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A test of the predictive accuracy of three caloric expenditure formulas for level walking at two speeds

Gregory James Hicks
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DOI: <https://doi.org/10.31979/etd.674s-q45j>
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San Jose State University, 1990

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A TEST OF THE PREDICTIVE ACCURACY
OF THREE CALORIC EXPENDITURE FORMULAS
FOR LEVEL WALKING AT TWO SPEEDS

A Thesis
Presented to
the Department of Human Performance
San Jose State University

In Partial Fulfillment
of the Requirements for the Degree
Master of Arts

by
Gregory James Hicks
May, 1990

APPROVED FOR THE DEPARTMENT OF HUMAN PERFORMANCE

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ABSTRACT

THE PREDICTIVE ACCURACY OF CALORIC EXPENDITURE FORMULAS FOR LEVEL WALKING AT TWO SPEEDS

by Gregory J. Hicks

This study compared observed caloric expenditure with values predicted by three widely used equations for single bouts of continuous level walking at 3 and 4 miles per hour. Twenty-eight male subjects (mean age = 24.4 yrs) walked for 21 minutes at each walking speed. To test the hypotheses of this study, predicted-observed difference scores were computed for each subject for each speed by equation condition. Analyses of these data revealed a significant main effect for both equations and speeds and insignificant equations by speed interaction. Further, the results indicated that the Passmore and Durnin equation predicted caloric expenditure most accurately at 3 miles per hour, while the Bobbert equation was the most accurate at 4 miles per hour. Finally, the Fellingham et al. equation substantially underpredicted caloric expenditure and was not recommended for use.

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CHAPTER I

INTRODUCTION

Statement of the Problem

For a number of years, the calculation of target heart rate has been the basis for developing individualized aerobic exercise prescriptions. However, the use of target heart rate for this purpose has been criticized by some researchers who cite difficulty in attempting to quantify the amount of activity performed when target heart rate is used. This concern has created a need to develop more accurate, safe and reliable methods of creating exercise prescriptions. For example, Christensen (personal communication, September 1, 1986) proposed the use of alternative procedures which predict caloric expenditure for specific aerobic activities. In this regard, for walking, Bobbert (1960); Fellingham, Roundy, Fisher and Bryce (1978); and Passmore and Durnin (1955) have derived formulas which predict caloric expenditure. While these formulas are commonly cited and used, for the several years that they have been available, none of them has been validated against objective evidence. Thus, the purpose of this study was to compare values predicted from each of these formulas with

observed caloric expenditure, and by so doing evaluate their relative predictive accuracy.

Research Hypotheses

This study addressed the following hypotheses:

1. There is a significant difference between the accuracy of the three methods of predicting caloric expenditure.
2. There is a significant difference between the three methods of predicting caloric expenditure and actual energy expenditure.
3. Variations in level walking speed significantly affect the accuracy of predicted levels of caloric expenditure.
4. A significant interaction exists between the three equations under consideration and the speed of level walking which influences the accuracy of predicted levels of caloric expenditure.

Delimitations

The delimitations of this study were as follows: only level-walking at speeds of 3 and 4 mph were tested and only college males between the ages of 19 to 30 years were recruited as subjects. These delimitations were deemed necessary to adequately test the three formulas in question.

Limitations

The limitations of this study appear to stem from: the homogeneity of the sample, the specificity of the exercise being analyzed, and the fact that this study was, in general, only a short-term observation. Additionally, resting metabolic rate was not controlled.

Terminology

A steady-state pertains to the time period during which a physiological function (i.e., heart rate) remains at a constant or a steady value (Fox & Mathews, 1981).

Accuracy refers to the degree of conformity of a measure to a standard or true (observed) value (Hayes, 1963).

CHAPTER II

REVIEW OF LITERATURE

Introduction

Predictive caloric expenditure equations, not employing target heart rate, could be very useful for quantifying the amount of exercise performed. This would be particularly true for level walking, as it is a frequently prescribed activity. To better understand the potential role of these equations, the following discussion will include a review of (a) current exercise prescription technique issues, (b) the benefits of predictive caloric expenditure in exercise prescription, (c) the rationale for level walking, and finally, (d) formulas used for predicting caloric expenditure.

Current Exercise Prescription Technique Issues

The American College of Sports Medicine [ACSM] (1978) and Pollock (1978) indicate that, for positive cardiorespiratory and body composition changes, an individual should exercise 3 to 5 days per week for 15 to 60 minutes while maintaining a heart rate (HR) which is 60 to 90% of his or her HR range. In addition, these authors state that the total amount of exercise accomplished is of importance. These are useful guidelines, but they fail to indicate exactly how much activity is sufficient to

produce the aforementioned effects. That is, should one exercise 15 minutes, 3 days per week at 90% of HR range or 60 minutes, 3 days a week at 60% of HR range? Further, these guidelines do not indicate how to create a progressive program for continued improvement in cardiorespiratory fitness. More useful information is obtained from other individuals who state that, for complete health and body composition changes, exercise should be sufficient to expend 1000 to 2500 kilocalories per week (ACSM, 1983; Berg, 1978; Leon, Conrad, Hunninghake & Serfass, 1979; Walsh, 1983; Zuti & Golding, 1976) or 300 kilocalories per session (Miles et al., 1973). These are exacting quantifications of the amount of activity which should be performed, but none provide an indication of how many kilocalories are utilized in various activities when performed for a specified duration. Thus, the reader is left wondering how much walking (or other activity) one must do to expend 300 kilocalories.

Williams (1983) presents information regarding weight loss and exercise which is somewhat typical of that presented by other authors. He indicates that as the duration or intensity of exercise increases, an individual utilizes more calories, and the essential factor to weight loss is a negative caloric balance (i.e., more calories

are expended than consumed). However, when he describes his program for weight loss, he presents the reader with information on how to calculate exercise heart rate and a progressive program involving increases in yards/miles covered, not number of calories expended during the activity.

Cooper (1982) suggests a points system, based upon oxygen consumption during exercise, as a foundation for designing an exercise program. His is a precise way to monitor a progressive program and he loosely quantifies work done, but this does not give a precise measure of the work completed. However, the total amount of work accomplished can be determined when work is reported in calories utilized.

The Benefits of Caloric Expenditure in Exercise Prescription

The use of calories in the prescription of exercise could be beneficial in at least three ways. First, the precise amount of exercise could be calculated. Since the amount of exercise accomplished is important (ACSM, 1978), professionals could be certain of developing a sufficient, yet safe, exercise program for improved cardiovascular efficiency and body composition changes.

Second, a progressive program of exercise could be planned by gradually increasing the weekly amount of

exercise (in calories) performed. Many individuals beginning fitness programs are injured because they attempt too much exercise at too high an intensity or they progress too quickly. The use of calories in the planning of a progressive fitness program could thus help to prevent injuries because reasonable increases could be planned (e.g., while a 10% increase in the quantity of activity accomplished from one week to the next might be safe, a 20% increase might result in injury), (C. L. Christensen, personal communication, September 1, 1986).

Third, the combination of information about calories with exercise heart rate could ensure that sedentary or elderly persons beginning an exercise program are achieving a sufficient activity level (300 calories) to show physiological adaptation, yet are completing bouts which are not harmful. Elderly and sedentary individuals may find it difficult to apply the ACSM guidelines (ACSM, 1978) due to extremely low fitness levels. These persons could perform several short bouts of exercise until the total daily caloric expenditure was performed, thereby performing a sufficient amount of exercise while reducing the risk of an orthopedic injury and/or a cardiac event (C. L. Christensen, personal communication, September 1, 1986).

The Rationale for Level Walking

Level walking was chosen as the mode of exercise for this study for several reasons. First, it requires no special training and can be performed virtually anywhere and at any time. Second, the risk of orthopedic injuries and/or cardiac events is significantly less in all individuals (especially in individuals with heart disease, and in elderly and sedentary persons) when compared with running or similarly stressful activities (Clement, Taunton, Smart & McNicol, 1981; Koplan, Powell, Sikes, Shirley & Campbell, 1982). Third, walking has become a standard adjunct to the treatment of many diseases, especially coronary heart disease. Cardiac rehabilitation programs begin the day after an infarct (heart attack) when patients are assisted from their beds and started on a walking program (Erb, Fletcher & Shellfield, 1980; Hanson, Griesse & Corliss, 1980).

The Formulas Used For Predicting Caloric Expenditure

In this study three formulas (i.e., Bobbert, 1960; Fellingham et al., 1978; Passmore & Durnin, 1955), which predict caloric expenditure in level walking, were compared. In this section each formula will be described and discussed in turn.

These three formulas were selected as they appeared to provide the most frequently cited predictive formulas

for determining caloric expenditure. It should be noted that while other formulas exist for determining energy expenditure of level walking (such as the one presented in the ACSM Guidelines for Graded Exercise Testing and Exercise Prescription, 1986) none of these formulas provide the necessary constants for the conversion of oxygen consumption values into kilocalories of expended energy. Thus, none of these other formulas can provide a prediction of caloric energy expenditure and were therefore excluded.

Bobbert (1960) tested two subjects independently at three different speeds and four different gradients to establish the effect of speed and gradient on total energy output (E_w). When energy expenditure for these various speeds and gradients was plotted, a curvilinear increase was seen with rising speed. Since the form of the curve suggested a quadratic function, E_w was plotted against the square of the speed and, in this way, produced a nearly straight line for each gradient. Regression equations were then calculated on this assumption. Since Bobbert found that energy expenditure increased with gradient in a curvilinear fashion (suggesting a logarithmic rise) logarithms of E_w were plotted against the gradients and, in this way, Bobbert felt that nearly linear relationships were obtained when his regression equations were applied.

