To the Graduate Council:

I am submitting herewith a thesis written by Elizabeth R. Galloway entitled "The Energy Requirement for Walking Different Smoky Mountain Trails." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in Physical Education.

Edward T. Howley

Edward T. Howley, Major Professor

We have read this thesis
and recommend its acceptance:

B. D. Franks

Jean Lewis

Accepted for the Council:

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Vice Chancellor
Graduate Studies and Research

THE ENERGY REQUIREMENT FOR WALKING DIFFERENT SMOKY MOUNTAIN TRAILS

A Thesis

Presented for the

Master of Science

Degree

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Elizabeth R. Galloway

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ABSTRACT

The purpose of this study was to measure the energy requirement for walking two Smoky Mountain Trails in order to (1) compare the direct measures of the energy expenditure with the estimated energy expenditure based on grade, speed, and distance of the trail; and (2) to construct tables in terms of multiples of resting metabolic rate (METS) for the trails so that a guide will exist concerning the strenuousness of that particular trail.

Six physically active subjects (four female and two male) participated in the study. The test situation required the subject to walk up Chimney Tops and Laurel Falls Trails at his/her own pace with a portable respirometer on the back. Measurements taken from the meter at specific intervals during the test included: (1) actual volume of the expired air, and (2) a sample of that expired air. The oxygen uptake was calculated from these data.

The slope of the trail was calculated with the use of an altimeter measure the vertical displacement and a rotary measuring device to measure the distance of the trail. The estimated energy requirements for walking these two trails were systematically higher than the directly measured energy requirement. The mean VO_2 $ml(kg \cdot min)^{-1}$ was 23.8 for the estimated, and 22.0 for the measured for Chimney Tops; the mean VO_2 $ml(kg \cdot min)^{-1}$ was 19.9 for the estimated, and 17.4 for the measured for Laurel Falls. The mean estimated MET levels were 7.0 and 5.8; the mean measured MET levels were 6.6 and 5.1 for Chimney Tops and

Laurel Falls, respectively. The difference between the estimated and measured energy requirement was not significant ($p < 0.05$) for either trail.

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INTRODUCTION

Studies on the energy expenditure of the soldier were some of the earliest non-clinical investigations in the area of applied physiological research (Goldman, 1961). The determination of the food rationing was one of the main purposes of these studies, for the soldier needed a certain amount of food to perform many different types of work. Obviously, the greater the amount of work performed, the greater the food intake needed to be.

The growing urbanization and mechanization of modern life have made it easier for people to become less physically active, yet humans must be physically active or they will deteriorate (Åstrand and Rodahl, 1977). Physical activities need to be prescribed in measured amounts according to the needs and capacities of the individual. In addition, it is necessary to determine, fairly accurately, the level of physical activity of an individual to ascertain the relationship of physical activity to health and disease. A "Pharmacopeia of Physical Activities" needs to be developed and used in prescribing activities (Karpovich and Sinning, 1971).

The knowledge that exists on the energy expenditure of cycling, running or walking on the track, treadmill, or any hard, even surface makes these physical activities easy to prescribe. This is not true for surfaces other than smooth ones. Rough and hilly terrain makes the estimation of the energy requirement less accurate. The energy requirement for walking on this type of surface needs to be known so that activities such as hiking on trails as those found in the Smoky Mountains can be prescribed in the correct dosages.

The purpose of my study was to measure the energy requirement for walking two trails in the Smoky Mountain National Park in order to (1) compare the direct measures of the energy expenditure with estimates based on grade and speed, and (2) to contruct tables in terms of multiples of resting metabolic rate (METS) for the trails so that a guide will exist concerning the strenuousness of that particular trail.

Definitions of Terms Used

Calorie or kilocalorie (kcal). The amount of heat that is needed to raise one kilogram (kg) of water 1 degree Celsius.

Energy expenditure. The number of kcals used in performing activities. There is a direct relationship between energy expenditure and oxygen consumption; the use of one liter of oxygen yields approximately five kcals of energy.

Kofranyi-Michaelis Respirometer (K-M). A light and portable respiration gas meter which measures the total volume of expired air, collects .6% of that expired air, and is used to determine the energy expended.

Kilogram meter (kgm). Work (force times distance) defined as one kg-force moved through a distance of one meter. Used in vertical work, one kgm requires approximately 1.8 mililiters (ml) of oxygen.

MET. A measure of exercise intensity; one MET refers to the resting rate of energy expenditure and is equal to 3.5 ml $O_2(kg \cdot min)^{-1}$ or 1 kcal $(kg \cdot hr)^{-1}$.

$ml(kg \cdot min)^{-1}$. A unit of measurement used in describing the rate of oxygen consumption in milliliters (ml) per (kg) of body weight per minute (min).

STPD. A correction factor which adjusts the volume measurement to an atmospheric pressure of 760 mm Hg, a temperature of 0 degrees Celsius, and dry conditions.

CHAPTER I

REVIEW OF LITERATURE

The Measurement of Energy Expenditure

One of the most common of the several methods used to measure the energy cost of various tasks is indirect calorimetry. The open circuit method of indirect calorimetry can be used when a subject is walking. The subject breathes readily available atmospheric air, and the exhaled air is collected for analysis (Consolazio, Johnson and Pecora, 1963). The fraction of expired oxygen (F_EO_2) and the fraction of expired carbon dioxide (F_ECO_2) in the exhaled air are determined along with the total volume of the expired air. From this information, one can accurately calculate the type and amount of substances utilized from the metabolic pool (Knoebel, 1971) and calculate the caloric cost and the MET level of walking.

When using indirect calorimetry, it is necessary to relate the caloric values of carbohydrates, fats, and proteins to the volumes of oxygen consumed during the oxidation of each of these substances in the body. Both carbohydrates and fats are completely oxidized to carbon dioxide and water whether in vitro or vivo. The average value of heat production for carbohydrates is 4.1 kcal per gram and the value for fat is 9.3 kcal per gram (Table 1). Protein differs from carbohydrates and fat, for protein is not completely oxidized in the body. This means that the amount of heat which is produced by the oxidation of one gram of protein in the body is less than that which is produced

TABLE 1

METABOLIC VALUES FOR CARBOHYDRATES, FATS AND PROTEINS

Units of Measurement	Carbohydrates	Fats	Proteins
kcal/gram	4.1	9.3	4.3
liters of CO_2/gram	0.75	1.43	0.78
liters of O_2/gram	0.75	2.03	0.97
respiratory quotient	1.0	0.70	0.80
kcal/liter of O_2	5.0	4.7	4.5

when the same amount of protein is combusted in a bomb calorimeter. By taking into account the energy lost in the excreta, the protein value of heat combustion in the body is 4.3 kcal per gram (Table 1).

The amount of oxygen required in metabolism depends on the food being metabolized (Durnin and Passmore, 1967). The ratio of the volume of carbon dioxide expired per minute (VCO_2) to the volume of oxygen consumed (VO_2) in the lungs during the same time period is called the respiratory exchange ratio (R). Usually, the VCO_2/VO_2 ratio at the cellular level is referred to as the respiratory quotient (RQ). In using R to estimate the types of substances used in oxidative metabolism during exercise, the VCO_2 must represent only carbon dioxide given off in metabolic reactions. Therefore, steady state conditions are needed because any hyperventilation would increase the R (Knoebel, 1971). If only carbohydrates are oxidized, the R is 1.0, whereas the specific oxidation of fat gives an R of 0.70. Values which fall between these extremes indicate the oxidation of various mixtures of carbohydrates, fats, and proteins. The R of a subject eating a mixed diet is approximately 0.85 and that of a fasting subject is 0.82.

