education. New York: D. McKay, 1962.

29. Gray, E., et al. "Nutritional Requirements for Men at Work in Cold, Temperate and Hot Environments." Journal of Applied Physiology. 4 (1951), 270-5.

30. Hart, W. L. Trigonometry. Boston: D. C. Heath and Co., 1954.

31. Henry, F. M. "The O_2 Requirement of Walking and Running." Research Quarterly. 24 (1953), 169-175.

32. Hertig, B. A., et al. "Artificial Acclimatization of Women to Heat." Journal of Applied Physiology. 18 (1963), 383-386.

33. Hill, A. V. "The Mechanics of Work." Science. 131 (1960), 897-899.

34. Hoel, P. Elementary Statistics. 2nd ed. New York: J. Wiley and Sons, Inc., 1966.

35. Horvalt, S. M., and Golden, H. "Men Performing a Standard of Work in Low Ambient Temperatures." Journal of Clinical Investigation. 26 (1947), 311-19.

36. Johnson, R. E. Federation Process. 22 (1963), 1439-1446.

37. Johnson, Warren R. (Ed.). Science and Medicine of Exercise and Sports. New York: Harper and Brothers Publishers, 1960.

38. Keys, A., and Brozek, J. "Body Fat in Adult Man." Physiological Reviews. 33 (1953), 245-325.

39. Klausen, K., et al. "Metabolic Reactions to Work in the Desert." Journal of Applied Physiology. 22 (1967), 292-298.

40. Kleiber, M. "Body Size and Metabolic Rate." Physiology Review. 27 (1947), 511-41.

41. McDonald, Ian. "Statistical Studies of Recorded Energy Expenditure of Man, II Expenditure on Walking Related to Weight, Sex, Age, Height, Speed and Gradient." Nutrition Abstracts Review. 31 (1961), 739-62.

42. Mahadeva, K., et al. "Individual Variations in the Metabolic Cost of Standardized Exercises; the Effects of Food, Age, Sex, and Race." Journal of Physiology. (London), 121 (1953), 225-31.

43. Malhotra, M. S., et al. "Effect of Environmental Temperature on Work and Resting Metabolism." Journal of Applied Physiology. 15 (1960), 767-770.

44. _____. "Influence of Body Weight on Energy Expenditure." Journal of Applied Physiology. 17 (1962), 433-35.

45. Margaria, R., et al. "Kinetics and Mechanism of Oxygen Debt Contraction in Man." Journal of Applied Physiology. 18 (1963), 371-7.

46. Miller, A. T. "Influence of Body Type and Body Fat Content on the Metabolic Cost of Work." Journal of Applied Physiology. 8 (1955), 139-41.

47. Montoye, H. J. "Probability as Applied to the Design of Experiments in Health, Physical Education, and Recreation." The Research Quarterly. 26 (1955), 486-487.

48. Morimoto, T., et al. "Sex Differences in Physiological Reactions to Thermal Stress." Journal of Applied Physiology. 22 (1967), 526-32.

49. Myhre, L. "A Comparison of Potassium-40 Measurements of Body Composition." Unpublished Ed.D. Dissertation, Indiana University, 1966.

50. Nelson, N. A., et al. "Influence of Clothing, Work and Air Movement on the Thermal Exchanges of Acclimatized Men in Various Hot Environments." Journal of Clinical Investigation. 27 (1948), 209-216.

51. Ogasawara, M. "Energy Expenditure in Walking and Running." Journal of Physiology. 81 (1934), 255-64.

52. Orsini, D., and Passmore, R. "Energy Expended Carrying Loads Up and Down Stairs." Journal of Physiology. 115 (1951), 95-100.

53. Passmore, R., and Durnin, J. V. G. A. "Human Energy Expenditure." Physiology Reviews. 35 (1955), 801-840.

54. _____, and Johnson, R. E. "Some Metabolic Changes Following Prolonged Moderate Exercises." Metabolism. 5 (1960), 452-5.

55. Peters, John P., and Van Slyke, D. D. Quantitative Clinical Chemistry Methods, (Vol. II). Baltimore: William and Wilkins Co., 1932.

56. Rasch, P. J., and Pierson, W. R. "The Relation of Surface Area, Mass, and Indices to Energy Expenditure." Review of Canadian Biology. 21 (1962), 1-6.