The equation for this relationship may be represented in general as follows:

$$\log Ew = a + (b \times \alpha)$$

In this equation a and b are coefficients of speed and α represents gradient. From this general equation, further regression equations were produced, and these yielded a prediction equation (Bobbert, 1960).

Fellingham et al. (1978) used the actual oxygen consumption (oxygen expenditure) of 24 male subjects to determine caloric expenditure of walking. This was performed by having each subject walk a total of one mile on a level treadmill at three different speeds. Prior to each test, a resting metabolic rate was established for each subject, in a sitting position. The caloric expenditure for the exercise was then determined by calculating the area under the curve, found by plotting the caloric expenditure against time. Resting caloric expenditure was subtracted from each value; the exercise expenditure was thus total cost minus resting expenditure. The area under the curve was determined using the trapezoidal rule to approximate the integral. Further, these authors indicated that the dependent variable was total caloric cost per mile (Y), and that the independent variables were body weight in kilograms, and the square of

the speed in miles per hour times the body weight in kg. Finally, they indicated what the additional constants were, and that a prediction equation had been generated (see Chapter III, page 14 for equation).

Passmore and Durnin (1955) summarized the results of five studies from which two regression equations were derived. The first equation expresses energy expenditure (cal/min) in relation to speed. The authors noted that over the range of 3 to 6.5 km/hr (approximately 2-4 mph) energy expenditure is linearly proportional to speed. The second equation, while expressing energy expenditure in a similar fashion (i.e., cal/min), does so in relation to body weight. These equations were used in combination by the authors to create a table of predictive energy expenditure for level walking. It is important, however, to note that, Passmore and Durnin omitted much of the methodological basis for the development of their constants and equations. Their methodological omissions created the need to develop two additional equations which permitted the application of the values that appear in Table 2, to the continuous weight data that were collected in this study (see Chapter III, pages 15, 16 and 17 for further details).

CHAPTER III

METHODS

Subjects

The subjects were 28 male college student volunteers. These subjects were between the ages of 19 and 30 years ($M = 24.4 \pm 2.8$ yrs) and their body weight varied from 50.2 to 141.3 kg ($M = 78.6 \text{ kg} \pm 16.57$). The sample size set for this study was deemed necessary as the minimum number of subjects needed to accurately determine reliable relationships (Hayes, 1963). Descriptive data concerning subjects' volume of oxygen consumed per minute (VO_2), volume of carbon dioxide produced each minute (VCO_2), volume of air expired in one minute (VE), and respiratory exchange ratio (R) values for both speeds appear in Table 1.

All subjects completed a medical history questionnaire and informed consent form (Appendix A; this was approved by the Institutional Review Board -- Human Subjects at San Jose State University) prior to being selected for the study. Each subject was in good general health, normotensive (resting blood pressure below 140/90 mmHg), and free of any known coronary heart disease. Additionally, any person who was either 20% over or under their ideal body weight (as determined by the Metropolitan

Table 1

Descriptive Data For Subjects

n = 28	Mean	<u>SD</u>
Age (yr)	24.4	± 2.80
Weight (kg)	78.6	± 16.57
VO ₂ ^a at 3 mph (L/min)	.94	± .17
VO ₂ ^a at 4 mph (L/min)	1.39	± .34
VCO ₂ ^b at 3 mph (L/min)	.86	± .24
VCO ₂ ^b at 4 mph (L/min)	1.22	± .33
VE ^c at 3 mph (L/min)	24.09	± 4.8
VE ^c at 4 mph (L/min)	33.62	± 7.7
R ^d at 3 mph	.87	± .05
R ^d at 4 mph	.87	± .05

^aVO₂ = volume of oxygen consumed per minute

^bVCO₂ = volume of carbon dioxide produced each minute

^cVE = volume of air expired in one minute

^dR = respiratory exchange ratio

Life Insurance Company (Height)/Weight Tables; cited in Neiman, 1986) was excluded from the study. When accepted into the study, each subject was provided with an information sheet which described the proper testing attire as well as the date, time, and place of his specific testing session.

Computation of Equations

The computation of the Bobbert (1960) formula requires: speed (v) measured in meters per minute (m/min) and gradient (a) measured in degrees. Log Ew is energy expenditure in cal/kg/min. This formula, with its constants, is expressed as follows:

$$\begin{aligned} \text{Log Ew} = & 1.4272 + (0.004591 \times v) + (0.024487 \times a) \\ & + (0.0002658 \times v \times a) \end{aligned}$$

Computation of the Fellingham et al. (1978) formula requires the following: the square of the speed in miles per hour times the body weight measured in kilograms (SSW); the subject's body weight expressed in kilograms (W). Total caloric cost (Y) is expressed as kcals per mile. This formula, with its constants is expressed as follows:

$$Y = 3.7104 + .2678 \times W + .0359 \times \text{SSW}$$

Although Passmore and Durnin (1955) presented the two equations which appear below, they did not indicate how these were used in combination to form the table which they derived for the computation of energy expenditure. Their equations use the following variables: the speed in kilometers per hour (V) and the subject's body weight in kilograms (W). These equations, with their constants are expressed as follows:

$$C \text{ (Cal/min)} = 0.8V + 0.5$$

$$C \text{ (Cal/min)} = 0.0047W + 1.02$$

The table that Passmore and Durnin (1955) derived from these equations for the computation of energy expenditure is presented in Table 2.

The wide gaps in weights that they included in their table (Table 2) necessitated the development of two additional equations which permitted the application of the Passmore-Durnin values to the continuous weight data that were collected in this (or any other) study of this type. These equations were derived by using a computer-assisted linear regression model applied to the data presented in Table 2 for the 3 and 4 mph walking speeds.

Table 2

Relationship Between Energy Expenditure (Cal/min) and
Speed of Walking (mph) and Gross Body Weight (lb)
(Passmore & Durnin, 1955)

Speed (mph)	Weight (lb)						
	80	100	120	140	160	180	200
2.0	1.9	2.2	2.6	2.9	3.2	3.5	3.8
2.5	2.3	2.7	3.1	3.5	3.8	4.2	4.5
3.0	2.7	3.1	3.6	4.0	4.4	4.8	5.3
3.5	3.1	3.6	4.2	4.6	5.0	5.4	6.1
4.0	3.5	4.1	4.7	5.2	5.8	6.4	7.0

These equations are as follows:

$$3\text{mph: } C \text{ (Kcal/min)} = 0.021428 \times W \text{ (kg)} + 0.985714$$

$$4\text{mph: } C \text{ (Kcal/min)} = 0.028928 \times W \text{ (kg)} + 1.192857$$

The standard error of y estimates, r^2 , the standard error of the raw-score coefficients, and the constants for each equation are presented in Table 3. These equations use constants expressed in miles per hour and depend upon kilogram values for body weight (W).

This study examined the relationship between predicted and actual energy expenditure in level walking for each formula. Thus, by using level walking only, any difference in the use of gradients between these formula was held constant. Finally, it should be noted that since this study employed the speed constants of 3 and 4 miles per hour, it was necessary to convert these values into their corresponding metric distances per unit of time for the computation of the predicted values using the Bobbert formula.

Test Procedures

The data collected for this study were those required for the computation of each of the three formulas under consideration (i.e., speed, gradient, body weight, actual oxygen consumption, heart rate, room temperature, barometric pressure, and relative humidity).

Table 3

Regression Data For Derivation of the Equations Used to
Refine the Passmore and Durnin Table

Speed (mph)	Std. Error of Y Estimate	Std. Error of Coeffiecient	r^2	Constant
3	0.033806	0.000319	0.998890	.985714
4	0.029277	0.000276	0.999542	1.192857

Environmental data were measured and recorded prior to the beginning of each test. Prior to measuring caloric expenditure, all subjects were informed of the test procedures and the possible discomforts, risks, and potential benefits to be expected. Next, with subjects clothed in tee shirt and shorts, body weight (in kilograms) and height (in centimeters) was measured and recorded. These values were compared with those of the Metropolitan (Height)/Weight Tables (Neiman, 1986). None of the subjects were found to be 20% over or under the values set forth by the aforementioned chart and were not excluded from the study.

Electrodes were then placed on the subject in a modified CM5 configuration. Next the subject was asked to sit quietly for approximately 3 minutes. After this period, pre-exercise blood pressure and heart rate measurements were taken. When this procedure was concluded, the subject donned his running shoes and was given final specific instructions for the treadmill test. These instructions included an explanation of the test protocol, signs of exertional intolerance, and hand signals to be used during the test. The mouthpiece and nose clip were then placed on the subject and adjusted as necessary. The subject was positioned on the treadmill and allowed to practice walking for approximately 3

minutes at a speed of 2.5 mph. At this time, each subject was instructed to walk at a stride frequency and stride length that felt natural and/or comfortable for each speed. Immediately following the practice and warm up period the subject was required to walk continuously first at 3 mph for 21 minutes and at 4 mph for an additional 21 minutes. The treadmill was not stopped and restarted during either transition from 2.5 mph to 3 mph or 3 mph to 4 mph.

According to Bobbert (1960), Erickson, Simonson, Taylor, Alexander and Keys (1946), Hogberg (1952), McDonald (1961), Ralston (1958), and van der Walt and Wyndham (1973), stride length, stride frequency, and leg length do not significantly influence $\dot{V}O_2$ in level walking, unless they are artificially or arbitrarily regulated. Bobbert and Erickson et al. further state that the optimal stride and frequency are those chosen by the subject and not those imposed by the experimenter.