Knowing the R and the VO_2, one can calculate the kcal production. For example, if the R equals 1.0 and the VO_2 is 1.0 $\ell \cdot min^{-1}$, then 5.0 kcal min^{-1} are being produced. If the R. equals 0.7 and the VO_2 is 1.0 $\ell \cdot min^{-1}$, then 4.7 kcal min^{-1} are being produced.

If only the oxygen consumption is known and the R cannot be calculated, the caloric expenditure can still be estimated with little loss in precision. Durnin and Passmore (1967) estimate this error to be 0.5% or less. The energy expenditure can be calculated from the measurement of the volume of expired air and its oxygen content alone. If V is the volume of expired air in liters per minute ($\ell \cdot min^{-1}$) at STP and O_{2e} is its oxygen content expressed as a percentage, the following equation can be used to calculate the energy requirement (Durnin and Passmore, 1967).

$$E(kcal/min) = \frac{4.92V}{100}(20.93 - O_{2e})$$

Factors Which Affect the Energy Requirement of Walking

There are several different factors that affect the caloric cost of grade walking (Givoni and Goldman, 1971). These include body weight, external load carried by the subject, speed, grade, surface type, and possibly gender of the subject.

The effects of body weight and external load on the energy requirement for walking. Experimental studies (Durnin and Manslowski, 1959; Erickson, Somonson, and Taylor, 1946; and Pandolf, Givoni, and Goldman, 1977) have demonstrated that the metabolic cost of walking is linearly related to the weight of the body. Mahadevala, Passmore and Woolf (1953) found that body weight had a significant influence on the caloric cost of walking while age, gender, race and prior consumption of food had none. Malhotra, Ramasway and Ray (1962) studied the energy cost of a group of Indians performing a variety of physical activities and demonstrated that there was a linear relationship between expenditure and body weight.

The placement of the external load (on the head, in the hands, attached to the feet, or carried on the back) is another consideration (Pandolf et al., 1977). The additional energy required for load carriage by foot appears to be five times greater than that by the back. The energy cost per kilogram of load carried on the back has been shown to be identical to the energy cost per kilogram of body weight (Goldman and Iampietro, 1965). This statement is true for extra loads weighing 30 kg or less. This load is carried with about the same efficiency as the body weight; therefore, a man weighing 60 kg and carrying a 10 kg load on the back will expend about as much energy as a man weighing 70 kg (Durnin and Passmore, 1967). In the present study, the K-M respirometer, which weighs approximately 3 kg, was worn on the subject's back in a manner similar to that of a hiker carrying a backpack.

The effects of speed on the energy requirements for walking. As the walking speed increases, the energy cost for walking increases. Figure 1 illustrates that the true relationship between the energy cost and speed of walking is not linear. At speeds below

50 m·min^{-1} and over 100 m·min^{-1}, walking becomes less efficient and the energy cost rises above the linear prediction. This figure is based on data from Benedict and Murschhauser (1915); Douglas and Haldane (1912); and Margaria (1963). At walking speeds between 50 m·min^{-1} and 100 m·min^{-1}, there is a linear increase in the energy requirement for walking. If a subject walks a distance of two miles at the speed of 50 m·min^{-1} as compared to 100 m·min^{-1}, the VO_2 is 8.5 ml(kg·min)$^{-1}$ and 13.5 ml(kg·min)$^{-1}$, respectively. It takes one 64 minutes to walk two miles at 50 m·min^{-1}, whereas, walking the same distance at 100 m·min^{-1}takes 32 minutes. The net energy cost for walking two miles at these two different speeds is the same, but the rate of energy expenditure for 100 m·min^{-1} is greater.

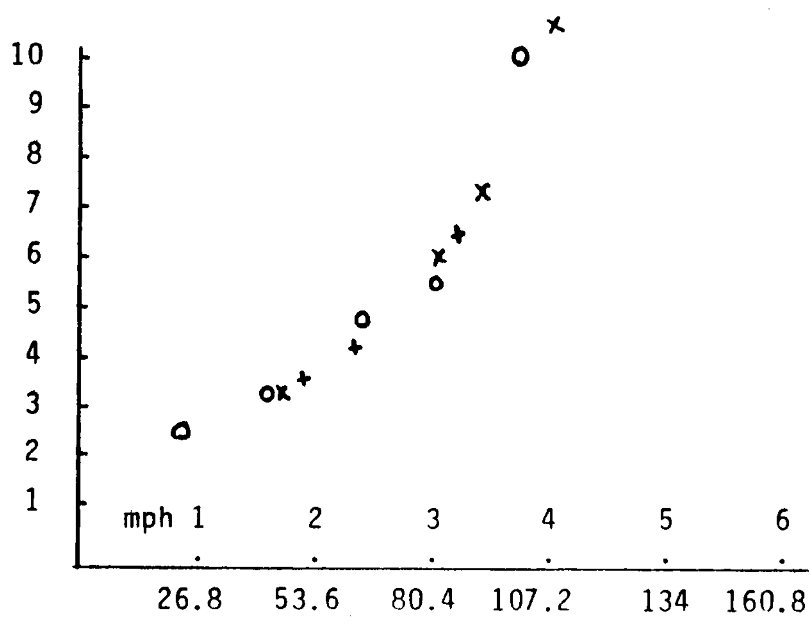


Figure 1. Energy Expenditure Walking on the Level at Different Speeds. Benedict and Murschhauser +. Doublas and Haldane [], and Margaria o, as redrawn from Passmore and Durnin (1967).

Durnin and Passmore (1967) constructed Table 2 which predicts the energy requirement of persons of different body weight walking at various speeds.

TABLE 2

RELATIONSHIP BETWEEN ENERGY EXPENDITURE ($KCAL \cdot MIN^{-1}$), THE SPEED OF WALKING ($M \cdot MIN^{-1}$), AND GROSS BODY WEIGHT (KG). FROM PASSMORE AND DURNIN (1967)

Speed ($m \cdot min^{-1}$)	Weight, kg 36	45	55	64	73	82	91
53.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8
67.0	2.3	2.7	3.1	3.5	3.8	4.2	4.5
80.4	2.7	3.1	3.6	4.0	4.4	4.8	5.8
93.6	3.1	3.6	4.2	4.6	5.0	5.4	6.1
107.3	3.5	4.1	4.7	5.2	5.8	6.4	7.0

The effect of grade (slope) on the energy requirement for walking. As the slope increases, the energy requirements for walking also increases. Workman and Armstrong (1963) stated that in grade walking on a treadmill, work is done in raising the body against the pull of gravity, and is the product of body weight times the vertical distance moved. The vertical distance is calculated from the product of the belt speed and the gradient. Cotes and Mead (1960) found that the extra energy expenditure of walking up a grade, in excess of the energy expenditure of walking at the same speed on the level, is a curvilinear function of the product of body weight times the vertical distance moved. This finding is shown in Figure 2.