57. Robinson, S. "Effect of Body Size Upon Energy Exchange in Work." American Journal of Physiology. 136 (1942), 363-368.

58. Seltzer, C. C. "Body Build and Oxygen Metabolism at Rest and During Exercise." American Journal of Physiology. 129 (1940), 1-13.

59. Siegel, S. Nonparametric Statistics for the Behavioral Sciences. New York: McGraw-Hill Book Co., Inc., 1956.

60. Van Slyke, D., and Sendroy, J. "Manometric Analysis of Gas Mixtures. I. The Determination by Simple Absorption of Carbon Dioxide, Oxygen and Nitrogen in Mixtures of These Gases." Journal of Biological Chemistry. 95 (1932), 509-529.

61. Weinman, K. P., et al. "Reactions of Men and Women to Repeated Exposure to Humid Heat." Journal of Applied Physiology. 22 (1967), 533-8.

62. Workman, J., and Armstrong, B. W. "Oxygen Cost of Treadmill Walking." Journal of Applied Physiology. 18 (1963), 798-803.

63. _____. "A Nomogram for Predicting Treadmill Walking Oxygen Consumption." Journal of Applied Physiology. 19 (1964), 150-1.

64. Wilmore, J. H. "The Use of Actual, Predicted and Constant Residual Volumes in the Assessment of Body Composition by Underwater Weighing." Medicine and Science in Sports. 1 (1969), 87-90.

APPENDIX A

EXPERIMENTAL EQUIPMENT

The experimental equipment used in this investigation consisted of the following: (1) residual volume apparatus, (2) underwater weighing device, (3) Van Slyke monometric apparatus, (4) treadmill, (5) Beckman LB-1 and E2 gas analyzers, (6) Parkinson-Cowan CD4 Gasometer, (7) Tissot gasometer, and (8) anthropometer breadth caliper. A detailed description of the equipment is presented in this appendix. The exact procedure followed in performing the experiments is given in Chapter IV.

Residual Volume Apparatus

The residual lung volume was measured by the open circuit dilution method described by Myhre (49). For descriptive purposes, the apparatus used in this experiment may be separated into the following three categories: (1) expired gas collection, (2) terminal alveolar air sampling, and (3) the system for measuring and sampling the collected gas.

(1) Expired gas collection. A cylinder of oxygen was connected to the small-hose inlet of a 5-liter anesthesia bag by a length of rubber tubing. The large-diameter outlet of this bag was directly connected to a two-way breathing

valve. A rubber mouthpiece attached to the valve was easily removed for cleaning. (In one position, the breathing valve allowed the subject to breathe room air, while in the other position, oxygen from the anesthesia bag was expired into a 100-liter meteorological balloon.) Collection proceeded for seven minutes.

(2) Terminal alveolar air sampling. A hole was drilled through the outer wall of the one-way valve, located between the breathing valve and the collection bag, and a tube, 6 cm long, 4 mm inside and 6 mm outside diameter, was inserted and brazed in position. A stopcock was slipped into the tube. The alveolar air sample was drawn from this sampling cock near the end of the 7 minute breathing period.

(3) System for measuring and sampling the collected gas. The meteorological balloon was metered through a Parkinson-Cowan dry gas meter. The gas volume was read to the nearest tenth of a liter and the temperature of the gas was taken by means of a telethermometer placed in the gas meter.

The alveolar air gas samples were drawn into 50 ml ground glass syringes which were lubricated with ethylene glycol. The expired air gas sample was analyzed directly from the meteorological balloon by the Beckman- CO_2 and O_2 analyzer. The alveolar air gas sample was analyzed on the Van Slyke apparatus.

Underwater Weighing Device

A post mortem scale, Aloe precision, 9 kg capacity with 10 g graduations, was attached to the pool diving board. The weighing pan (original equipment) was removed from the scale and a number of lead weights attached in its place. The weights coupled with a minor adjustment of the fine adjustment screw provided a balanced scale.

Analysis of O_2-N_2 on the Van Slyke Monometric Apparatus

The alveolar gas samples were analyzed on the Van Slyke monometric apparatus using the following method described by Dill (17), which was a modified version of the method described by Van Slyke and Sendroy (60), and later by Peters and Van Slyke (55).