The entire testing session lasted approximately 55 minutes and was divided into the following phases or stages: pre-exercise (minutes -3 to 0), practice walking and warmup (minutes 0 to 3), stage one (minutes 4 to 25), stage two (minutes 26 to 47) and the post exercise or recovery phase (minutes 48 to 55). The entire test

procedure, together with the type of data collected and the data collection sequence is presented in Table 4. Heart rate (HR) was recorded on electrocardiograph (ECG) paper during the last 10 seconds of each minute for the entire test and was determined from the tracing by dividing 1500 by the number of millimeters between one R-R interval.

The HR measures assisted in providing an indication of the achievement of steady state after each change in speed (i.e., as in the transition from stage 1 at 3.0 mph to stage 2 at 4.0 mph). Additionally, the ECG and blood pressure data provided an indication of the presence of any cardiovascular abnormalities (e.g., pre-ventricular contractions or abnormal blood pressure responses). Steady state was achieved when the subject's HR had not changed more than five beats per minute for six consecutive minutes. Blood pressure was measured and recorded during the last 30 seconds of minutes 0, 5, 10, 15, 20, 25, 27, 32, 37, 42, 47, 48, 50, 52, and 54.

Respiratory gas collection began at minute four (the first minute of stage one) and was performed on a minute by minute basis until minute 47 (the last minute of stage two). As was noted elsewhere, treadmill grade was maintained at zero degrees for the entire test period.

At minute 48, the treadmill speed was reduced to 2.5

Table 4

The Treadmill Testing and Data Collection Sequence

Event	Time (min)	Speed (mph)	Data Collected
Pre-exercise	-3 to 0	0	HR ^a , BP ^b
Practice Walking & Warmup	0 to 3	2.5	None
Stage 1	4 to 25	3.0	HR ^a , V0 ₂ ^c
	5,10,15,20 & 25	3.0	BP ^b
Stage 2	26 to 47	4.0	HR ^a , V0 ₂ ^c
	27,32,37,42 & 47	4.0	BP ^b
Post Exercise	48 to 55 48,50,52 & 54	2.5	HR ^a BP ^b

^aHR = heart rate

^bBP = blood pressure

^cV0₂ = volume of oxygen consumed per minute

mph and the mouth piece and nose clip were removed from the subject. Heart rate was monitored on a minute by minute basis while blood pressure was measured at the intervals listed above. Both measures were typically discontinued after minute 55 as most subjects' HR and blood pressure levels had approached near preexercise values. If however, the subjects' HR had reached or exceeded 150 bpm during stage 2 (as was the case with three subjects) both measures were monitored past the 55 minute mark, and continued as determined by the subjects' active cool down response. The electrodes were detached from the subject and the remaining electrode paste was wiped off the subject typically after the treadmill was stopped.

Following the test, HR, volume of air inspired in one minute (VI), fractional concentration of oxygen in expired air (FeO_2) and fractional concentration of carbon dioxide in expired air (FeCO_2) data were entered onto a computer using a software program developed by Dr. Carol Christensen (1984) and VO_2 , VCO_2 , VE and R values were calculated.

Instrumentation

A Quinton programmable treadmill model #18-60 was used for testing. It was checked for safety and accuracy of speed prior to the initiation of the study and speed

was checked at minutes 5, 10, 15, 20, 26, 30, 35 and 40 of the test.

Heart rate was continuously monitored throughout each test on a Quinton Model 623A Electrocardiograph monitoring system with oscilloscope. Blood pressure was measured with a Hader aneroid sphygmomanometer, model #2273 and a standard stethoscope.

Respiratory gases were collected using standard open circuit calorimetry. With a nose clip in place, subjects inhaled room air through an Otis-McKerrow two-way valve attached to a Parkinson-Cowan CD-4 gas meter fitted with a rotary potentiometer. The output from this meter (inspired gas volume) was continuously recorded on a Gilson 5/6H Biomedical Multichannel Strip Recorder, which was calibrated prior to each test.

The expired air passed into a mixing chamber, and was drawn through CaSO_4 crystals to remove any respiratory water. A sample was then drawn into a sampling bag on a Wilmore-Costill valve, and finally passed through the gas analyzers. Gas samples were analyzed for oxygen and carbon dioxide concentrations with an Applied Electrochemistry S-3A Oxygen Analyzer and a Beckman LB-2 Carbon Dioxide Medical Gas Analyzer, respectively. These analyzers were calibrated prior to each test with a standard gas of known composition.

An Apple II series computer and printer, and an IBM AT and laserjet printer were used in conjunction with two programs, one developed by Dr. Carol Christensen, titled Research Programs and Other Public Domain Programs, the other a commercially-produced statistical analysis package (CRISP: Crunch Interactive Statistical Package, 1986). The former calculated actual energy expenditure from oxygen consumption, respiratory exchange ratio (RER) values, and a table of caloric equivalents for non-protein RER values (Fox & Mathews, 1981).

Preparation of the Data for Statistical Analysis

In deriving the values to be used to test the hypotheses of this study, the first 10 minutes and the last 1 minute of each set of data at each speed for each subject were excluded. These data were excluded as they were observed consistently to be the least stable minutes of each stage (i.e., they were nonsteady-state minutes). Thus, observed caloric expenditures for each subject were defined as the means derived from a 10 minute block of data at each walking speed.

For each subject, predicted caloric energy expenditure was computed using each of the three equations. Then a set of three difference scores was computed for each subject for each speed by subtracting the observed caloric energy expenditure for each speed

from each of the predicted caloric energy expenditure values. Thus, in all, six predicted-observed difference scores were derived for each subject.

The hypotheses were tested with a two (walking) speeds by three (equations) analysis of variance (ANOVA) with repeated measures in both factors. A simple t -test for significance was also employed. Although the CRISP statistical analysis program provides a thorough selection of post hoc tests, the Bonferroni technique was used, as it is somewhat more sensitive than the other post hoc analysis techniques (Hayes, 1963). The alpha level set for this technique was $p < .05$, which was consistent with the other the statistics used in this study.

CHAPTER IV

RESULTS AND DISCUSSION

Results

The means and standard deviations of the difference scores for each equation are summarized in Table 5. A negative mean indicates that the predicted value under-estimated the observed value and, conversely, a positive value indicates an over-estimation. The closer the value is to zero, the less the prediction differs from actual energy expenditure. In addition, the means and standard deviations for predicted and actual caloric energy expenditure for each speed are summarized in Table 6 (data for individuals are found in Appendix B).

The results of the ANOVA are summarized in Table 7. As can be seen by inspecting this table, the main effects for both speed ($F, 27=10.36, p<.004$) and equations ($F, 54=605.66, p<.001$) were significant as was the speed by equation interaction ($F, 54=472.40, p<.001$). The significant main effect computed for speed resulted from the fact that overall the difference between the predicted and observed values was less for 3 mph than was the case at 4 mph. The substantial main effect computed for equations was the result of the large discrepancies in the accuracy with which these equations predicted actual caloric expenditure.

Table 5

The Means and Standard Deviations for the Difference
Scores Between Predicted and Observed Caloric Expenditure
(Cal/Min) for Each Equation for Each Speed

Walking Speeds	Difference Scores for Equations					
	Bobbert		Fellingham et al.		Passmore & Durnin	
	Mean	<u>SD</u>	Mean	<u>SD</u>	Mean	<u>SD</u>
3 mph	0.287	± 0.745	-2.133	± 0.612	0.051	± 0.630
4 mph	-0.290	± 1.129	-2.178	± 1.170	-0.643	± 1.141

Table 6

Means and Standard Deviations of Subjects' Predicted and Actual Caloric Energy Expenditure at Three and Four Miles Per Hour

Speeds	Equations							
	Bobbert		Fellingham et al		Passmore & Durnin		Actual	
	Mean	<u>SD</u>	Mean	<u>SD</u>	Mean	<u>SD</u>	Mean	<u>SD</u>
3 mph	4.928	± 1.020	2.420	$\pm .6700$	4.530	± 1.160	4.640	$\pm .8500$
4 mph	6.549	± 1.356	3.370	$\pm .9400$	5.980	± 1.550	6.600	± 2.090

Table 7

Results of the Two (Speeds) by Three (Equations) ANOVA

SOURCE	<u>df</u>	Sum Squares	Mean Squares	<u>F</u>	<u>p</u>
<u>Between</u> <u>Subjects</u>	27	114.24			
<u>Within</u> <u>Subjects</u>	140	192.24			
A (Speeds)	1	8.08	8.08	10.36	<.004
A x SwGrps	27	21.05	.78		
B (equations)	2	157.76	76.38	605.66	<.001
B x SwGrps	54	6.81	.13		
AB	2	3.35	1.67	472.40	<.001
AB x SwGrps	54	.19	.0035		

Table 8 shows the results of the Bonferroni post hoc tests, which revealed that for each speed all of the means listed in Table 5 were significantly different from each other ($p < .01$). Thus, it is clear that the significant speed by equation interaction ($p < .001$) computed from these data resulted from the fact that the Passmore and Durnin (1955) equation as it was utilized in this study, predicted observed caloric expenditure with significantly greater accuracy ($p < .001$) than either the Bobbert (1960) or Fellingham et al. (1978) equations at 3 mph while the accuracy of the Bobbert equation was significantly better ($p < .001$) than the other two equations at 4 mph.