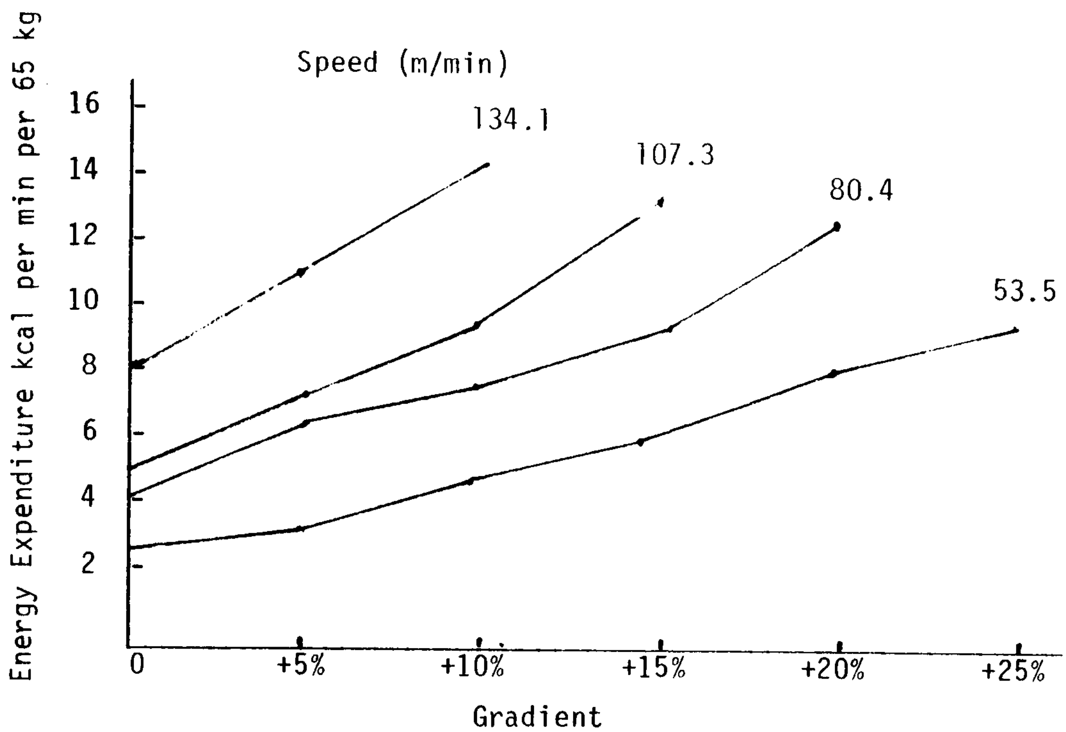


Figure 2. Energy Expenditure of Walking at Different Speeds on Various Gradients. Redrawn from Passmore and Durnin (1967).

<u>The effects of surface type on the energy requirements for walking</u>. A slightly uneven road such as a rough road or a country path can cause an increase in the caloric cost of walking by as much as 10% (Durnin and Passmore, 1967).

Dill reported an increase in energy cost for walking on various terrains which ranged from the hard, even surface to the swampy bog. Soule and Goldman (1972) have suggested that a coefficient be used for predicting the energy requirement for the following terrains:

Hard-surfaced road	1.2	Dirt road	1.1
Ploughed fields	1.5	Light brush	1.2
Hard snow	1.6	Heavy brush	1.5
Sand dunes	1.8	Swampy bog	1.8

<u>The effects of gender of the subject on the energy requirement for walking</u>. There is disagreement in the literature regarding the effects of gender on walking energy requirement, even when expressed as

kcal $(kg \cdot min)^{-1}$. Booyens and Keatinge (1957) found that women expend approximately 10% fewer kcal $(kg \cdot min)^{-1}$ than men during walking. Howley and Glover (1974) found that women used 8% more kcal $(kg \cdot mile)^{-1}$ than the men in both walking and running one mile. Durnin and Manslowski (1959) showed no difference due to gender in the energy expenditure of walking. Durnin and Passmore (1967) illustrated that the energy cost of walking was unrelated to age, gender, or race. In the above studies, the greatest difference reported was only 10%. While no clear statement can be made regarding the effect of gender on the energy requirement for walking, the use of male and female subjects should introduce little error to the estimation of the energy requirement for walking the trails.

CHAPTER II

METHODOLOGY

Two male and four female physically active students volunteered to participate in this study. Each subject signed an informed consent form before the study began (Appendix A).

The Equipment Used in Data Collection

To measure the energy requirement for walking the two different trails, the following equipment was used:

Equipment	Obtained from
K-M meter	Physical Education Division University of Tennessee
Logan Rotary Device	Physical Education Division University of Tennessee
Stopwatch, nose clip	Physical Education Division University of Tennessee
Altimeter	Tennessee Valley Authority George Titcomb Telephone (615) 632-2564
Barometer	Smoky Mountain National Park Ray Matthews Telephone (615) 436-5615

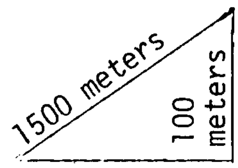
The Calculation of Grade of Each Trail

The altitude of each trail was measured by an altimeter. At the start and end of each walk, altitude was recorded in feet. The altitude change for the trail was the difference between the final altitude reading and the initial reading. For example, if the starting altitude was 3500 feet and the final altitude was 5000 feet, then the altitude change was 1500 feet. Knowing the distance of the trail and the change in altitude, the grade of each trail was calculated in the following manner:

Distance of trail (run) = 1500 meters

Change in altitude (rise) = 100 meters

$$\% \text{ grade} = \frac{\text{rise}}{\text{run}} = \frac{100 \text{ meters}}{1500 \text{ meters}} = .06666 \text{ or } 6.66\% \text{ grade}$$



The Measurement of Distance of Each Trail

A Logan Rotary Device was used to measure the distance of each trail. A technician pushed this device (wheel) and followed the path of the subject. Each time the subject stopped walking, the distance that appeared on the rotary device was recorded in feet. To calculate the speed of the subject, the distance in feet was converted to meters and divided by the time. For example, if the subject walked 3500 feet in 15 minutes, the following calculation were made:

1. 3500 feet = 1066 meters
2. 1066 meters ÷ 15 minutes = 71.06 meters per minute $(m \cdot min)^{-1}$

The Measurement of Barometric Pressure

The Smoky Mountain National Park Laboratory measures the barometric pressure at 2800 feet and 3400 feet. Since this measurement of barometric pressure was recorded hourly, it was used in this study. As one goes from a low elevation to a higher one, the barometric pressure value decreases .025 millimeters of mercury per foot ($mmHg \cdot ft^{-1}$). For example, if the barometric pressure is 684 mmHg·ft at 2800 feet, and one wants to know the barometric pressure for 3400 feet, the following steps are used:

3400 ft - 2800 ft. = 600 ft.	1. Subtract the two elevations to get difference
600 ft x .025 mmHg ft^{-1} = 15 mmHg	2. Multiply difference by correction factor
684 mmHg - 15 mmHg = 669 mmHg	3. Subtract the product from the barometric pressure if going from a low to a higher elevation; add the product if going from a high to a lower elevation.

The Measurement of Ventilation

Each subject hiked a black top trail and a dirt trail with the K-M meter on his/her back. This meter measures the volume of air expired and in addition, collects .6% of this expired air into the bladder attached to the meter. This meter has been shown to be reliable and valid in several studies (Consolazio, Johnson and Pecora, 1963; Goldman, 1965; Orsini and Passmore, 1951) as well as in our laboratory.