Absorbing reagent. The oxygen-carbon absorbing reagent was sodium hydrosulfite (sodium dithionite), $Na_2S_2O_4$, 10 g in 40 ml of 2N KOH. To prepare the reagent, the sodium hydrosulfite was introduced into a 50 ml Erlenmeyer flask, followed by the KOH. The flask was stoppered and mixed long enough to dissolve the sodium hydrosulfite. The stopper was removed and a 1 cm layer of mineral oil was quickly added to prevent access to the air.

The procedure followed in analyzing the gas samples from the residual volume experiment was as follows:

1. The analysis began with the Van Slyke apparatus completely void of gases. The main entry stopcock bores were

plugged with mercury; the cup contained about 1 ml of mercury.

2. The initial reading was made by lowering the mercury in the extraction chamber to the 50 ml mark. P_0 was recorded.

3. After the initial reading, the mercury was allowed to rise slowly to the top of the extraction chamber; the mercury leveling bulb remained at the lower level.

4. Introduction of the sample. The 50 ml sampling syringe was supported alongside the Van Slyke with its connected tube a few cm above the cup on top of the extraction chamber. The syringe was supported vertically with the plunger up, exerting a slight positive pressure on the gas sample. The glass tubing used in transferring the sample had an inside diameter of 1 mm and an outside diameter of 7 mm. One end was attached to the syringe and the other end, provided with a rubber tip, was drawn down and submerged in the mercury in the bottom of the cup. About 10 ml of the sample was bubbled through the mercury to flush out the connection. At this point the sample was admitted into the extraction chamber by holding the rubber tip of the glass tube firmly against the bottom of the cup and slowly opening the main entry stopcock (mercury leveling bulb still at the lower level.)

5. When about 35 ml of the sample had been introduced into the chamber, the main entry stopcock was closed and the glass tube attached to the sampling syringe was removed. The stopcock bore was then plugged with mercury and the mercury in the extraction chamber was lowered to the 50 ml mark.

P_1 was recorded.

6. With the mercury still at the 50 ml mark, 3 ml of the absorbing reagent was admitted. The tip of the 3 ml pipette was submerged in the mercury in the cup and held firmly against the bottom of the cup. The reagent was entered by first opening the main entry stopcock and then by slowly opening the pipette stopcock. The stopcock bore was again plugged with mercury.

7. The sample was mixed with the reagent for four minutes. At the end of every minute, the leveling bulb was raised and lowered two or three times to aid in the mixing of the gas.

8. At the end of four minutes, the mercury was lowered to the 50 ml mark. P_2 was recorded. The mercury was adjusted to the 10 ml level once more and mixed for another minute. P_2 reading checked. If P_2 had decreased, the shaking procedure was repeated until a constant reading was achieved.

9. With the mercury leveling bulb at the upper level, the remaining gas (nitrogen) was evacuated from the extraction chamber by slowly bubbling the gas through the mercury still in the cup. The mercury was lowered to the 50 ml mark. P_3 was recorded.

10. The concentration of nitrogen in the gas sample was determined by the following formula:

$$\text{Per Cent } N_2 = 100 \times \frac{\left[P_2 - P_3\right](.94)}{P_1 - P_0}$$

Calculation of Residual Volume

The nitrogen in the cylinder of oxygen was determined and subtracted from the nitrogen concentration of the collected expired gas. The formula for determining residual volume from the above observation was as follows:

1. The volume of gas collected V_s at temperature t_s, was calculated to body temperature and pressure dry:

$$V_s = \frac{(L)\ (310)\ (B - 47)}{(273 - t_s)\ (B - pH_2 \text{ at } t_s)}$$

Where L is the volume of the collected gas in liters as read from the gas meter t_s was the mean temperature of the gas as determined by the thermometers attached to the meter.

pH_2O at t_s was the pressure of saturated water vapor at t_s.

2. The ml of nitrogen, C, evolved from tissues during the 7 minute period was calculated according to the observations of Cournand, Yarmush, and Riley (56):

$$C = (\text{surface area in } m^2)\ (96.5) + 35$$

The surface area was estimated from height and weight.