As is indicated in Table 9, the differences for the 3 and 4 mph walking conditions between observed and predicted caloric expenditure were not significant for the Bobbert (1960) equation (i.e., $t = 2.007$, $p < .05$ and $t = 1.336$, $p < .05$, respectively). The results of these analyses for the Passmore and Durnin (1955) equation were mixed in that the difference between observed and predicted caloric expenditure was not significant for the 3 mph condition ($t = .4210$, $p < .05$) but was significant for the 4 mph walking condition ($t = 2.923$, $p < .05$). Finally, when this statistical procedure was applied to the Fellingham et al. (1978) equation data, highly significant t ratios were computed for

Table 8

Bonferroni Post hoc Test Summary of Compared Means for the
Three Predictive Energy Expenditure Equations at Three and
Four Miles Per Hour

Speed	Comparison	p
3 mph	Passmore and Durnin with Fellingham et al.	.001
	Passmore and Durnin with Bobbert	.007
	Fellingham et al. with Bobbert	.001
4 mph	Passmore and Durnin with Fellingham et al.	.001
	Passmore and Durnin with Bobbert	.001
	Fellingham et al. with Bobbert	.001

Table 9

Results of T-tests (t) for Comparison of Observed Caloric Expenditure with Predicted Energy Expenditure Values as Derived From Each of the Three Equations for Each Speed

Walking Speed	Equations		
	Bobbert	Fellingham et al.	Passmore & Durnin
	<u>t</u>	<u>t</u>	<u>t</u>
3 mph	2.007	18.080	0.421
4 mph	1.336	9.680	2.923

Critical t ($p < .05$) (df=27) = 2.052

both the 3 and 4 mph conditions, (i.e., $t=18.080$, $p<.001$ and $t=9.680$, $p<.001$, respectively).

Discussion

The relationship of the results to each hypothesis. As was stated on page 2, Hypothesis 1 proposed that 'There is a significant difference between the accuracy of the three methods of predicting caloric expenditure.' The F value reported for equations in Table 7 together with the results of post hoc tests indicates that there is a significant difference between the predictive accuracy of the Bobbert (1960), Fellingham et al. (1978) and Passmore and Durnin (1955) equations. Thus, clearly these equations do not provide interchangeable estimates of caloric expenditure and in fact they vary widely in the accuracy with which they estimate these values.

Hypothesis 2 stated that 'A significant difference exists between the three methods of predicting caloric expenditure and actual energy expenditure.' Overall these data suggest that the Bobbert (1960) equation is the least likely to predict caloric expenditure with significant error when both 3 and 4 mile per hour conditions are used (i.e., the values predicted by this equation appear to be closest to the observed values at both speeds). However, further inspection of these data suggest that this conclusion may be a tenuous one. To explain, it is interesting to note that

by inspecting the tables in Appendix B, none of the predicted values for any subject exactly coincided with the observed values for the subjects. Consistent with the results of this study at 3 mph, the Passmore and Durnin (1955) equation provided the closest predictions for 15 subjects, the Bobbert equation was the closest predictor for 12 subjects and the Fellingham et al. (1978) was closest for only 1 subject. Additional inspection of these data reveals that for the 15 subjects for which the Passmore and Durnin equation predicted best, the absolute differences between the predicted and observed values were all within 1 calorie of the predicted values (i.e., range = .0750 - .8660). The median difference for this group was .3200 and thus the observed values for the majority of these subjects did not differ from the predicted value by more than one-third of a calorie. For the 12 subjects for which the Bobbert equation predicted best, the results of an identical type of inspection of these data yielded similar findings. That is, for these 12 subjects the absolute differences between observed and predicted values were less than 1 calorie and ranged from .0230 to .6420 with a median of .3775.

At the 4 mph speed, the above pattern was in part reversed with the Bobbert (1960) equation predicting closest for 17 subjects, the Passmore and Durnin (1955) was closest for 10 subjects and again, the Fellingham et al. (1978)

equation was closest for only one subject. However, further inspection of these data modify to a degree the conclusions that may be drawn from these observations. That is, for the 10 subjects for which the Passmore and Durnin equation predicted closest, the differences between the observed and predicted values were all less than 1 calorie and ranged from .0580 to .5790 with a median of .4125, while for the 17 subjects whose observed responses were most closely predicted by the Bobbert equation, the absolute differences ranged from .0860 to 3.1160 with the median = .9000. In addition, nearly half (eight) of these subjects deviated by more than one calorie from the value predicted for them by the Bobbert equation. In a general way, these observations serve to buttress one of the major conclusions of this study in that they provide further demonstration of the inadequacies of the Fellingham et al. equation as tested in this study.

Hypothesis 3 stated that 'Variations in level walking speed significantly affect the accuracy of predictions made from the three equations that were under consideration in this study.' By inspecting Table 7, it is clear that walking speed had a significant effect ($F = 10.36$; $p < .004$) on the accuracy of prediction from these equations. Further as is shown in Table 5, each of the equations predicted caloric expenditure closer to the observed value at 3 mph

(with respective mean difference scores for Bobbert, Fellingham et al. and Passmore and Durnin of 0.287, -2.133 and 0.051) than was the case at 4 mph (-0.290, -2.178 and -0.643).

Finally, Hypothesis 4 addressed the issue that 'A significant interaction exists between the three equations under consideration and the speed of level walking, which influences the accuracy of predicted levels of caloric expenditure.' As can be seen in Table 7, the interaction between these variables was significant. Further, as was reported above, the differences between all of the equation means for each speed were significant. These data clearly indicate that at 3 mph, the Passmore and Durnin (1955) equation, as it was elaborated for use in this study, predicted caloric expenditure more accurately (mean difference score of 0.051) than either the Bobbert (1960) (mean difference score of 0.287) or Fellingham et al. (1978) (mean difference score of -2.133) equations. However at 4 mph, the Bobbert equation predicted caloric expenditure with significantly greater accuracy ($p < .001$ for all comparisons) than either of the other two equations. In this regard, it should be noted (see Tables 5 and 8) that the Fellingham et al. equation under-estimated observed caloric expenditure by a significant degree ($p < .001$, $< .007$ & $< .001$ for all comparisons at 3 mph; $p < .001$ for all comparisons at 4 mph)

at both of the level walking speeds and was the least accurate of the three. Thus, these data lead to serious doubts about the validity of the Fellingham et al. equation as an alternative to either the Passmore and Durnin or Bobbert equations.

General Discussion. Although these equations predict caloric expenditure with varying degrees of accuracy at different speeds, it should be noted that in a practical application, at 3 mph, either the Bobbert (1960) or the Passmore and Durnin (1955) equations would provide a reasonable estimate of caloric energy expenditure. Ideally, if either were to be recommended, the user should be cautioned as to which equation is most accurate, and that both tend to over-predict. At 4 mph only the Bobbert equation could be recommended for use. As was noted earlier, the Fellingham et al. (1978) is not a suitable alternative at either speed.

It is interesting to note that as the walking speed increased, the predictive accuracy of the Passmore and Durnin (1955) equation declined, while in relative terms, the opposite was true for the Bobbert (1960) equation. If this is a trend, it raises several intriguing questions. First, would the magnitude of the predictive error increase in the Passmore and Durnin equation as the speed increased further? Second, would the magnitude of the error observed

in the Bobbert equation decline further with increased walking speed? Third, do either of these equations possess some inherent optimal speed for function? These questions should be the subject of further research.

Finally, the Passmore and Durnin equation has been in use since 1955, Bobbert's since 1960 and the Fellingham et al. equation since 1978. The original works in which each of these equations appeared have been routinely cited by others since their introductions into the literature, yet no attempt at evaluating the predictive accuracy of these equations has been published. Thus, it appears that a thorough reevaluation of the literature that has used these equations is in order.

There are several factors which may have assisted in producing results which differ from those of the three studies analyzed. First, the methodology of this experiment did not exactly duplicate the procedures employed by the other authors, as each differed somewhat from one another. Specifically, Bobbert (1960) used a 2 to 4 minute segment of data from each 10 minute block of walking at different speeds. A 10 minute data segment from each 21 minute block of walking time was analyzed in this study. Additionally, Bobbert began data collections at the moment of assumed steady state rather than at an observed moment of steady state. Fellingham et al. (1978) omitted a methodological

description of these points. Passmore and Durnin (1955), drew their conclusions from the accumulated results of several studies concerned with walking and energy expenditure.

Second, resting VO_2 was not measured in this study, but was however, by Fellingham et al. (1978) and Bobbert (1960). Further, Fellingham et al. reported subtracting this value from "total (caloric) cost" for each subject, in order to derive an "exercise (caloric) cost." The effect of subtracting resting caloric cost may have had a significant effect on the predictive accuracy of this equation. However, such an effect, if it exists remains the subject of future research. Bobbert omitted information concerning his use of resting VO_2 .

Third, the fitness levels of subjects used by Bobbert (1960) and Fellingham et al. (1978) exceeded those of subjects used in this study. Specifically, the two subjects used by Bobbert were reported to be "trained" adult males. The subjects used by Fellingham et al. were "mainly varsity athletes, capable of running the mile in 6:40 (9 mph) or faster." None of the subjects used in this study were "trained" or "varsity athletes." Rather the majority of the subjects used for this investigation fell into the categories of either sedentary or moderately active (i.e., engaged in some type of aerobic conditioning activity no

more than two days per week, as defined for this study).
The subjects that participated in the studies reviewed by
Passmore and Durnin (1955) were of mixed fitness levels.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The predicted values for caloric energy expenditure derived from three equations (i.e., Bobbert, 1960; Fellingham et al., 1978 and Passmore and Durnin, 1955) were compared with measured data as a check on their relative predictive accuracy.

Twenty-eight healthy college-age males volunteered to participate in this study. Each subject walked continuously on a level treadmill for 21 minutes at three and four miles per hour for a total of 42 minutes. Heart rate (HR) was monitored continuously and measured during the last 10 seconds of each minute. HR was used as the determinant of steady-state (i.e., heart rate changed less than ± 5 beats per minute for six consecutive minutes). Blood pressure was measured and recorded during the last 30 seconds of minutes 0, 5, 10, 15, 20, 25, 27, 32, 42, 47, 48, 50, 52, and 54. Gas samples and ventilatory data (using standard open circuit calorimetry) were collected each minute. The treadmill speed was frequently checked for accuracy.