To determine the calibration factor for our laboratory, the Parkinson Cowan (PC) meter and Physiograph Desk Model Type DMP-4A were used to measure inspired ventilation while the K-M meter was used to measure expired ventilation. A hose was attached from the PC box to the K-M valve and mouthpiece assembly. The Physiograph recorded inspired ventilation (V_I). The valve allowed the subject to inhale air from the PC box and direct the expired air through another hose going to the K-M meter which collected .6% of the expired ventilation (V_E). Gas fractions were analyzed for oxygen content by using the Applied Electrochemistry S-3A Oxygen Analyzer and for carbon dioxide with the Beckman LB-2

Analyzer. The nitrogen content (F_EN_2) was calculated by the following:

$$F_EN_2 = 1 - (F_EO_2 + F_ECO_2)$$

where: F_E = fraction of expired gas (N_2, O_2, CO_2)

The following equations were used to calculate V_I and V_E at STPD:

From the Physiograph and PC box:

1. $$V_I STPD = \text{volume} \times \frac{273°K}{273°K + \text{temp. } (°C)} \times \frac{\text{barometric pressure} - \text{water vapor} \times \text{rel. humidity}}{760 \text{ mmHg}}$$

From the K-M meter:

1. Total Volume(liters) = final volume reading - initial volume reading
2. $V_E(\ell \cdot min^{-1})$ = Total Volume ÷ number of minutes
3. $$V_E STPD(\ell \cdot min^{-1}) = V_E(\ell \cdot min^{-1}) \times \frac{273°K}{273°K + \text{temp } (C°)} \times \frac{\text{barometric pressure} - \text{water vapor}}{760 \text{ mmHg}}$$

Table 3 shows V_I from the PC box and Physiograph and also V_I from the PC box and Physiograph and also V_I calculated from V_E using the following: $V_I = \frac{V_E \times F_EN_2}{F_IN_2}$

TABLE 3

V_I CALCULATED FROM THE PHYSIOGRAPH AND V_I CALCULATED FROM V_E

SUBJECT	V_IPC box	V_I from V_E
1	33.34	33.64
2	19.01	20.25
3	27.64	28.30
4	24.19	25.19

The Procedures for Data Collection

1. The K-M meter was placed in a comfortable position on the subject's back with the mouthpiece and nose clip in their proper positions.

2. The temperature and initial volume reading from the K-M meter were recorded.

3. The clamp was loosened from the bladder to allow .6% of the expired air to enter the bladder, the stopwatch was started, the meter was engaged and the walk was begun.

4. One technician followed the subject to carry the altimeter and push the Logan rotary device.

5. Whenever the bladder was almost full, the meter was disengaged; time, temperature, volume reading, altimeter reading, and distance were recorded. Then gas aliquots from the bladder were transferred to plastic syringes to be analyzed later in the laboratory.

6. The Sage Instruments Syringe Pump Model 341 was used to transfer the expired air in the syringe through the Aquasorb to the Applied Electrochemistry S-3A Oxygen Analyzer, which analyzed the expired air for its oxygen content.

Calculation of Oxygen Uptake and Energy Expenditure

The amount of oxygen in $1 \cdot min^{-1}$ was converted into $kcal \cdot min^{-1}$ and expressed as METS. The following equations were used:

1. $VO_{2STPD} = V_{ESTPD} \times (.2093 - F_EO_2)$

   where: VO_2 = rate of oxygen uptake $1 \cdot min^{-1}$

   V_E = volume of expired ventilation per minute

   F_EO_2 = fraction of expired oxygen

2. $kcal \cdot min^{-1} = VO_2(l \cdot min^{-1}) \times 4.92\ kcal \cdot l^{-1}$

3. $METS = kcal \cdot min^{-1} \times 60\ min \cdot hr^{-1} \div$ body weight (kg)

The Estimation of VO_2 (Energy Expenditure)

The distance of the trails was measured by a rotary device, the grade was measured by an altimeter, and the speed was calculated from the distance of the trail divided by the time it took the subject to walk the trail at his/her own pace. Using these three variables, the following formulas were used to estimate the energy requirement for walking: (American College of Sports Medicine, 1980)

Horizontal

$VO_2\ ml(kg \cdot min)^{-1}$ = speed $m \cdot min^{-1} \times 0.1\ ml\ O_2\ (kg \cdot min)^{-1}$ per $m \cdot min^{-1} + 3.5\ ml(kg \cdot min)^{-1}$

Vertical

$VO_2\ ml(kg \cdot min)^{-1}$ = grade (fraction) X speed $m \cdot min^{-1} \times 1.8\ ml \cdot kgm^{-1}$

Total VO_2 requirement = Horizontal + Vertical VO_2

CHAPTER III

RESULTS

Two male and four female subjects participated in this study. Each subject walked up Chimney Tops and Laurel Falls trail.

Each subject waled at a comfortable pace until the bladder on the K-M meter was full (approximately 15 minutes). This procedure was performed three or four times while walking up Chimney Tops Trail and one or two times while walking Laurel Falls Trail. The total oxygen requirement was calculated in the following manner. In this example, two gas collection periods were involved. The oxygen consumption was calculated as described previously.

Gas Collection Period 1: VO_2 - 1.3 $\ell \cdot min^{-1}$; time, 15 min.

Gas Collection Period 2: VO_2 = 1.6 $\ell \cdot min^{-1}$; time, 12 min.

Total O_2 requirement for the trail:

$$(15 \text{ min.} \times 1.3\ \ell \cdot min^{-1}) + (12 \text{ min} \times 1.6\ \ell \cdot min^{-1}) = 39.06$$

Knowing the weight of the subject and the total time to walk the trail (27 minutes) this value was then expressed in $ml(kg\ min)^{-1}$ and METS as described previously.

To estimate the energy requirement for walking each trail, the following example illustrates the procedures used:

Given: Grade of trail = 13.7%

Speed of subject = 73.77 $m \cdot min^{1}$

Horizontal

VO_2 ml(kg•min)$^{-1}$ = speed(m•min)$^{-1}$ X 0.1 ml(kg•min)$^{-1}$ per (m•min)$^{-1}$ + 3.5 ml(kgm)$^{-1}$

= 73.77 m•min^{-1} X .0 ml O_2(kg•min)$^{-1}$ per m•min^{-1}+ 3.5 ml O_2(kg•min)$^{-1}$

= 7.38 ml O_2(kg•min)$^{-1}$ + 3.5 ml O_2(kg•min)$^{-1}$

VO_2 = 10.9 ml(kg•min)$^{-1}$

Vertical

VO_2 ml(kg•min)$^{-1}$ = grade(fraction) X speed m•min^{-1} X 1.8 ml kgm^{-1}

= 0.137 x 73.77 m•min^{-1} X 1.8 ml kgm^{-1}

VO_2 = 10.9 ml(kg•min)$^{-1}$

Total VO_2 = Horizontal + Vertical

= 10.9 + 18.2

Total VO_2 = 29.06 ml(kg•min)$^{-1}$

Knowing the weight of the subject, this value was converted to VO_2 (ℓ•min), kcal•min^{-1} and METS

VO_2 ℓ•min = 29.1 ml(kg•min)$^{-1}$ ÷ 1000 x 55 kg = 1.59 ℓ•min^{-1}

Kcal•min^{-1}= 1.59 ℓ•min^{-1} X 4.92 kcal ℓ$^{-1}$ = 7.81 Kcal•min^{-1}

METS = 7.8 Kcal•min^{-1} X 60 min•hr^{-1} ÷ 55 kg = 8.5

A paired t-test was used to determine if the difference between the directly measured energy cost and the estimated energy cost of walking certain trails was significant at the $p < .05$ level. A Pearson Product-Moment Correlation coefficient was calculated to determine the relationship between the directly measured and the estimated energy cost.

