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Civil Aeromedical Research Institute
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OKLAHOMA CITY, OKLAHOMA

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ABSTRACT

The relative contributions of rate of progression (1.5 to 4.0 mph), grade (4 to 9%), and load (10 to 30 Kg), to the total energy cost of treadmill work were determined. The data obtained were integrated graphically with some of the available energy cost data in the literature. A useful graph is provided for estimating energy expenditure. It was tentatively concluded that for grade walking over the ranges studied, the energy cost per unit weight is essentially the same whether the weight is of the body or the load. The data are useful in that a correlation between the diverse literature reports on treadmill studies using different speeds and loads is made feasible.

INTRODUCTION

In a current attempt to formulate an expression relating the energy cost of progression with such parameters as load, speed and grade, information on the interaction of load and speed with grade was not available. Experimental work was carried out to supply this data and the results have been incorporated with other data (1, 3) for the energy cost of walking at various speeds and grades with no load and carrying loads on the level.

METHODS

Ten men in good physical condition were selected from a group of volunteer subjects; their physical characteristics are presented in Table I. The subjects walked on two large (4 man) treadmills which were set at a given grade (3%, 6%, or 9%) and speed (1.5, 2.5, 3.5 or 4 mph). Three standard loads were selected and made up on packboards so that the total weight of load and packing was 10, 20 or 30 Kilograms. All measurements were completed by 1045 hours.

Duplicate Tissot collections of expired air were taken on each subject during the last fifteen minutes of a 45-minute walk and oxygen concentration was measured with a Beckman paramagnetic O_2 analyzer. Energy cost was calculated according to the method suggested by Weir (2).

Load, speed and grade were statistically randomized to minimize training effects. The design for the study called for 22 conditions (i.e. 3% slope, 10 Kg load, 2.5 mph; 3% slope, 20 Kg load, 2.5 mph; etc., Table II) with five subjects studied in each condition. Subjects were ranked with respect to percent body fat so that the five subjects studied for a given condition represented a cross-section within the relatively narrow range of body fat presented by the group, thus reducing the effect of individual variation.

RESULTS AND DISCUSSION

The results (Table II) show that energy cost per unit weight (subject weight plus loads of from 10 to 30 Kg) is a constant for a given grade and speed. Using data from Bobbert (3), to suppply values for the energy cost of walking on the level, it was possible to calculate the slopes of the curves for energy cost versus grade at each of the progression rates studied. These slopes were then plotted against progression rate (Fig. 1). Thus, the slope for any rate of progression may be taken from Figure 1. A family of lines can then be drawn which allows rapid estimation of energy expenditure for any grade between 0 and 9% and any rate of progression between 1.5 and 4.0 miles per hour for subjects with loads up to 30 Kg (Fig. 2).

The pooled data from this study and open literature (1,3) were treated statistically and the following curve fitting formula evolved relating progression rate, load and grade over the ranges, 1.5 to 4.5 mph (S), 0 to 30 Kg load (L), 0 - 9% grade (G).

$$\text{Energy cost (70 Kg subject), Kcal/min} = 4.3 + [-1.1S - 0.22S^2] + [-6.3G + 8.2GS - 0.05GS^2 + 3.6G^2S^2] + [4.06LG - 1.77LGS + 0.003LS^2 + 0.24LGS^2 - 0.06LG^2S^2]$$

Calculations of predicted values for energy cost from this formula are in close agreement with observed values and with predicted values using the formula presented by Bobbert (3). However, Figure 2, with appropriate interpolation, should be more useful than application of either formula. The fact that the present results agree with earlier work (1) indicates that reasonable estimates can be made for energy expenditure under a wide variety of conditions.

Variations in such parameters as stature, stride, physical condition, and skill in adjustment of a load all influence the energy cost of progression. For this reason estimates of energy cost must be regarded as first approximations subject to correction for nature of the terrain, physical condition, stature of the subject, and other variables. However, it seems probable that for a given rate of progression and grade the energy cost per unit weight is essentially the same, regardless of the distribution of total weight between body weight and load within the range 0 to 30 Kg load for a reasonably fit individual.

Table I

Some Characteristics Of Test Subjects

Subject	*Age* *yrs*	*Height* *cm*	*Weight* *Kg*	*%Fat*
1	28	172	69.5	9.5
2	19	175	80.8	16.3
3	19	175	59.5	9.0
4	21	183	70.8	9.1
5	21	175	84.0	10.1
6	21	178	77.6	11.3
7	19	180	74.5	10.0
8	33	178	84.9	12.8
9	21	178	83.1	12.2
10	21	183	71.3	8.7
Mean	22	178	75.6	10.9

REFERENCES

1. Passmore, R. and J. V. G. A. Durnin. Physiol. Rev. 35:801, 1955.
2. Weir, J. B. DeV. J. Physiol. 109:1, 1949.
3. Bobbert, A. C. J. Appl. Physiol. 15:1015, 1960.

