Oxygen Cost of Work When the Body Weight Is Not Lifted Against Gravity

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ABSTRACT

An exercise program wherein the body was not lifted against gravity was administered to 24 male college students. Oxygen consumption rates were measured during rest, exercise, and recovery to resting levels. At no time did the oxygen consumption exceed that associated with "light" work, but for the nine minutes of exercise, over five minutes were required for the return to resting level. There was no relationship between oxygen consumption and total body weight or surface area.

ESTIMATES OF LIFE SUPPORT requirements for extended space missions are usually based upon energy expenditures of comparable activities in standard gravity. Because most of man's work is performed in an erect position and against gravity, few of these activities are truly comparable. It is possible to make estimates of the cost of physical work in weightlessness based on theoretical considerations and this has been attempted for locomotion.[12] However, such considerations are themselves based on the phenomenology of standard gravity.

It was the purpose of this study to investigate oxygen consumption during activities performed in a manner which does not require that the body weight be lifted against gravity. Of secondary consideration were the relationships of total body weight, surface area, and oxygen consumption for the same activities.

METHOD

Twenty-four male college students served as subjects. Their age, height, and weight were recorded and body surface area then estimated from the DuBois and DuBois nomogram.[6,7] Although body surface area is not as effective a reference standard for metabolic rate as total body weight,[8,13,14,17] it was included because of its common usage and because it might be more representative of body size than is weight in activities where the body is not lifted against gravity. Oxygen consumption, measured by having the subject breathe through a Rudolph high-velocity light-weight valve connected to a Beckman F-3 Oxygen Analyzer, was recorded during rest, exercise, and recovery to resting level. The Oxygen Analyzer was checked by a factory representative before and after the collection of the data and was calibrated at least once each day of testing. There were ten exercises in the program and each was performed twenty times. Exercises performed on the floor were on a segmented plastic-coated mat one-half inch thick and dance wax was placed between the mat and the tile floor. The mat was not fixed and the exercises could be performed with very little surface resistence. The exercise program is presented in the Figure. Resting O_2 levels were recorded after the subject had reached a steady state for two minutes.

In the statistical analyses, the five per cent level of probability was accepted as indicating statistical significance.

RESULTS

The results of the collection of the data are presented in Figure 1 and Tables I-III. The basal calorie consumption as predicted by the Harris-Benedict[9] method was 79.0 kcal/hr and by the method of Boothby, Berkson, and Dunn,[4] 82.6 kcal/hr. A comparison of these and the observed supine rate revealed significant

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differences ($F = 58.4$ with 2 and 69 df.) and Tukey's procedure for comparing individual means in an analysis of variance[18] indicated that this was because the observed rates were lower than predicted. There also was a significant difference in the O_2 consumption rates during resting supine and resting sitting ($t = 2.62$). The O_2 consumption rates for each of the exercises were compared by analysis of variance and significant differences were found ($F = 48.9$ with 9 and 230 df.). Tukey's procedure revealed that the rates for exercises 1, 2, and 3, as a group, were lower than that of exercise 4, which in turn was lower than the remaining exercises. There was no significant correlation for the mean exercise O_2 consumption rate and total body weight ($r = 0.31$) or body surface area ($r = 0.10$).

DISCUSSION

Generally speaking, O_2 consumption rates of less than 0.4 L/min are associated with *sedentary* activity and rates of 0.4 to 0.8 L/min with *light* work.[2] Despite the vigorousness of certain of the exercises, none could be considered as eliciting an O_2 consumption rate associated with even *moderate* work. For comparison, a treadmill walk of 1.73 mph on a ten per cent grade consumes oxygen at the rate of 0.85 L/min and one of 3.5 mph on an 8.6 per cent grade, 1.9 L/min.[5,15] Noteworthy, however, is the fact that for the nine minutes of exercise, more than five minutes and 1.74 liters of oxygen were required for recovery to the normal resting rate. This debt is superimposed on subsequent activities and should be an important consideration in any attempt to estimate life support requirements for extended space missions.

Bevegard, Holmgren, and Jonsson[3] and Holmgren, Jonsson, and Sjöstrand[10] noted that the O_2 consumption of their subjects in the supine position was higher than

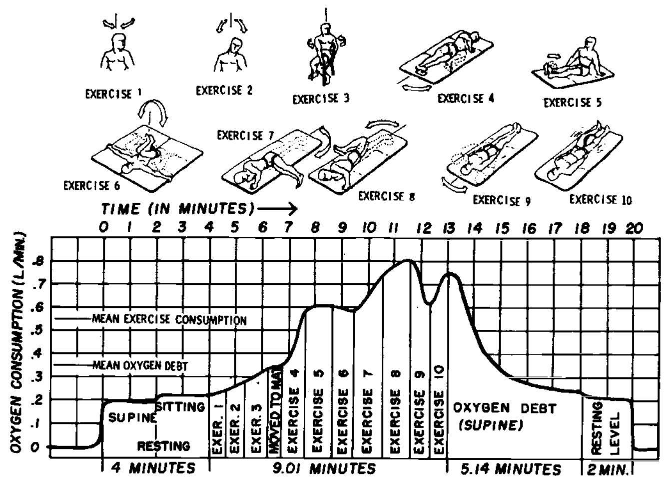

Fig. 1. Oxygen consumption during rest, exercise, and recovery to rest. (N=24)

predicted by the Harris-Benedict method. Apart from the fact that their data were obtained during heart catheterization, there is no ready explanation for the difference in results.