Tables 4 and 5 contain data calculated on each subject

TABLE 4

INDIVIDUAL SUBJECT ENERGY EXPENDITURE FOR CHIMNEY TOPS TRAIL

SUBJECT	VO_2 $\ell \cdot min^{-1}$	VO_2 $ml(k.min)^{-1}$	Kcal min^{-1}	Kcal $trail^{-1}$	Kcal$(kg.trail)^{-1}$	METS
1	(1.4) 1.5	(22.1) 23.3	(6.9) 7.3	(319.4) 345.7	(5.0) 5.5	(6.5) 7.0
2	(1.1) 1.2	(22.1) 24.6	(5.4) 6.0	(249.4) 278.2	(5.1) 5.6	(6.5) 7.2
3	(1.4) 1.3	(25.7) 23.9	(6.7) 6.3	(262.4) 244.2	(5.0) 4.6	(7.6) 7.1
4	(1.6) 1.3	(23.0) 19.6	(7.7) 6.6	(342.9) 292.2	(5.0) 4.3	(6.8) 5.8
5	(2.1) 2.0	(23.8) 22.8	(10.4) 10.0	(446.0) 427.7	(5.0) 4.8	(7.1) 6.7
6	(1.6) 1.5	(24.2) 22.2	(8.0) 7.4	(337.0) 310.1	(5.0) 4.6	(7.1) 6.6

Estimated values are in ( ); measured values are below ( ).

Each measured value is based on three or four gas collections

Average speed = 70.44 $m \cdot min^{-1}$; Grade = 10.2%

TABLE 4

INDIVIDUAL SUBJECT ENERGY EXPENDITURE FOR CHIMNEY TOPS TRAIL

SUBJECT	VO_2 $\ell \cdot min^{-1}$	VO_2 $ml(k.min)^{-1}$	Kcal min^{-1}	Kcal $trail^{-1}$	Kcal$(kg.trail)^{-1}$	METS
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4	(1.6) 1.3	(23.0) 19.6	(7.7) 6.6	(342.9) 292.2	(5.0) 4.3	(6.8) 5.8
5	(2.1) 2.0	(23.8) 22.8	(10.4) 10.0	(446.0) 427.7	(5.0) 4.8	(7.1) 6.7
6	(1.6) 1.5	(24.2) 22.2	(8.0) 7.4	(337.0) 310.1	(5.0) 4.6	(7.1) 6.6

Estimated values are in ( ); measured values are below ( ).

Each measured value is based on three or four gas collections

Average speed = 70.44 $m \cdot min^{-1}$; Grade = 10.2%

for Chimney Top and Laurel Falls Trails, respectively. The number in parenthesis is the estimated energy requirement. Averages are caclulated for VO_2, energy expenditure and METS are displayed in Figures 3,4 and 5, respectively. It is clear that the estimated values were slightly higher than the measured. However, there were no statistically significant differences for Chimney Tops ($t = .693$ $p < .05$) and Laurel Falls ($t = 1.69$, $p < .05$). The correlation coefficient was + .0308 and +.9493 for Chimney Tops and Laurel Falls, respectively.

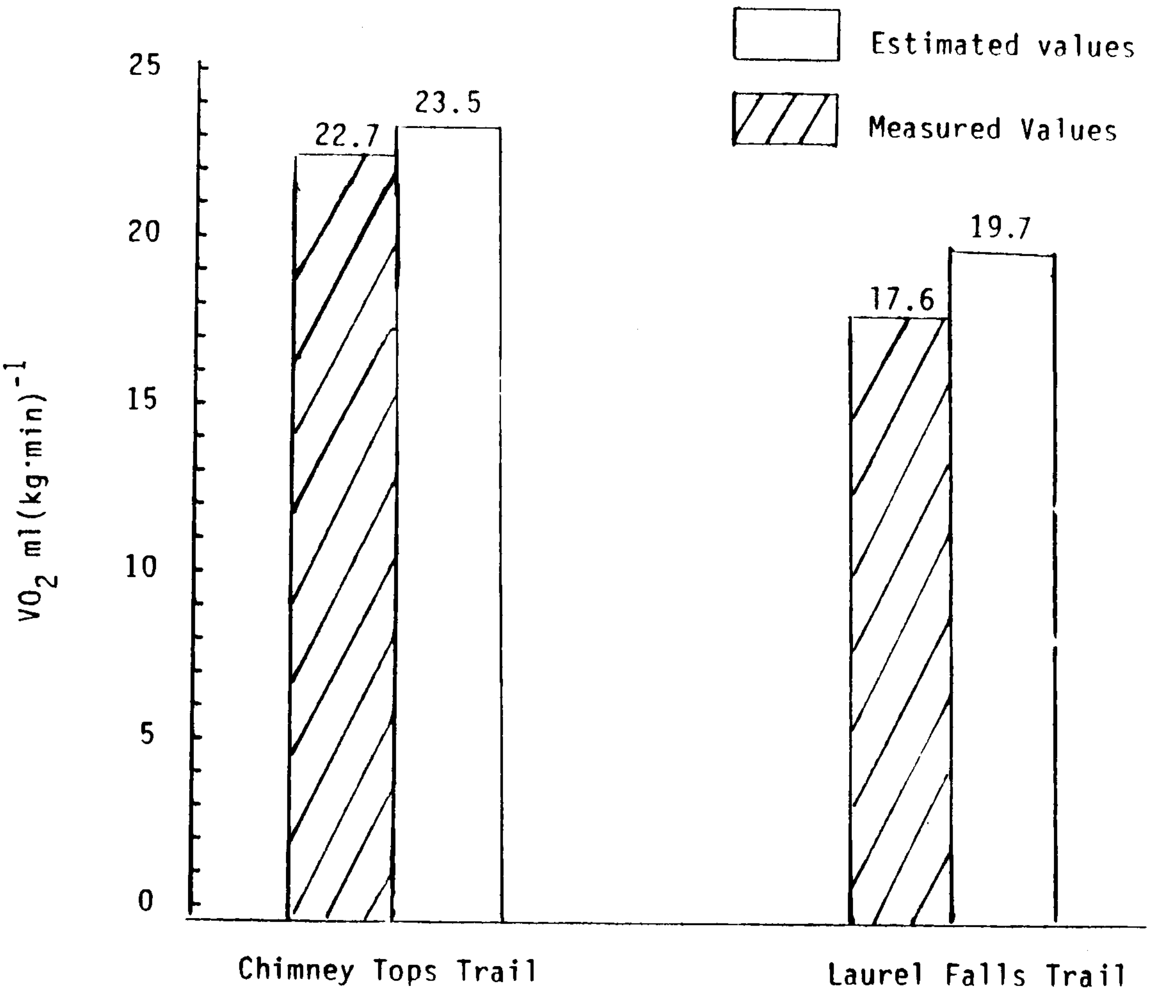

Figure 3. Mean Energy Expenditure Values Expressed as Kcal(kg·trail)$^{-1}$ for Walking Chimney Tops and Laurel Falls Trails