Table II

Energy Expenditure As a Function of Rate of Progression, Load Carried and Grade

Speed (mph)	1.5			2.5									3.5								4.0	
Grade (%)	9			3			6			9			3			6			9		3	
Load (kg)	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	30	10	20	10	20
Kcal/min/Kg subject wt[1] without load	.088	.091	.096	.071	.078	.088	.084	.093	.107	.106	.114	.121	.103	.116	.128	.136	.160	.166	165	.182	.142	.148
Kcal/min/Kg total wt[2]	.077	.073	.070	.063	.063	.064	.074	.075	.077	.093	.090	.087	.091	.094	.091	.120	.125	.119	.145	.143	.125	.123
Mean Kcal/min/Kg total wt		.073			.063			.076			.090			.092			.121		.144		.124	
Standard Error		±.007			±.007			±.004			±.004			±.006			±.008		±.014		±.017	

[1]The 5 subject mean value of: $\frac{\text{Individual calculated energy cost (Kcal/min)}}{\text{Individual subject dressed weight}}$

[2]The 5 subject mean value of: $\frac{\text{Individual calculated energy cost (Kcal/min)}}{\text{Individual subject dressed weight + load}}$

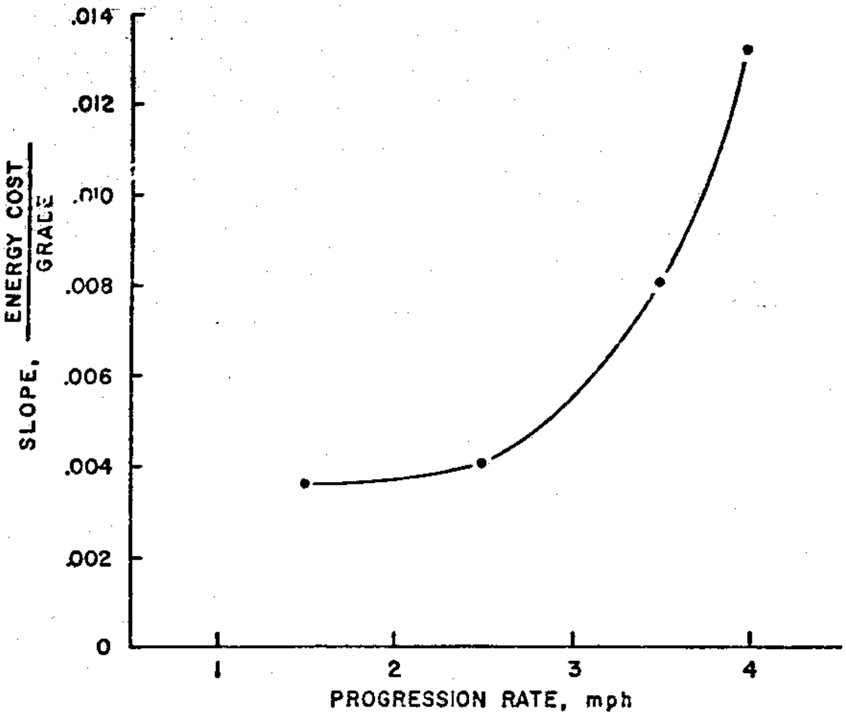

FIGURE 1 – Slope of the curve for energy cost versus grade plotted against progression rate.

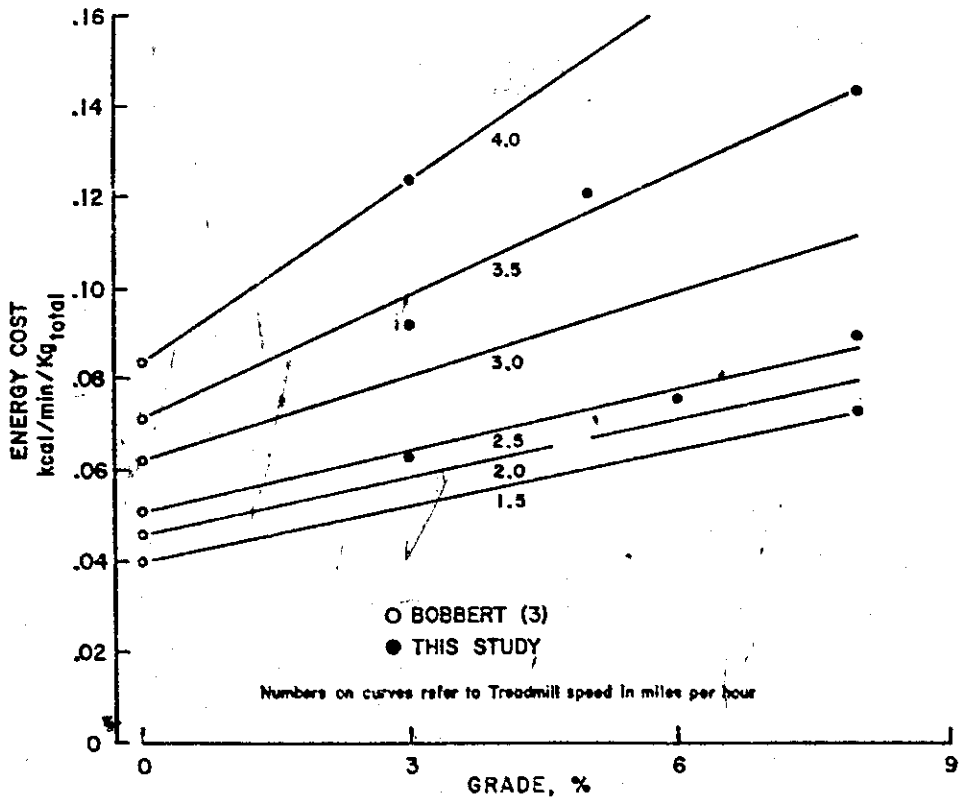

FIGURE 2 – Graph for estimating energy cost for rates of progression between 1.5 and 4.0 miles per hour, and grades up to 9% with loads up to 30 Kg.