The difference scores computed between the predicted and obtained values in caloric energy expenditure were analyzed by use of a two (speeds) by three (equations)

analysis of variance with repeated measures in both factors. Significant main effects were computed for both speed and equations as well as for the speeds by equations interaction. Bonferroni post hoc tests were used to elaborate the significant interaction. Finally, the direct difference method of computing t was used to analyze differences between predicted and actual energy expenditure for each equation at each walking speed. Although differences observed for the Bobbert (1960) equation were not significant at either speed it should be noted that the t ratio computed for 3 mph closely approached significance (i.e., $p < .05$). A significant difference was computed for the Passmore and Durnin (1955) equation at 4 mph but not at 3 mph, and significant differences were computed for the Fellingham et al. (1978) equation at both speeds. Thus, the three equations under consideration here predicted caloric expenditure with different degrees of accuracy. The Bobbert and Passmore and Durnin equations appear to be most useful, but their relative accuracy interacted with walking speed. The fact that the Fellingham et al. equation significantly under-predicted at both speeds, in combination with the other significant differences mentioned above, clearly indicates that it should not be used as tested in this study.

Conclusions

On the basis of the results of this study the following conclusions can be drawn:

1. All three equations displayed significantly different levels of prediction at different speeds.
2. If caloric expenditure was to be predicted for an individual walking on a level surface at 3 mph, only the Passmore and Durnin (1955) equation would be the best of the three equations. However, if the same person was only walking at 4 mph over a level surface the Bobbert (1960) equation would be the predictive formula of choice. Thus, the accuracy of the equation that is used to predict caloric expenditure is dependent upon the walking speed, and equations should not be used interchangeably if optimum accuracy of prediction is desired.
3. The Fellingham et al. (1978) equation (as tested in this study) cannot be recommended for use, because it significantly under-predicted energy expenditure at both speeds (i.e., it was deemed inaccurate at either speed).

Recommendations

From the results presented in this study, the following recommendations for future research are suggested.

1. Research should be undertaken to investigate the relative predictive accuracy of these three equations at the

same speeds using a graded surface and at higher speeds using a level surface.

2. The fact that the Bobbert (1960) equation was very close to significance at 3 mph suggests that further work or a replication of this work must be in order before one concludes that it predicts accurately at either speed.

3. More accurate predictive energy expenditure equations should be developed or more accurate derivations of the Bobbert, Fellingham et al. and Passmore-Durnin equations should be explored.

4. The interaction between age, ethnic background and varying fitness levels with the predictive accuracy of each of these equations, should be examined.

5. Additional prediction equations should be identified, examined for accuracy and compared with those investigated in this study.

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APPENDIX A

INFORMED CONSENT AND MEDICAL HISTORY QUESTIONNAIRE

INFORMED CONSENT FOR EXERCISE TESTING
Human Energy Expenditure During Exercise: Individual Variations
from Widely Used Prediction Equations

I. Testing Procedures

All testing will be supervised by Gregory Hicks or Dr. Carol L. Christensen. Certified CPR personnel will be present during all testing sessions. During your visit to the Exercise Physiology/Biomechanic Laboratory you will be asked to complete a medical history form and exercise on a treadmill for 60 minutes. You will be weighed on a balance type scale, and your height will be assessed. Three to six electrodes will be attached to your chest area in a standard configuration. These will be attached to an electrocardiograph (ECG) by a cable so that your heart rate can be monitored during the exercise. Your blood pressure will be taken prior to, during, and after exercise with standard equipment and procedures. You will then sit quietly for 3 minutes, after which your pre-exercise heart rate and blood pressure will be taken. During this period, the test protocol, along with an explanation of the hand signals to be used during the test, will be given. Next, you will be given instructions on how to walk on the treadmill. You will begin walking. The first 3 minutes will be at a speed of 2.5 miles per hour (mph); this will serve as a warm-up and practice period. Then you will insert a sterilized mouthpiece attached to a breathing valve into your mouth and place a noseclip on your nose to prevent escape of air. The treadmill speed will be increased to 3 mph and after 20 minutes to 4 mph. The slope will remain at 0% during the entire test. During the testing period oxygen consumption, heart rate, blood pressure, and perceived exertion data will be collected at predetermined times. Following exercise, your heart rate will be monitored for several minutes if your exercise heart rate exceeds 85% of your heart rate range. If your exercise heart rate does not exceed this value you will not be monitored following exercise. During exercise your outward appearance and the ECG will be monitored continuously, if any signs of exercise distress are observed the test will be stopped immediately. In addition, you may stop the test at any time for any reason (e.g., muscle cramping, nausea, dizziness).

2. Discomforts and Risks

As with any exercise task there are certain risks and discomforts of which you should be aware. The discomforts are those associated with breathing through a mouthpiece (e.g., it is uncomfortable on the mouth, dry throat) with a nose clip in place. During the exercise you may experience some of the discomforts commonly associated with exercise: sweating; increased heart rate, breathing rate and body temperature; and fatigue. If you are not accustomed to continuous, paced walking you may experience some muscle soreness during the 24 to 72 hours following exercise. In addition, if you do exercise regularly you may experience abnormal blood pressure, faintness, dizziness, muscle cramps, nausea, and abnormalities in heart beat. These events are not anticipated because: (a) the exercise will be submaximal, (b) individuals will be excluded from participating in this investigation when abnormalities in ECG recordings are observed, and (c) individuals will be excluded from participation in this investigation when contraindications are noted in the medical history.

3. Benefits

This study will benefit the subject by providing her/him with an evaluation of her/his present body composition and a determination of the number of calories used during 30 minutes of exercise. This information is particularly valuable to individuals concerned about weight control. In addition, the results will provide valuable information about individual variation from widely used energy expenditure prediction equations.

4. Inquiries, Withdrawal of Consent, and Confidentiality

The investigators and assistants will answer any questions pertaining to the test procedures. Please feel free to ask for explanations if you have any doubts or questions.

You may withdraw your consent and discontinue participation in the project at any time (including during the exercise testing) without prejudice. You are free to decline to answer any specific item or question on the medical history questionnaire.

The data generated from this project may be used for medical and/or scientific purposes, including publication and presentation at professional meetings. Your identity will not be revealed unless your express consent is granted prior to the publication or presentation of the data.

In case of an emergency notify Greg Hicks at 408-253-3541 or 415-723-6095 or call the lab at 408-277-9567. If you have complaints address them to the investigators or Dr. Serena Stanford, Associate Academic Vice President of Graduate Studies, 408-277-2943.

5. Consent

Having read the above, I agree:

- (a) that the procedures were verbally explained to me by an investigator,
- (b) to participate in the study, knowing that there are some discomforts and minimal risk,
- (c) that I understand that I may withdraw at any time, and
- (d) that I understand that the data are confidential but may be published or presented without revealing my identity except with my express consent.

SIGNATURE _____ DATE _____

PRINT NAME _____

SIGNATURE OF INVESTIGATOR _____ DATE _____
(witness)

MEDICAL HISTORY QUESTIONNAIRE

Exercise Energy Expenditure Study
 Department of Human Performance
 San Jose State University, San Jose, CA 95192

Completion of this medical history form is essential for physiological assessment to be completed at San Jose State University. All information will be kept confidential. This information will be used in evaluating your health and physical fitness. You will want to make this record as accurate and complete as possible, yet free of meaningless detail. Please fill out this form carefully and thoroughly. Then check it over to be sure you have left nothing out and sign the third page.

Name _____ Age _____ Sex _____ Date _____

Height _____ Weight _____ Phone Number home: () _____ Work: () _____

Personal Physician (Local):

Address:

Phone Number: () - _____

Person to Contact in Case of an Emergency:

Address:

Relationship to you:

Phone Number: home: () - _____ work: () - _____

MEDICAL (Check if yes)

Past History: In the past have you ever had:

☐ Heart Attack/Stroke	☐ Allergic reactions
When?	Explain:
☐ Rheumatic Fever	☐ Tuberculosis
☐ Heart Murmur	☐ Bronchitis
Heart Trouble:	☐ Asthma
☐ Heart surgery	☐ Arthritis of legs or arms
☐ Rhythm abnormalities	☐ Abnormal chest X-ray
☐ High Blood Pressure	☐ Dizziness or fainting spells
☐ Disease of Arteries	☐ Scarlet fever
☐ Varicose Veins	☐ Anemia
☐ Lung Disease	☐ Thyroid problems
☐ Injuries to back,	☐ Urinary tract infections, kidney
knees or ankles	stones, prostate problems
☐ Epilepsy or convulsions	☐ Elevated cholesterol
☐ Diabetes or abnormal	☐ Hernias
blood sugar test	☐ None of the above

Family History: Have any blood relatives had (include parents, sisters, brothers, aunts, uncles, and grandparents):

☐ Heart attacks under age 50	☐ Diabetes
☐ Strokes under age 50	☐ Congenital heart disease
☐ Heart operations	☐ Asthma or hay fever
☐ High blood pressure	☐ Obesity
☐ High cholesterol	☐ None of the above

Present Symptoms: Have you recently (in the past 6 months) had:

☐ Chest pain or pressure	☐ Arthritis
☐ Shortness of breath	☐ Swollen legs
☐ Heart palpitations	☐ Awakened short of breath
☐ Light headedness	☐ Loss of consciousness
☐ Cough on exertion	☐ Joint soreness
☐ Coughing up blood	☐ Chronic muscle soreness
☐ Back pain	☐ None of the above

Do you presently have:

☐ any open sores	☐ any infectious condition that prevents
☐ a urinary infection	your entry into a public swimming pool
☐ a vaginal infection	☐ none of the above

List any prescribed medication you are now taking.