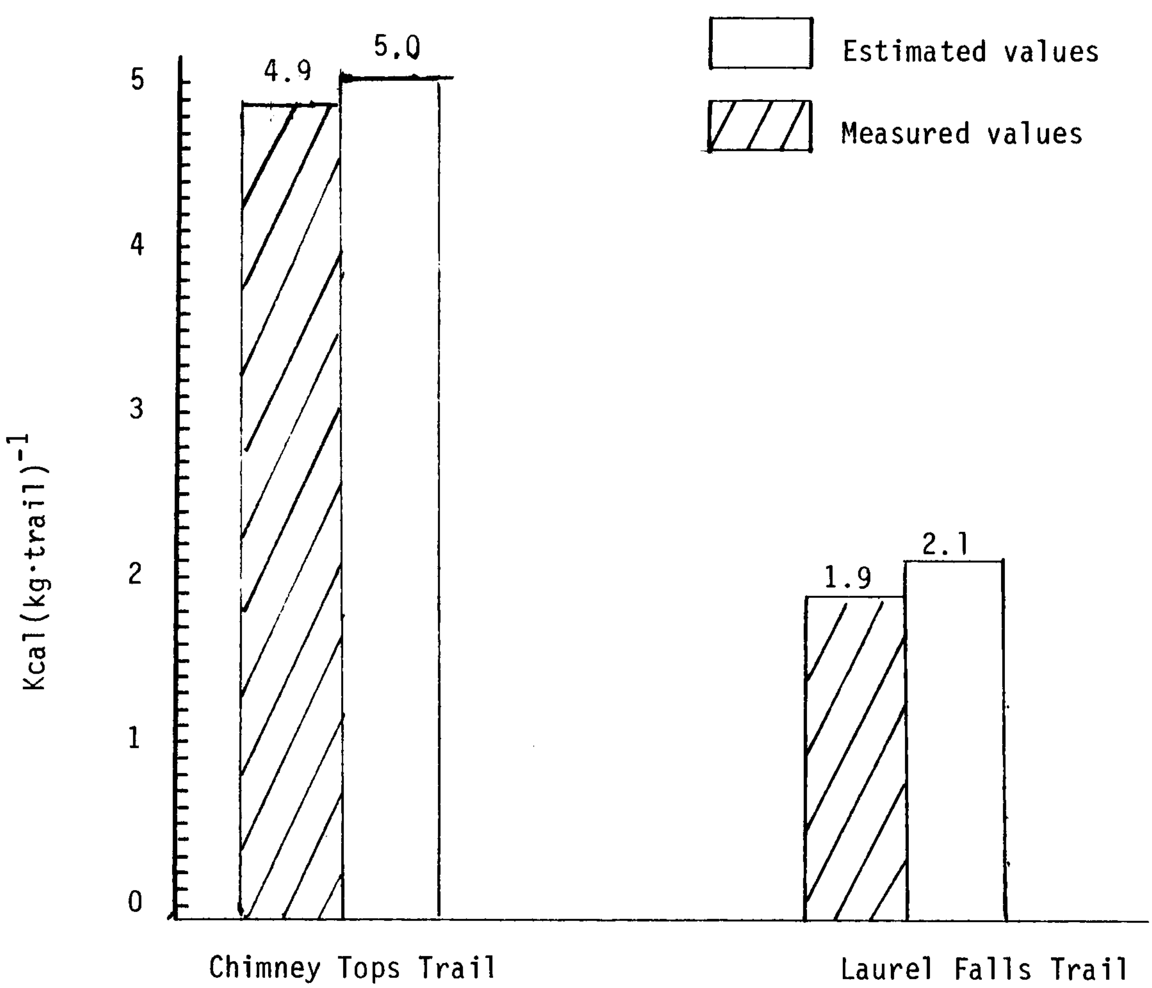

Figure 4. Mean Energy Expediture Values Expressed as Kcal(Kg·trail)$^{-1}$ for Walking Chimney Tops and Laurel Falls Trails.

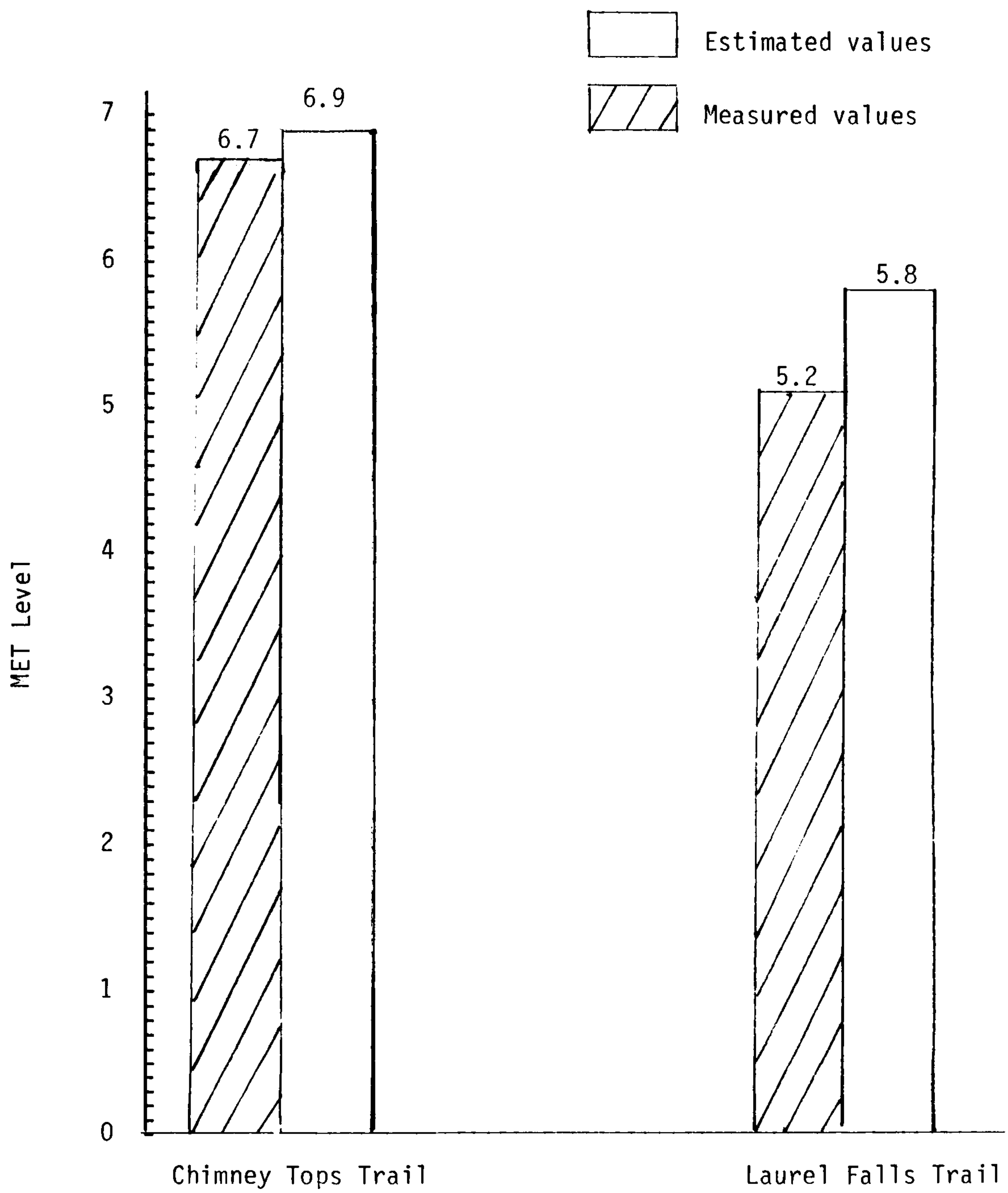

Figure 5. Mean MET Level for Walking Chimney Tops and Laurel Falls Trails.