3. The residual volume, dry, V_{Rd} was calculated as follows:

$$V_{Rd} = \frac{V_s\ (N_2\ (\%) \text{ in expired gas} - N_2\ (\%) \text{ in cylinder of } O_2)}{0.81 - (N_2\ (\%) \text{ in alveolar sample})} - C$$

4. Residual volume at body temperature and atmospheric pressure, saturated with water vapor, was calculated:

$$V_R = V_{Rd} \quad \frac{B}{B - 47}$$

Treadmill

A Quinton Treadmill Model 18-60 was used in this investigation. Speed and grade calibrations were conducted with the subject walking on the treadmill.

Calibration of Speed. A Revolution Counter was used to check the exact speed of the treadmill. The Revolution Counter was set at zero; the treadmill was adjusted to 80 meters per minute; the revolutions were counted for exactly one minute.

Calibration of Grade. A carpenter's level was used to level the treadmill. A distance of 91.44 centimeters was measured from the back of the treadmill toward the front. At the 91.44 centimeter mark the treadmill was raised 6.4 centimeters.

Beckman LB-1 and E2 Gas Analyzer

The Beckman Gas Analyzers were calibrated with standardized gases that had previously been analyzed by the Haldane Apparatus or the Van Slyke Apparatus.

Parkinson-Cowan CD4 Gasometer

The gasometer was calibrated with a tissot gasometer.

Tissot Gasometer

A Collins 120 liter chain-compensated gasometer was used to collect resting gas samples.

Anthropometer Breadth Caliper

The breadth caliper used in this experiment was constructed from an architecture T and a clear plastic angle.

Scale

Body weights were measured prior to each session by a Buffalo scale with a sensitivity of $\pm$ 10 grams.

APPENDIX B

PHYSICAL CHARACTERISTICS DATA

TABLE 5

AGE, HEIGHT AND WEIGHT VALUES FOR THE MALE SUBJECTS

Subject	Age	Ht(cm)	Wt(kg)
1	20.25	171.7	63.97
2	21.10	164.2	66.23
3	21.58	168.5	68.73
4	20.67	169.9	62.42
5	20.60	166.9	63.29
6	20.58	173.2	75.31
7	20.83	171.3	65.33
8	20.78	168.5	65.91
9	20.92	169.9	60.40
10	20.83	173.0	67.13
11	20.25	167.6	60.91
12	20.75	171.2	71.44
$\bar{X}$	20.76	169.6	65.92
SD	.36	2.65	4.34

TABLE 6

AGE, HEIGHT AND WEIGHT VALUES FOR THE FEMALE SUBJECTS

Subject	Age	Ht(cm)	Wt(kg)
13	19.58	166.7	61.47
14	20.08	171.2	69.85
15	20.83	174.7	60.11
16	19.67	167.0	62.83
17	20.42	168.6	61.24
18	20.33	173.7	63.97
19	20.58	164.6	59.88
20	20.00	168.9	60.56
21	20.42	170.6	65.77
22	19.67	172.6	82.88
23	19.42	172.8	71.45
24	19.42	169.2	64.19
$\bar{X}$	20.03	170.1	65.35
SD	0.48	3.09	6.65

TABLE 7

UNDERWATER WEIGHT, RESIDUAL VOLUME, BODY DENSITY AND FAT FREE BODY MASS OF MALE SUBJECTS

Subject	Underwater Weight (Kg)	Residual Lung Volume (L)	Body Density (g/cc)	Fat Free Mass (Kg)
1	2.48	1.79	1.06	53.29
2	2.77	1.70	1.06	55.39
3	3.33	1.53	1.06	58.47
4	3.42	1.30	1.07	56.11
5	3.18	1.70	1.07	55.12
6	2.16	1.59	1.04	56.87
7	4.93	1.64	1.10	64.51
8	5.56	1.49	1.11	64.76
9	3.27	1.46	1.07	53.58
10	2.51	1.12	1.05	53.03
11	3.77	1.43	1.08	55.94
12	2.86	1.65	1.06	58.32
$\bar{X}$	3.35	1.53	1.07	57.11
SD	1.00	.19	.02	3.93