The nonsignificant correlations noted for O_2 consumption and weight or body surface area are in contradiction to those noted for work in the erect position, but were not entirely unexpected.[1,8,11,16] Wyndham and his co-workers[19] have posited that, "If the task is such that body weight is not lifted against gravity, then the oxygen consumption of the heavier man and the lighter man will be similar."

For the population represented by the sample and under the conditions of the study, the following conclusions appear justified:

1. Indirect calorimetry of work performed in the erect position does not reflect the O_2 consumption or O_2

TABLE I. OXYGEN CONSUMPTION BEFORE, DURING, AND AFTER EXERCISE (LITERS PER MINUTE)

	Resting Supine	Resting Sitting	Exercise	O_2 Debt	Exercise + Debt
Mean	0.198	0.224	0.546	0.338	0.446
S.D.	0.043	0.058	0.067	0.057	0.060
kcal/hr	57.29[a]	64.92[a]	158.01[b]	97.96[b]	135.06[b]
btu/hr	227.4	257.7	627.3	388.9	536.2

[a]. RQ = 0.82
[b]. RQ = 0.89

TABLE II. OXYGEN CONSUMPTION OF EXERCISES (LITERS PER MINUTE)

Exercise No.	1	2	3	< 4	< 5	6	7	8	9	10
Mean	0.235	0.272	0.318	0.506	0.605	0.596	0.670	0.783	0.716	0.682
S.D.	0.056	0.056	0.015	0.097	0.147	0.146	0.110	0.168	0.145	0.277
kcal/hr	69.1	80.0	93.5	148.8	177.9	175.2	197.0	230.2	210.5	200.5
btu/hr	274.3	317.6	371.2	590.7	706.3	695.5	782.1	913.9	835.7	796.0

< significantly lower ($P \leq .05$)

TABLE III. ANTHROPOMETRIC MEASURES

	Age (yrs)	Height (cm)	Weight (kg)	Surface Area (M^2)
Mean	20.6	180.36	77.71	1.98
S.D.	2.4	7.85	9.15	0.02

debt of that task were it performed in a manner where the body weight is not lifted against gravity, and

2. In work where the body weight is not lifted against gravity, there is no correlation for O_2 consumption and total body weight or surface area.

REFERENCES

1. ASTRAND, P. O. and RHYMING, I.: A nomogram for calculating the aerobic capacity from pulse-rate during submaximal work. *J. Appl. Physiol.*, 7:218, 1954.
2. BARTELS, H., BÜCHERL, E., HERTZ, C. W., RODEWALD, G., and SCHWAB, M.: *Methods in Pulmonary Physiology.* Hafner, 1963.
3. BEVEGÅRD, S., HOLMGREN, A., and JONSSON, B.: The effect of body position on the circulation at rest and during exercise, with special reference to the influence on the stroke volume. *Acta Physiol. Scand.*, 49:279, 1960.
4. BOOTHBY, BERKSON, and DUNN: *Amer. J. Physiol.*, 116:468, 1936. Cited in *Geigy Scientific Tables*, 1962.
5. CONSOLAZIO, C. F., JOHNSON, R. E., and MAREK, E.: *Metabolic Methods.* C. V. Mosby, 1951.
6. DIEM, K., editor: *Documenta Geigy Scientific Tables*, 6th ed. Geigy Pharmaceuticals, 1962.
7. DUBOIS and DUBOIS: *Arch. Int. Med.*, 7:863, 1916. Cited in *Geigy Scientific Tables*, 1962.
8. DURNIN, J. V. G. A.: The use of surface area and body-weight as standards of reference in studies of human energy expenditure. *Brit. J. Nutr.*, 13:68, 1959.
9. HARRIS and BENEDICT: Pub. No. 279, Carnegie Institution of Washington, 1919. Cited in *Geigy Scientific Tables*, 1962.
10. HOLMGREN, A., JONSSON, B., and SJÖSTRAND, T.: Circulatory data in normal subjects at rest and during exercise in recumbent position, with special reference to the stroke volume at different work intensities. *Acta Physiol. Scand.*, 49:343, 1960.
11. IAMPIETRO, P. F. and GOLDMAN, R. E.: Prediction of energy cost of treadmill work. Rpt. 62-5, C.A.R.I., F.A.A., 1962.
12. JOHNSON, R. E.: Caloric requirements under adverse environmental conditions. *Fed. Proc.*, 22:1439, 1963.
13. MITCHELL, H. H.: The significance of surface area determinations. *J. Nutr.*, 2:437, 1930.
14. OLIVER, W. J., GRAHAM, B. D., and WILSON, J. L.: Lack of Scientific validity of body surface as a basis for parenteral fluid dosage. *J. Amer. Med. Assoc.*, 167:1211, 1958.
15. RASCH, P. J. and PIERSON, W. R.: Evaluation of a submaximal test for evaluating physical work capacity. *Ergonom.*, 3:9, 1960.
16. RASCH, P. J. and PIERSON, W. R.: The relationship of body surface area, mass, and indices to energy expenditure. *Rev. Canad. Biol.*, 21:1, 1962.
17. ROYCE, J.: Use of body components as reference standards for basal metabolic rate. *Res. Quart. AAHPER*, 29:60, 1958.
18. TUKEY, J. W.: Comparing individual means in the Analysis of Variance. *Biomet.*, 5:99, 1949.
19. WYNDHAM, C. H., STRYDOM, N. B., MORRISON, J. F., WILLIAMS, C. G., BREDELL, G., PETER, J., COOKE, H. M., and JOFFE, A.: The influence of gross body weight on oxygen consumption and on physical working capacity of manual labourers. *Ergonom.*, 6:275, 1963.