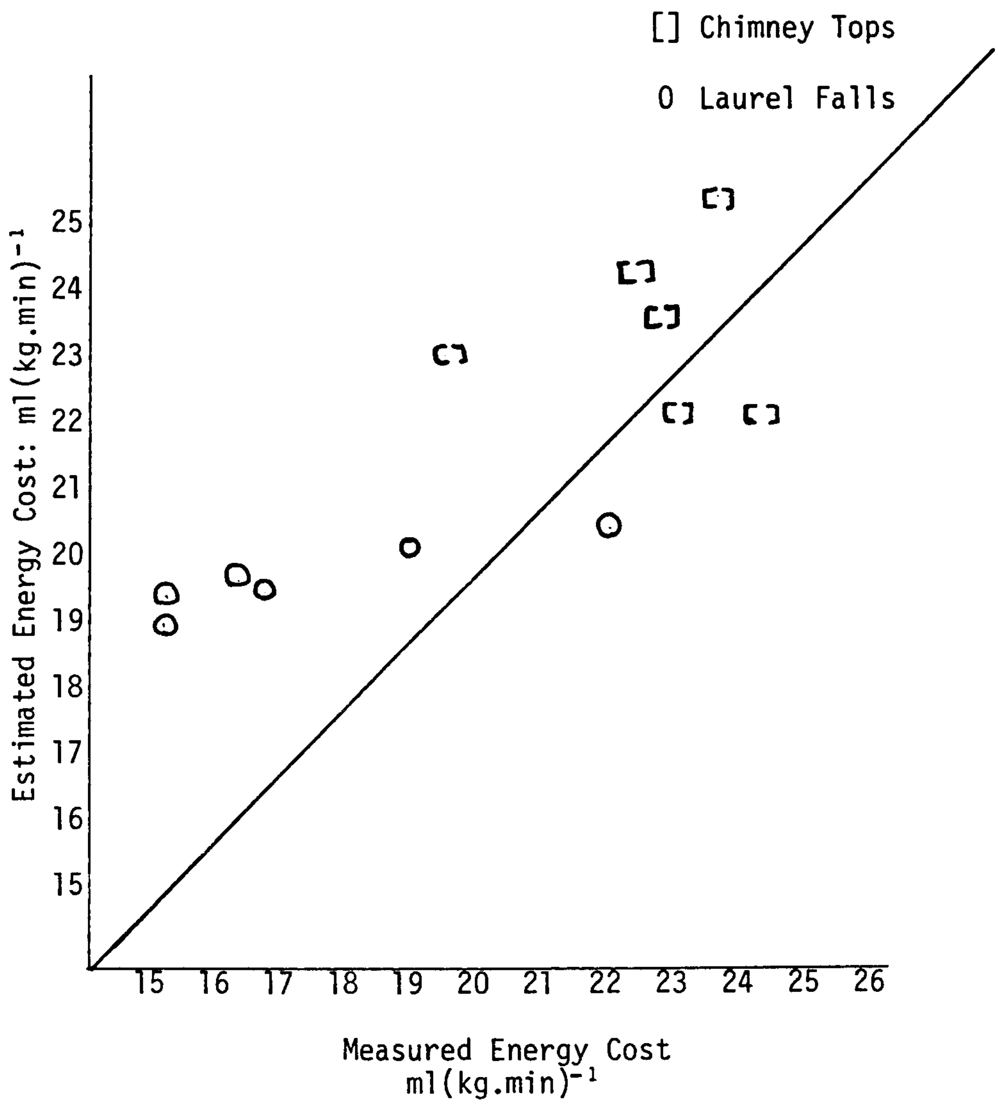

Figure 6. A Comparison of Estimated Energy Cost vs. Measured Energy Cost.

CHAPTER IV

DISCUSSION, CONCLUSIONS, AND RECOMMENDATIONS

The data showed that the estimated energy requirement for walking Chimney Tops and Laurel Falls Trail was higher (3.5% and 11.9%, respectively) than the directly measured energy requirement. While these differences between the measured and estimated values were not significantly different, it was interesting to find nine of the twelve estimated values higher than their measured values. In an attempt to find an explanation of this we evaluated the calibration of the K-M meter again. The K-M meter was found to be reliable after the study, with V_I measured from the PC box being 41.93 $\ell \cdot min^{-1}$ compared to 42.03 $\ell \cdot min^{-1}$ as calculated from the V_E measured by the K-M meter.

The factors that affected the energy cost of grade walking were the same for the directly measured value and the estimated value. For example, the K-M meter which weighs 3.6 kg, was carried on the subject's back and was calculated as the total body weight for each measurement for each subject. A load of this size can be carried just as efficiently as the body weight alone (Durnin and Passmore, 1967).

The speed of the subject, which was always between 50 and 100 $m \cdot min^{-1}$, was the same for both the estimated and the directly measured energy cost. An accurate stopwatch was used to obtain the correct time; the rotary device measured the distance of the trails within a maximum error of 10 feet. Therefore, the distance, time and speed could not account for the average 7.7% difference between the estimated and directly measured energy cost.

The surface type of Chimney Tops Trail included dirt, gravel and three wooden bridges; whereas, Laurel Falls was a trail with a black top. If one used the terrain coefficient to calculate the estimated energy cost, then the difference between the estimated and measured energy cost would have been greater than the reported 7.7%.

For Chimney Tops and Laurel Falls, the grade calculated from the altimeter was 10.2% and 4.1% respectively. By working the equation backwards to estimate VO_2 and solving for the unknown, the mean grade calculated for the measured VO_2 was 10.3% and 4.1% for Chimney Tops and Laurel Falls Trails, respectively. These values are very close to those measured with the altimeter.

Even though there was a small difference between the measured energy requirement and estimated energy requirement for walking these two trails, this study has its potential usefulness. One can still determine the MET level that is required to walk up different Smoky Mountain Trails. The estimated VO_2 $ml(kg\cdot min)^{-1}$ can be calculated by using the values of speed and grade with little loss in precision. The energy requirement for other trails could be calculated by the estimation equation for VO_2. From this information one could calculate the MET level for walking the specific trail and the strenuousness of the trail would be known. Table 6 illustrates the MET level for walking certain grades at a given speed. This table is based on the equation for the estimation of energy requirement.

TABLE 6

ENERGY REQUIREMENTS FOR WALKING UPHILL IN METS

Grade %	60	Speed(m•min)$^{-1}$ 65	70
8	5.2	5.5	5.9
10	5.8	6.2	6.6
12	6.4	6.9	7.3
14	7.0	7.5	8.0
16	7.7	8.2	8.8
18	8.3	8.9	9.5

Conclusion

1. Since the difference between the estimated and the measured energy requirement was only 7.7% for both trails, the estimated MET level for walking various trails could be calculated using the appropriate equation.

2. The K-M respirometer was shown to be a reliable device for measuring ventilation.

Recommendations

When studies of this nature are conducted, it would be ideal for the Smoky Mountain National Park Laboratory to have the altitude validated for each trail. If this is not possible, then only the most accurate altimeter should be used.

The author hopes that the findings in this study stimulate further interest and research in this area so that these findings can be validated. This validation could lead to all the Smoky Mountain trails having a known MET level and walking these trails can be prescribed according to the needs and capacities of individuals.

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APPENDIXES

APPENDIX A

INFORMED CONSENT

I wish to participate as a subject in the study conducted by Edward T. Howley and Libby Galloway to measure the energy requirement for walking various trails in the Smoky Mountains National Park.

I understand that I will be required to wear a small mouth piece and valve during each walk. Further, I understand that I will carry a small "gas meter" on my back to measure the volume of air I breathe.

I will be required to walk 1-2 miles on each of two trails, one smooth (paved) and one natural. The intensity of the activity should not be greater than experienced in slow jogging, bicycle riding or swimming.

I have read the foregoing, and I understand it, and any questions which may have occurred to me have been answered to my satisfaction.