TABLE 8

UNDERWATER WEIGHT, RESIDUAL VOLUME, BODY DENSITY AND FAT FREE BODY MASS OF FEMALE SUBJECTS

Subject	Underwater Weight (Kg)	Residual Lung Volume (L)	Body Density (g/cc)	Fat Free Mass (Kg)
13	.50	1.72	1.03	42.54
14	2.96	1.49	1.06	57.15
15	2.56	1.13	1.05	48.56
16	1.86	1.08	1.04	46.98
17	2.36	1.61	1.06	50.72
18	1.62	1.81	1.05	49.45
19	1.91	1.18	1.05	48.06
20	1.16	1.53	1.04	44.18
21	2.46	1.40	1.05	52.31
22	1.96	1.43	1.03	59.14
23	.44	.97	1.01	44.10
24	2.66	1.32	1.04	61.86
$\bar{X}$	1.87	1.39	1.04	50.42
SD	.82	.26	.01	6.17

TABLE 9

BITROCHANTER WIDTH, LATERAL MALLEOLUS WIDTH, LEG LENGTH, FUNCTIONAL LEG LENGTH AND STRIDE LENGTH--LEG LENGTH RATIO OF MALE SUBJECTS

Subject	Bitrochanter Width (cm)	Lateral Malleolus Width (cm)	Leg Length (cm)	Function Leg Length (cm)	Stride Length / Functional Leg Length
1	29.8	9.5	86.2	85.60	.8189
2	31.7	13.8	81.2	80.70	.7992
3	33.1	21.2	87.0	86.80	.7680
4	32.0	11.2	85.5	84.86	.8414
5	34.2	14.4	86.0	85.43	.7608
6	35.8	8.0	84.1	83.04	.8304
7	31.7	16.2	85.0	84.65	.7810
8	28.0	15.2	85.2	84.95	.7840
9	30.8	10.5	87.5	86.91	.7663
10	33.2	11.8	83.5	82.81	.8320
11	37.1	8.0	89.0	87.80	.8428
12	32.8	16.5	91.2	90.83	.7463
$\bar{X}$	32.52	13.02	86.96	85.36	.7975
SD	2.48	3.93	2.59	2.61	.033

TABLE 10

BITROCHANTER WIDTH, LATERAL MALLEOLUS WIDTH, LEG LENGTH, FUNCTIONAL LEG LENGTH AND STRIDE LENGTH--LEG LENGTH RATIO OF FEMALE SUBJECTS

Subject	Bitrochanter Width (cm)	Lateral Malleolus Width (cm)	Leg Length (cm)	Function Leg Length (cm)	Stride Length / Functional Leg Length
13	34.0	7.5	90.0	89.02	.7976
14	32.5	9.8	92.3	91.60	.7132
15	34.2	14.5	93.2	92.67	.7400
16	33.7	8.3	90.8	89.91	.7847
17	32.3	11.4	87.8	87.18	.7540
18	33.9	10.1	88.0	87.19	.7646
19	33.6	14.4	90.7	90.19	.7775
20	34.3	14.6	83.4	82.82	.7546
21	35.5	16.2	90.1	89.58	.7765
22	36.3	17.6	90.5	90.02	.7284
23	35.8	10.5	96.0	95.16	.7421
24	35.2	15.5	92.5	91.97	.7129
$\bar{X}$	34.27	12.53	90.44	89.78	.7538
SD	1.24	3.32	3.15	3.14	.026

TABLE 11

ENERGY COST, STRIDE LENGTH AND FREQUENCY AND LEG LENGTH OF MALE SUBJECTS

Subject	Energy Cost (L/min)	Stride Length (cm)	Stride Frequency str/min	Leg Length (cm)	$\frac{\text{Stride Length}}{\text{Leg Length}}$
1	1.54	70.10	114	86.2	.8132
2	1.62	64.50	124	81.2	.7943
3	1.59	66.66	120	87.0	.7662
4	1.65	71.40	112	85.5	.8350
5	1.44	65.00	123	86.0	.7558
6	1.63	68.96	116	84.1	.8190
7	1.57	66.11	121	85.0	.7778
8	1.60	66.60	120	85.2	.7817
9	1.42	66.60	120	87.5	.7611
10	1.62	68.90	116	83.5	.8251
11	1.37	74.00	108	89.0	.8310
12	1.77	67.79	118	91.2	.7433
$\bar{X}$	1.57	68.05	117.67	85.95	.7919
SD	.11	2.77	4.68	2.60	.030