List any self-prescribed medication or diet supplements you now take.

Date of last complete physical exam: month year ☐ can't remember
 results were: ☐ normal ☐ abnormal

Date of last chest X-ray: month year ☐ can't remember
 results were: ☐ normal ☐ abnormal

Date of last electrocardiogram (ECG): month year ☐ can't remember
 results were: ☐ normal ☐ abnormal

Have you ever had any major chronic skeletal or muscular injuries?
☐ yes ☐ no If yes, explain:

List hospitalization including dates and reasons for hospitalization:

List any allergies (including drug allergies):

EXPLAIN ANY OTHER SIGNIFICANT MEDICAL PROBLEM THAT YOU CONSIDER IMPORTANT
 FOR US TO KNOW. Use back of page if necessary.

SMOKING

Have you ever smoked cigarettes, cigars or a pipe? () yes () no

If no, skip to next section.

Do you presently smoke? () yes () no

If no, when did you quit? month year () can't remember

If you did or do smoke:

cigarettes, how many per day?

age started:

cigars, how many per day?

age started:

pipes, how many pipefuls per day?

age started:

DIET

Weight (lbs): now one year ago at age 21

Have you gained() or lost() weight in the last 2 months? ()yes ()no
how much (lbs)?

What is the most you have ever weighed?

EXERCISE

Are you currently involved in a regular exercise program? ()yes ()no

If yes:

what kind of activity?

how often (number of days per week)?

Do you regularly walk or run one or more miles continuously? ()yes ()no

If yes, average number of miles you cover per workout or day:

What is your average time per mile? minutes () don't know

Do you frequently participate in competitive sports? () yes ()no

If yes, which one or ones?

GENERAL HEALTH

How would you describe your general health?

() poor () fair () average () good () excellent

Have you ever been advised by a physician not to exercise because of a medical problem? () yes () no If yes, explain:

I certify that, to the best of my knowledge, the foregoing answers are accurate and true.

Signature

Date

APPENDIX B

SUBJECT RAW DATA AND ASSOCIATED MEANS,
STANDARD DEVIATIONS, BODY WEIGHT AND
PREDICTED ENERGY EXPENDITURE VALUES
AT 3 MPH AND 4 MPH

Table B-1

Subject Raw Caloric (Kcal) Data and Associated Means and Standard Deviations at 3 mph

Subject	Minute										Mean	<u>SD</u>
	1	2	3	4	5	6	7	8	9	10		
1	4.41	4.63	4.67	4.45	4.83	5.29	5.13	4.87	4.79	5.08	4.82	0.27
2	4.48	5.43	4.85	5.16	4.76	5.17	5.16	4.85	6.32	5.47	5.07	0.50
3	3.28	2.29	2.81	3.11	2.85	2.94	3.37	3.52	2.77	2.99	2.99	0.34
4	3.45	4.22	4.55	3.72	3.86	3.35	3.90	4.28	4.45	4.59	4.03	0.41
5	3.96	4.79	4.59	6.10	4.23	4.44	4.83	5.00	4.33	4.29	4.65	0.57
6	5.83	6.10	5.37	4.85	5.88	4.48	5.75	6.37	4.42	5.81	5.69	0.59
7	4.80	5.18	4.60	5.10	4.96	5.16	4.56	5.14	5.30	4.72	4.95	0.25
8	6.09	6.18	5.98	5.51	6.90	5.39	6.35	6.63	5.81	5.69	6.05	0.46
9	4.55	4.67	4.41	4.63	4.95	4.55	5.10	4.87	4.97	4.86	4.76	0.21
10	4.97	5.67	4.31	4.06	5.69	4.42	4.46	5.13	5.32	5.01	4.90	0.54

Table B-1 - Continued

Subject Raw Caloric (Kcal) Data and Associated Means and Standard Deviations at 3 mph

Subject	Minute										Mean	SD
	1	2	3	4	5	6	7	8	9	10		
11	3.83	4.29	4.28	3.94	4.31	4.29	4.33	4.26	4.19	4.32	4.20	0.17
12	7.58	6.37	7.71	7.14	7.79	8.10	8.00	6.92	7.32	7.79	7.47	0.51
13	4.53	4.25	4.74	4.68	4.74	4.67	4.66	4.80	4.59	4.90	4.66	0.17
14	3.63	4.42	4.65	3.67	4.33	4.16	3.71	4.29	4.28	3.72	4.09	0.35
15	3.60	4.49	4.35	3.82	4.42	4.42	4.10	4.17	4.63	4.51	4.25	0.31
16	4.69	4.86	5.10	4.65	5.20	4.45	5.10	4.77	4.75	4.92	4.85	0.22
17	4.17	4.60	4.45	4.56	4.45	4.12	4.57	4.54	4.17	4.57	4.42	0.18
18	5.12	4.84	5.47	5.00	5.58	4.95	5.44	5.35	5.27	5.07	5.21	0.24
19	4.16	3.94	4.08	4.41	3.84	4.29	4.06	4.28	4.14	4.27	4.15	0.17
20	3.42	3.33	3.31	3.83	3.60	3.90	3.16	3.52	3.44	3.81	3.53	0.24

Table B-1 - Continued

Subject Raw Caloric (Kcal) Data and Associated Means and Standard Deviations at 3 mph

Subject	Minute										Mean	<u>SD</u>
	1	2	3	4	5	6	7	8	9	10		
21	4.95	4.55	4.73	4.37	5.36	4.57	4.83	4.91	4.88	4.14	4.73	0.32
22	4.21	4.22	4.22	4.18	4.47	4.05	4.43	4.44	4.18	3.99	4.24	0.15
23	3.71	3.56	3.22	3.71	3.46	3.56	3.51	3.50	3.54	3.54	3.53	0.13
24	4.78	4.71	4.68	5.16	4.88	4.42	5.00	4.75	4.80	4.76	4.79	0.19
25	6.02	5.50	4.46	5.29	5.83	5.29	4.92	4.54	5.13	4.55	5.15	0.51
26	4.78	4.63	4.49	4.52	5.15	4.52	4.63	4.74	4.74	4.24	4.65	0.23
27	4.09	4.17	3.99	4.35	4.16	3.98	4.12	4.16	4.19	4.02	4.12	0.11
28	4.42	3.63	4.00	3.79	4.11	3.67	3.72	4.46	4.05	4.08	3.99	0.28

Table B-2

Subject Raw Caloric (Kcal) Data and Associated Means and Standard Deviations at 4 mph

Subject	Minute										Mean	SD
	1	2	3	4	5	6	7	8	9	10		
1	6.82	6.44	6.76	6.61	6.59	6.43	6.66	6.77	6.67	6.58	6.63	0.12
2	8.55	7.58	7.44	7.99	7.96	7.87	7.14	7.82	7.17	8.06	7.76	0.41
3	4.96	4.43	4.72	4.91	4.45	4.39	5.40	4.13	4.59	3.71	4.57	0.45
4	5.42	6.40	6.53	6.14	6.42	6.48	6.12	6.05	6.46	6.10	6.21	0.32
5	7.06	7.70	7.00	6.30	7.60	6.95	6.88	7.22	7.29	6.65	7.06	0.39
6	8.19	8.10	9.21	9.09	11.52	8.09	8.57	6.53	8.54	11.72	8.95	1.50
7	7.58	8.10	7.98	7.95	7.38	8.35	7.96	7.20	8.01	7.81	7.82	0.33
8	9.18	10.34	11.19	10.35	9.30	10.64	11.54	10.91	10.64	10.79	10.49	0.71
9	6.48	6.38	6.10	6.73	6.45	6.32	6.04	6.40	5.46	6.05	6.25	0.31
10	6.53	6.94	6.42	6.72	7.14	6.32	6.95	6.31	6.42	6.79	6.65	0.28

Table B-2 - Continued

Subject Raw Caloric (Kcal) Data and Associated Means and Standard Deviations at 4 mph

Subject	Minute										Mean	SD
	1	2	3	4	5	6	7	8	9	10		
11	5.87	5.52	4.53	5.65	5.35	5.83	5.35	5.69	5.29	5.84	5.49	0.38
12	13.06	13.39	12.43	13.06	13.15	12.54	12.62	12.90	12.42	13.20	12.88	0.33
13	6.84	6.52	6.61	6.77	8.90	7.28	6.87	7.04	6.85	6.96	7.06	0.65
14	6.21	6.68	7.03	5.64	6.16	5.63	5.90	6.35	5.83	5.26	6.07	0.50
15	5.64	5.09	5.59	5.53	5.25	5.57	5.67	5.54	5.15	5.88	5.49	0.24
16	7.58	7.24	6.96	6.66	7.76	6.92	5.68	7.72	6.61	7.22	7.04	0.59
17	6.79	6.79	7.03	6.92	7.15	6.61	6.87	7.21	6.73	6.70	6.88	0.19
18	7.64	7.38	7.97	7.56	7.93	7.54	7.34	7.62	7.21	7.24	7.54	0.25
19	6.52	5.66	5.93	6.01	6.16	5.87	6.16	6.27	6.30	6.53	6.14	0.27
20	5.40	5.24	5.93	5.45	5.66	6.70	5.54	5.64	6.58	5.31	5.75	0.48

Table B-2 - Continued

Subject Raw Caloric (Kcal) Data and Associated Means and Standard Deviations at 4 mph