Signatures:

Participant: ______________________

Witness: ______________________

Date: ______________________

APPENDIX B

TABLE 7

DATA COLLECTED ON EACH SUBJECT FOR CHIMNEY TOPS TRAIL

SUBJECT	TIME min	DISTANCE m	SPEED $m.min^{-1}$	FINAL VOLUME ℓ	INITIAL VOLUME ℓ	V_E $\ell \cdot min^{-1}$	STPD	FeO_2 $m \cdot min^{-1}$
1	15:00	1109	73.93	20449.2	19882.3	37.79	.7951	.1684
	15:00	982	65.46	21159.0	20449.2	47.32	.7968	.1653
	16:43	975	58.34	21848.0	21159.0	41.93	.7670	.1639
2	17:00	1290	75.89	34013.9	33611.2	23.68	.7794	.1555
	14:50	895	60.35	34448.0	34013.9	29.94	.7652	.1515
	14:54	880	59.06	34739.0	34448.0	23.72	.7546	.1511
3	16:00	1554	96.68	23858.9	23118.3	42.28	.7825	.1745
	14:56	910	60.95	24584.1	23858.9	49.80	.7699	.1735
	8:55	611	68.44	24882.2	24584.1	34.86	.7614	.1683
4	15:00	1130	75.46	25463.0	24886.0	38.46	.7773	.1696
	14:01	882	63.00	26089.0	25463.0	44.68	.7761	.1655
	15:33	1054	67.75	26772.0	26089.0	44.55	.7614	.1736
5	15:00	2000	79.99	28821.8	28153.6	45.54	.7764	.1633
	11:47	803	68.19	29529.0	28821.8	61.66	.7654	.1608
	16:00	1062	66.37	30419.0	29529.0	65.62	.7504	.1598
6	10:00	1003	103.30	31738.6	31292.8	45.58	.7998	.1565
	15:00	1048	69.88	32358.0	31738.6	41.30	.7728	.1591
	13:00	721	55.46	32877.0	32358.0	29.00	.7631	.1547
	4:05	270	66.15	32962.0	32877.0	20.99	.7593	.1642

TABLE 8

DATA CALCULATED ON EACH SUBJECT FOR CHIMNEY TOPS TRAIL

Subject	V_E STPD $\ell \cdot min^{-1}$	VO_2 $\ell \cdot min^{-1}$	VO_2 ml$\cdot$(kg min)$^{-1}$	Kcal$\cdot min^{-1}$	Total Kcal trail^{-1}	Kcal(kg.trail)$^{-1}$	MET
	29.76	1.22	19.25	6.00		1.42	5.68
1	37.70	1.66	26.19	8.17	341.55	1.95	7.73
	32.16	1.46	23.04	7.80		2.02	6.80
	18.45	.992	20.21	4.88		1.69	5.96
2	22.91	1.32	26.89	6.49	249.96	1.91	7.94
	17.52	1.02	20.78	5.02		1.48	6.13
	33.08	1.15	21.70	5.66		1.71	4.99
3	38.34	13.7	25.85	6.74	231.19	1.85	5.95
	26.54	1.01	19.05	4.97		.80	4.38
	29.89	1.18	17.35	5.80		1.28	5.37
4	34.67	1.52	22.35	7.48	284.53	1.54	7.59
	33.92	1.23	18.09	6.05		1.37	6.83
	35.36	1.62	18.21	7.97		1.34	5.37
5	47.18	2.29	25.74	11.26	410.78	1.45	7.59
	41.73	2.06	23.16	16.13		1.82	6.38
	35.65	1.18	27.90	9.75		1.37	8.23
	31.91	1.58	23.45	7.77		1.73	6.92
6	27.13	1.21	17.96	5.95	301.91	1.15	5.30
	15.93	.781	11.59	3.84		.230	3.42

APPENDIX C

TABLE 9

DATA COLLECTED ON EACH SUBJECT FOR LAUREL FALLS TRAIL

SUBJECT	TIME min^{-1}	DISTANCE m	SPEED $m.min^{-1}$	FINAL VOLUME ℓ	INITIAL VOLUME ℓ min^{-1}	V_E ℓ min^{-1}	STPD	FeO_2
1	20:47	1992	95.86	22587.5	21850.2	36.20	.7488	.1678
2	20:17	1992	98.21	23118.3	22587.5	24.77	.7488	.1571
3	21:42	1992	91.80	27474.0	26795.0	31.69	.7397	.1742
4	22:22	1992	89.06	28153.5	27474.0	30.58	.7378	.1641
5	14:00	1275	91.07	30996.5	30419.0	41.25	.8243	.1660
	7:45	717	92.51	31292.5	3099.6	39.73	.8205	.1667
6	17:00	1572	92.47	33468.0	32962.0	29.76	.8404	.1633
	4:30	420	93.33	33611.0	33468.0	33.30	.8380	.1625

TABLE 10

DATA CALCULATED ON EACH SUBJECT FOR LAUREL FALLS TRAIL

SUBJECT	V_E STPD	$VO_2 \ell \cdot min^{-1}$	VO_2 ml(kg.min)$^{-1}$	Kcal min	Kcal trail	Kcal(kg.trail)	MET
1	26.96	1.12	17.67	5.51	112.80	1.78	5.22
2	19.70	1.03	20.23	5.07	102.26	2.04	5.97
3	23.44	.823	15.53	4.05	86.75	1.63	4.58
4	22.56	1.02	15.00	5.02	111.54	1.64	4.43
5	34.00 32.60	1.47 1.39	16.52 15.63	7.23 6.84	152.18	1.71	4.87 4.61
6	25.01 27.87	1.15 1.30	17.06 19.29	5.66 6.39	123.70	1.84	5.04 5.69

APPENDIX D

DESCRIPTION OF THE TRAILS

Chimney Tops Trail is a 1.97-mile strenuous trail. As one starts out, the trail is quite flat with some slight negative grades leading across several bridges. Then the trail begins to gradually increase in elevation. During this part of the trail, one walks on different surface types including dirt, gravel, and a wooden bridge. Approximately after the first three-quarters of a mile, the trail begins to steepen, making the walk fairly difficult. During this part of the trail, the surface type is dirt mixed with tree stumps and roots. About one-fourth mile to the end of the trail, the elevation decreases but still has some slight positive and negative grades. If a 60-kg person walks at an average speed of 70 $m \cdot min^{-1}$, the time required to walk this trail is 44 minutes; the MET requirement is 8.19.

Laurel Falls Trail is a 1.23-mile leisurely trail. It begins with a mild incline winding around the mountains. The black top surface extends throughout the trail which contributes to the enjoyable walk. Toward the end of the trail, there is a slight negative grade that ends at a waterfall. If a 60-kg person walks at an average speed of 70 $m \cdot min^{-1}$, the time required to walk this trail is 45 minutes; the MET requirement is 4.85.

APPENDIX E

TABLE 11

PHYSICAL CHARACTERISTICS OF SUBJECTS

SUBJECT	AGE (YR)	WT (KG)	HT (CM)
1	23	63.36	161.92
2	22	49.09	158.75
3	22	53.00	167.64
4	24	68.00	162.56
5	28	88.96	191.77
6	25	67.38	174.62
	$\bar{X}$ = 24	$\bar{X}$ = 64.96	$\bar{X}$ = 169.54

VITA

Elizabeth Reames Galloway was born in Rock Hill, South Carolina on January 23, 1956. She graduated from Northwestern High School in Rock Hill in May, 1974. In the fall of the same year, she entered Presbyterian College and remained there for two years and then transferred to the University of South Carolina and received her Bachelor of Science Degree in Physical Education in December, 1978.

She entered The University of Tennessee in January, 1979, and completed her Master of Science Degree in June, 1980.