TABLE 12

ENERGY COST, STRIDE LENGTH AND FREQUENCY AND LEG LENGTH OF FEMALE SUBJECTS

Subject	Energy Cost (L/min)	Stride Length (cm)	Stride Frequency str/min	Leg Length (cm)	$\frac{\text{Stride Length}}{\text{Leg Length}}$
13	1.41	63.49	126	90.0	.7054
14	1.59	67.79	118	92.3	.7344
15	1.43	72.72	110	93.2	.7802
16	1.50	67.79	118	90.8	.7465
17	1.49	66.66	120	87.8	.7592
18	1.44	67.79	118	88.0	.7703
19	1.27	66.00	120	90.7	.7277
20	1.40	62.50	128	83.4	.7494
21	1.47	69.56	115	90.1	.7720
22	1.80	65.57	122	90.5	.7245
23	1.70	68.96	116	96.0	.7183
24	1.53	65.57	122	92.5	.7089
$\bar{X}$	1.50	67.03	119.42	90.44	.7414
SD	.14	2.74	4.83	3.15	.024

APPENDIX C

ENERGY COST DATA

TABLE 13

RESTING, EXERCISE AND NET OXYGEN CONSUMPTION VALUES OF MALE SUBJECTS

Subject	Mean Resting Vo_2 (L/min)	Mean Working Vo_2 (L/min)	Net Vo_2 (L/min)
1	.31	1.54	1.23
2	.31	1.62	1.31
3	.30	1.59	1.29
4	.48	1.65	1.17
5	.26	1.44	1.18
6	.39	1.63	1.24
7	.41	1.57	1.16
8	.36	1.60	1.24
9	.31	1.42	1.11
10	.29	1.62	1.33
11	.28	1.37	1.09
12	.44	1.77	1.33
$\bar{X}$	.345	1.57	1.22
SD	.070	.111	.082

TABLE 14

RESTING, EXERCISE AND NET OXYGEN CONSUMPTION VALUES OF FEMALE SUBJECTS

Subject	Mean Resting Vo_2 (L/min)	Mean Working Vo_2 (L/min)	Net Vo_2 (L/min)
13	.31	1.41	1.10
14	.33	1.59	1.26
15	.26	1.43	1.17
16	.34	1.50	1.16
17	.29	1.49	1.20
18	.29	1.44	1.15
19	.28	1.27	.99
20	.26	1.40	1.14
21	.34	1.47	1.13
22	.38	1.80	1.42
23	.30	1.70	1.40
24	.29	1.53	1.24
$\bar{X}$	.306	1.50	1.20
SD	.035	.141	.121

TABLE 15

OXYGEN CONSUMPTION VALUES FOR THE TWO EXERCISE PERIODS

Subject	Sex	$Walk_1$ Vo_2 L/min	$Walk_2$ Vo_2 L/min	Mean Vo_2 L/min	$Walk_1$-$Walk_2$ Vo_2 L/min (Absolute)
1	M	1.60	1.48	1.54	.12
2	M	1.64	1.60	1.62	.04
3	M	1.61	1.58	1.59	.03
4	M	1.72	1.58	1.65	.14
5	M	1.49	1.40	1.44	.09
6	M	1.63	1.63	1.63	.00
7	M	1.56	1.58	1.57	.02
8	M	1.65	1.55	1.60	.10
9	M	1.44	1.41	1.42	.03
10	M	1.64	1.60	1.62	.04
11	M	1.41	1.34	1.37	.07
12	M	1.85	1.70	1.77	.15
13	F	1.47	1.35	1.41	.12
14	F	1.60	1.58	1.59	.02
15	F	1.44	1.43	1.43	.01
16	F	1.51	1.49	1.50	.02
17	F	1.49	1.49	1.49	.00

TABLE 15 (Continued)

Subject	Sex	$Walk_1$ Vo_2 L/min	$Walk_2$ Vo_2 L/min	Mean Vo_2 L/min	$Walk_1$-$Walk_2$ Vo_2 L/min (Absolute)
18	F	1.46	1.42	1.44	.04
19	F	1.28	1.28	1.28	.00
20	F	1.38	1.42	1.40	.04
21	F	1.50	1.44	1.47	.06
22	F	1.84	1.75	1.79	.09
23	F	1.71	1.69	1.70	.02
24	F	1.47	1.60	1.53	.13
$\bar{X}$		1.56	1.52	1.54	.06
SD		.14	.12	.13	.05