Subject	Minute										Mean	<u>SD</u>
	1	2	3	4	5	6	7	8	9	10		
21	6.84	7.69	8.76	7.29	6.78	7.18	6.14	6.50	6.97	6.22	7.01	0.73
22	5.23	5.44	5.89	5.40	5.91	5.33	5.70	5.79	5.30	5.72	5.57	0.24
23	5.32	4.45	4.91	4.89	4.86	4.81	5.23	4.94	5.08	4.83	4.93	0.23
24	6.61	6.92	6.39	6.48	6.18	7.30	7.00	6.55	6.68	7.01	6.71	0.32
25	6.90	7.27	6.87	6.66	7.72	6.88	7.31	6.58	6.68	6.03	6.89	0.44
26	5.41	6.13	5.87	6.09	5.77	6.69	5.75	5.92	5.81	6.68	6.01	0.38
27	6.05	5.38	6.52	5.44	6.12	6.11	6.25	5.87	5.73	6.14	5.96	0.34
28	5.54	5.78	5.90	5.63	5.19	6.16	5.14	5.82	5.59	5.47	5.62	0.29

Table B-3

Body Weight (kg) and Predicted Energy Expenditure (Kcal/min) for Subjects at 3 mph

Subject	Body Weight (kg)	Equations		
		Passmore & Durnin	Fellingham et al.	Bobbert
1	71.10	4.337	2.286	4.458
2	71.00	4.333	2.283	4.451
3	50.02	3.352	1.669	3.147
4	73.50	4.451	2.357	4.608
5	67.90	4.187	2.192	4.257
6	91.50	5.299	2.889	5.737
7	70.90	4.328	2.280	4.445
8	88.50	5.158	2.800	5.549
9	70.90	4.328	2.280	4.445
10	76.10	4.573	2.434	4.771
11	74.70	4.507	2.393	4.683
12	141.30	7.647	4.360	8.859

Table B-3 Continued

Body Weight (kg) and Predicted Energy Expenditure (Kcal/min) for Subjects at 3 mph

Subject	Body Weight (kg)	Equations		
		Passmore & Durnin	Fellingham et al.	Bobbert
13	74.70	4.507	2.393	4.683
14	68.50	4.215	2.209	4.295
15	61.57	3.888	2.005	3.860
16	67.20	4.154	2.171	4.213
17	79.80	4.748	2.543	5.003
18	96.00	5.511	3.022	6.019
19	85.50	5.016	2.712	5.360
20	95.10	5.469	2.995	5.962
21	100.50	5.723	3.155	6.301
22	76.40	4.587	2.443	4.790
23	64.50	4.026	2.091	4.044
24	82.30	4.865	2.617	5.160

Table B-3 Continued

Body Weight (kg) and Predicted Energy Expenditure (Kcal/min) for Subjects at 3 mph

Subject	Body Weight (kg)	Equations		
		Passmore & Durnin	Fellingham et al.	Bobbert
25	71.90	4.375	2.310	4.508
26	84.50	4.969	2.682	5.298
27	74.00	4.474	2.372	4.639
28	70.80	4.323	2.277	4.439

Table B-4

Body Weight (kg) and Predicted Energy Expenditure (Kcal/min) for Subjects at 4 mph

Subject	Body Weight (kg)	Equations		
		Passmore & Durnin	Fellingham et al.	Bobbert
1	71.10	5.718	4.239	5.924
2	71.00	5.711	4.234	5.915
3	50.02	4.388	3.066	4.183
4	73.50	5.871	4.374	6.124
5	67.90	5.514	4.060	5.657
6	91.50	7.016	5.385	7.623
7	70.90	5.705	4.228	5.907
8	88.50	6.825	5.216	7.374
9	70.90	5.705	4.228	5.907
10	76.10	6.036	4.520	6.340
11	74.70	5.947	4.442	6.224
12	141.30	10.19	8.181	11.77

Table B-4 Continued

Body Weight (kg) and Predicted Energy Expenditure (Kcal/min) for Subjects at 4 mph

Equations				
Subject	Body Weight (kg)	Passmore & Durnin	Fellingham et al.	Bobbert
13	74.70	5.947	4.442	6.224
14	68.50	5.552	4.093	5.707
15	61.57	5.111	3.704	5.130
16	67.20	5.470	4.020	5.599
17	79.80	6.271	4.728	6.649
18	96.00	7.302	5.637	7.998
19	85.50	6.634	5.048	7.124
20	95.10	7.245	5.587	7.923
21	100.50	7.589	5.890	8.373
22	76.40	6.055	4.537	6.365
23	64.50	5.298	3.869	5.374
24	82.30	6.431	4.868	6.857

Table B-4 Continued

Body Weight (kg) and Predicted Energy Expenditure (Kcal/min) for Subjects at 4 mph

Subject	Body Weight (kg)	Equations		
		Passmore & Durnin	Fellingham et al.	Bobbert
25	71.90	5.769	4.284	5.990
26	84.50	6.571	4.992	7.040
27	74.00	5.902	4.402	6.165
28	70.80	5.699	4.223	5.899

APPENDIX C
RESEARCH ARTICLE FOR PUBLICATION

A Test of the Predictive Accuracy of Three Caloric
Expenditure Formulas for Level Walking at Two Speeds

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Running Head: ACCURACY TEST FOR 3 CALORIC EXPENDITURE
FORMULAS

Abstract

This study compared observed caloric expenditure with values predicted by three widely used equations for single bouts of continuous level walking at three and four miles per hour. Twenty-eight male subjects (mean age = 24.4 yrs) walked for 21 minutes at each walking speed. To test the hypotheses of this study, predicted-observed difference scores were computed for each subject for each speed by equation condition. Analyses of these data revealed a significant main effect for both equations and speeds and a significant equations by speed interaction. Further, the results indicated that the Passmore and Durnin equation predicted caloric expenditure most accurately at 3 miles per hour, while the Bobbert equation was the most accurate at 4 miles per hour. Finally, the Fellingham et al. equation substantially underpredicted caloric expenditure and was not recommended for use.

Key words: predictive accuracy, observed caloric expenditure, predicted caloric expenditure

For a number of years, the calculation of target heart rate has been the basis for developing individualized aerobic exercise prescriptions. However, the use of target heart rate for this purpose has been criticized by some who cite difficulty in attempting to quantify the amount of activity performed when target heart rate is used. This concern has created a need to develop more accurate, safe, and reliable methods of creating exercise prescriptions. Some have proposed alternative procedures for quantifying the amount of exercise performed, however, none of these have provided exacting methods (ACSM, 1983; Berg, 1978; Cooper, 1982; Leon, Conrad, Hunninghake & Serfass, 1979; Milesis, et al, 1973; Walsh, 1983; Zuti & Golding, 1976). Several others have proposed alternative procedures to predict caloric expenditure for specific aerobic activities. In this regard, for walking, Bobbert (1960); Fellingham, Roundy, Fisher and Bryce (1978); and Passmore and Durnin (1955) have derived formulas which predict caloric expenditure. While these formulas are commonly cited and used for the several years that they have been available, none of them has been validated against objective evidence. Thus, the purpose of this study was to compare values predicted from each of these formula with observed caloric

expenditure, and by so doing evaluate their relative predictive accuracy.

Methods

Subjects

Twenty-eight male college student volunteers (mean age = 24.4 ± 2.8 yrs) who met certain conditions were the subjects for this study. To be included in the study, each student had to be healthy, free of any known coronary heart disease, have a resting blood pressure below 140/90 and not exceed the ideal values on the Metropolitan Life Insurance Company's Height/weight chart by $\pm 20\%$.

Apparatus and Procedures

Subjects were tested individually. After fully informing them of the nature of the test procedures, each subject completed a medical history and read and signed an informed consent form, which had been approved by the San Jose State University Institutional Review Board -- Human Subjects. Next, body weight, height and blood pressure were measured. If an individual met the criteria mentioned above, they were then prepared for the measurement of heart rate (HR) using a standard CM5 exercise electrocardiograph (EKG) lead configuration. After sitting quietly for approximately three minutes, preexercise blood pressure and

HR measurements were assessed and final specific instructions concerning the test protocol, signs of exertional intolerance, and procedures were given. Then, the subject was positioned on the Quinton Programmable Treadmill (model #18-10), the mouthpiece and nose clip were put in place, and given a 3-min period of practice walking at a speed of 2.5 mph. During the practice walking period, each subject was instructed to walk at a stride frequency and length that felt natural and comfortable as described by Bobbert (1960), Erickson, Simonson, Tylor, Alexander and Keys (1946), Hogberg (1952), and van der Walt and Wyndham (1973).

After completing the pretesting phase of this experiment and calibrating the equipment, the testing session, which lasted approximated 55 minutes, was started. The test session was divided into five phases and these are summarized in Table 1. During the test period, heart rate

Insert Table 1 about here

was continuously monitored and was recorded during the last 10 seconds of each walking period using a Quinton 623A Electrocardiograph Monitoring System with an oscilloscope.

HR was used as the indicator of steady state (change was ± 5 beats per minute for six consecutive minutes). Respiratory gases were collected using standard open circuit calorimetry. Subjects inhaled room air through an Otis-McKerrow two-way valve attached to a Parkinson-Cowan CD-4 gas meter fitted with a rotary potentiometer. The output from this meter (inspired gas volume) was continuously recorded on a Gilson 5/6H Biomedical Multichannel Strip recorder. Gas samples were analyzed for oxygen and carbon dioxide concentrations with an Applied Electrochemistry S-3A Oxygen Analyzer and a Beckman LB-2 Carbon Dioxide Medical Gas Analyzer, respectively.

Observed caloric expenditure was calculated for each subject, for each minute of walking, for each speed by multiplying the oxygen consumption (VO_2) values (L/min) with the caloric values obtained from a standard nonprotein respiratory quotient (RER) table (Fox & Mathews, 1981). The first ten minutes and the last 1 minute of each set of data were excluded as they usually did not reflect steady state. Thus, observed caloric expenditures for each subject were defined as the means derived from a 10 minute block of data at each walking speed. Predicted caloric energy expenditure was computed using each of the three equations that are the subject of this research. Six difference

scores were computed for each subject by subtracting the observed mean caloric energy expenditure value at each speed from the predicted energy expenditure value predicted for that speed by each equation.

Computation of Equations

The Bobbert (1960) formula is:

$$\begin{aligned} \text{Log } E_w = & 1.4272 + (0.004591 \times v) + (0.024487 \times a) \\ & + (0.9992658 \times v \times a) \end{aligned}$$

where v = speed, measured in meters per min.

a = gradient, measured in degrees

E_w = energy expenditure expressed in calories
per kilogram of body weight per minute
(cal/kg/min)

The Fellingham et al. (1978) formula with it's constants is expressed as follows:

$$Y = 3.7104 + .2678 \times W + .0359 \times \text{SSW}$$

where SSW = the square of the speed in miles per
hour times the body weight in kilograms

W = the subject's body weight in kilograms

Y = the total caloric cost, expressed as
kcal per mile

Although Passmore and Durnin (1955) presented the two equations which appear below:

$$C = 0.8V + 0.5$$

$$C = 0.0047W + 1.02$$

where V = speed, in kilometers per hour

W = the subject's body weight in kilograms

They did not indicate how these were used in combination to form the table which they derived for the computation of energy expenditure.

The table that Passmore and Durnin (1955) derived from these equations has wide gaps in weights that they included in their table. This necessitated the development of two additional equations which permitted the application of the Passmore-Durnin values to the continuous weight data that were collected in this study (or any other study of this type). These equations were derived by using a computer-assisted linear regression model. These equations are as follows:

$$3 \text{ mph: } C \text{ (Kcal/min)} = 0.021428 \times W \text{ (kg)} + 0.985714$$

$$4 \text{ mph: } C \text{ (Kcal/min)} = 0.028928 \times W \text{ (kg)} + 1.192857$$

This study examined the relationship between predicted and actual energy expenditure in level walking for each

formula. Thus, by using level walking only, any difference in the use of gradients between these formula was held constant. Finally, it should be noted that since this study employed the speed constants of 3 and 4 miles per hour, it was necessary to convert these values into their corresponding metric distance per unit of time for the computation of the predicted values using the Bobbert (1960) formula.

Results

The difference scores computed between the predicted caloric expenditure from each equation and the observed caloric expenditure at each walking speed are summarized in Table 2. A negative mean indicates that the predicted value

Insert Table 2 about here

under-estimated the observed value and conversely a positive value indicated an over-estimation. The closer the value is to zero, the greater accuracy of the prediction for a given equation.

These data were first analyzed by computing a two (speeds) by three (equations) factor analysis of variance with repeated measures. The results of this analysis are

summarized in Table 3. As can be seen by inspecting Table 3,

Insert Table 3 about here

the main effects for both speeds ($F, 27=10.36, p<.004$) and equations ($F, 54=605.66, p<.001$) were significant as was the speeds by equations interaction ($F, 54=472.40, p<.001$). The significant main effect computed for speeds resulted from the fact that predicted values were more accurate for the 3 mph speed than was the case at the 4 mph speed. The substantial main effect computed for equations was the result of the large discrepancies in the accuracy with which these equations predicted actual caloric expenditure at both walking speeds.

To better understand the significant speeds by equations interaction, a series of post hoc tests were carried out, using the Bonferroni procedure to test the differences between the means for each equation for both speeds. Table 4 lists the results of these post hoc tests.

Insert Table 4 about here

Collectively, the tests indicated that all of the means listed in Table 2 are significantly different from each

other ($p < .01$). Thus, it is clear that the significant speeds by equations interaction ($p < .001$) computed from these data resulted from the fact that the Passmore and Durnin (1955) equation as it was utilized in this study, predicted caloric expenditure with significantly greater accuracy ($p < .001$) than either the Bobbert (1960) or Fellingham et al. (1978) equations at the 3 mph speed while the accuracy of the Bobbert equation was significantly better ($p < .001$) than the other two equations at 4 mph.

The F value reported for equations in Table 3 together with the results of these post hoc tests indicates that there is a reliable difference between the predictive accuracy of the Bobbert (1960), Fellingham et al. (1978) and Passmore and Durnin (1955) equations. Thus, clearly these equations do not provide interchangeable estimates of caloric expenditure and in fact they vary widely in the accuracy with which they estimate these values.

To further clarify the relative predictive accuracy of these equations a second set of post hoc analyses were computed. Specifically, for each equations by speeds condition the differences between observed and predicted caloric expenditure were tested using the direct differences method for computing the t statistic.

The differences between observed and predicted caloric expenditure for 3 and 4 mph walking conditions were not significant for the Bobbert (1960) equation (i.e., $t=2.007$ $p<.05$ and $t=1.336$, $p<.05$ respectively). The results of these analyses for the Passmore and Durnin (1955) equation were mixed in that the difference between observed and predicted caloric expenditure was not significant for the 3 mph condition ($t=.4210$, $p<.05$) but was significant for the 4 mph walking condition ($t=2.932$, $p<.05$). Finally, highly significant t ratios were computed for the Fellingham et al. (1978) equation data for both the 3 and 4 mph walking conditions, (i.e., $t=18.080$, $p<.001$ and $t=9.680$, $p<.001$), respectively. Thus, overall these data suggest that the Bobbert equation is the most likely to predict caloric expenditure without significant error when both 3 and 4 mph conditions are used.

Discussion

Although these equations predict caloric expenditure with varying degrees of accuracy at different speeds, it should be noted that in a practical application, at 3 mph, either the Bobbert (1960) or the Passmore and Durnin (1955) equations could provide a fairly reasonable estimate of caloric energy expenditure (mean difference in observed and

predicted values ranged from .6 to .05 kcal/min), given the constraints suggested by the results of this study.

Ideally, if either were to be recommended, the user should be cautioned as to which equation is most accurate and that both tend to over predict. At 4 mph only the Bobbert equation can be recommended for use. As was noted earlier the Fellingham et al. (1978) equation as utilized in this study, does not appear to be a suitable alternative at either speed.

It is interesting to note that as the walking speed increased, the predictive accuracy of the Passmore and Durnin (1955) equation declined, while opposite appeared to be true for the Bobbert (1960) equation. If this is a trend, it raises several intriguing questions. First, would the magnitude of the predictive error increase in the Passmore and Durnin equation as the speed increased further? Second, would the magnitude of the error observed in the Bobbert equation decline further with increased walking speed; and third, do either of these equations possess some inherent optimal speed for function? These questions should be the subject of future research. Finally, the Passmore and Durnin equation has been in use since 1955, Bobbert's since 1960 and the Fellingham et al. equation since 1978.

The original works in which each of these equations appeared have been routinely cited by others since their introductions into the literature, yet no attempt at evaluating the predictive accuracy of these equations has been published. Thus, it appears that a thorough reevaluation of the literature that has used these equations is in order.

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Table 1

The Treadmill Testing and Data Collection Sequence

Event	Time (min)	Speed (mph)	Data Collected
Pre-exercise	-3 to 0	0	HR ^a , BP ^b
Practice Walking & Warmup	0 to 3	2.5	None
Stage 1	4 to 25 5,10,15,20 & 25	3.0 3.0	HR ^a , VO ₂ ^c BP ^b
Stage 2	26 to 47 27,32,37,42 & 47	4.0 4.0	HR ^a , VO ₂ ^c BP ^b
Post Exercise	48 to 55 48,50,52 & 54	0 0	HR ^a BP ^b

^aHR = heart rate^bBP = blood pressure^cVO₂ = volume of oxygen consumed per minute

Table 2

The Means and Standard Deviations for the Difference Scores
Between Predicted and Observed Caloric Expenditure (Cal/Min)
for Each Equation for Each Speed

Walking Speeds	Difference Scores for Equations					
	Bobbert		Fellingham et al.		Passmore & Durnin	
	Mean	<u>SD</u>	Mean	<u>SD</u>	Mean	<u>SD</u>
3 mph	0.287	± 0.745	-2.133	± 0.612	0.051	± 0.630
4 mph	-0.290	± 1.129	-2.178	± 1.170	-0.643	± 1.141

Table 3

Results of the Two (Speeds) by Three (Equations) ANOVA

SOURCE	<u>df</u>	Sum Squares	Mean Squares	<u>F</u>	<u>p</u>
<u>Between Subjects</u>	27	114.24			
<u>Within Subjects</u>	140	192.24			
A(Speeds)	1	8.08	8.08	10.36	<.004
A x SwGrps	27	21.05	.78		
B (equations)	2	157.76	76.38	605.66	<.001
B x SwGrps	54	6.81	.13		
AB	2	3.35	1.67	472.40	<.001
AB x SwGrps	54	.19	.0035		

Table 4

Bonferroni Post-hoc Test Summary of Compared Means for the
Three predictive Energy Expenditure Equations at Three and
Four Miles Per Hour

Speed	Comparison	p
3 mph	Passmore and Durnin with Fellingham et al.	.001
	Passmore and Durnin with Bobbert	.007
	Fellingham et al. with Bobbert	.001
4 mph	Passmore and Durnin with Fellingham et al.	.001
	Passmore and Durnin with Bobbert	.001
	Fellingham et al. with Bobbert	.001