ENDURANCE CAPACITY FOR CONTINUOUS EFFORT IN TERMS OF AEROBIC AND ANAEROBIC FRACTION OF OXYGEN SUPPLY

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Summary: Studies have been conducted on 13 young healthy adults of average fitness on endurance work of varying durations lasting for 2-31 minutes using bicycle ergometer. Aerobic-anaerobic fractions of oxygen supply during each effort was determined. The data from Åstrand and Rodahl on aerobic O_2 - supply and duration in maximal efforts from 1-120 minutes on a highly trained subject have also been considered. The plot of log endurance time against log (aerobic/anaerobic ratio) exhibits a slight departure from linearity, indicating independent contributions from aerobic and anaerobic fractions of oxygen supply. An equation was derived of the form :

$$T = Au_1^{k_1}u_2^{-k_2}$$

where u_1 end u_2 are the aerobic and anaerobic fractions respectively which has been found to yield highly significant correlation coefficient between log-estimated and log-observed endurance time (0.9996 for Åstrand and Rodahl's data on a single subject and 0.9640 for the present data on 13 subjects). This index is, therefore, quite suitable for the assessment of endurance capacity in terms of a single physiological parameter, and is likely to be superior to indices in current use.

Key words: endurance work aerobic and anaerobic fraction of oxygen supply

INTRODUCTION

Assessment of endurance work capacity of individuals is a problem of considerable importance in industrial and military situations, and also in sports. Light work can be sustained for an indefinite period because the energy requirement is met exclusively by aerobic process. While anaerobic energy yielding processes assume significant importance with increasing work load (19,20,21). It has also been fairly well established that the use of work load relative to the individual's aerobic capacity ($\dot{V}O_2$ max) eliminates most of the differences in endurance capacity among individuals (12). However, a trained athlete can work at a relatively higher oxygen uptake relative to his maximum (70-75 per cent) without any significant increase in oxygen deficiency and blood lactate concentration (9,10,28). Untrained subjects, on the other hand, show a rise in O_2 debt and lactate accumulation at only about 45-55% of their aerobic capacity (3.16,28). Experiments with animals and may have revealed that this adaptation in trained individuals is primar due to a change in the capacity of aerobic metabolism brought about by an increase in the enzymatic capacity for oxidative phosphorylation (17) and also due to higher percentage of ST fibers (10,13,14).

Prolonged work at a high intensity reduces the available energy stores and thereby limits the supply processes (1,5,18,23). Other associated factors limiting endurance effort are hyperthermia and dehydration (10,24,29,30).

It will thus be clear from the foregoing that assessments of individual endurance capacity from physiological measurements is a complex problem and that any simple index for the purpose based on a single parameter like aerobic capacity cannot have general applicability. Recently we observed a high degree of correlation between endurance work and combined cardiorespiratory stresses (26).

In one of our earlier study (25), it was observed that endurance time for heavy work was highly related to the aerobic-anaerobic ratio of oxygen supply (27). The present study was undertaken with a view to examining the merits of this alternative approach.

MATERIALS AND METHODS

Thirteen young healthy subjects of average fitness status were selected for the study. Mean age, height and weight of the subjects were 23.8 years, 166.6 cm, and 56.3 *kg* respectively their mean $\dot{V}O_2$ max was 2.36 1/min (42.5 *ml/kg*/min) and mean maximum heart rate, 187.5 beats/min.

The subjects reported in the laboratory in the morning after a light breakfast and after one hour rest, the resting O_2 consumption, pulmonary ventilation and heart rates were noted. The subject was then asked to perform a fixed rate of 800,1000 or 1200 *kg/min* work on bicycle ergometer till exhaustion which was taken to be the moment when the subject failed to maintain the fixed speed of 60 rpm. Endurance time was noted when the speed dropped to 50 rpm inspite of his best effort. Different work rates of 800-1200 *kg/min* were given to the same subject at intervals of 4-5 days to minimize any training effect. During exercise, the subjects were breathing through a Collin's Triple 'J' low - resistance breathing valve. The expired air volumes were collected continuously in large meteorological rubber baloons over a period of 5 minutes through a three-way stopcock. The volume of expired air from each baloon was measured by passing through Koffranyi Michaelis Respirometer and an aliquot sample collected during the process. Expired air samples were analysed for CO_2 and O_2 in Scholander Microgas Analyser. Thus the total O_2 consumed during the effort was determined (Exercise $\dot{V}O_2$). After cessation of exercise, recovery oxygen consumption over the resting level was also estimated for 30 min (recovery $\dot{V}O_2$). Thus the total aerobic and "anaerobic" O_2 utilised during the effort were calculated.

The studies were conducted indoors with room temperature and relative humidity varying from 20 - 22°C and 50-55 per cent respectively. Motivation of the subject was achieved by creating competitive spirit and seeking their best cooperation.

RESULTS

In Table I, experimental data on the 13 subjects have been presented which include endurance time (T) in minutes, O_2 consumed (above resting level), during work (Ex VO_2) and during recovery (Rec $\dot{V}O_2$), total O_2 requirement of the work, all expressed in litres at STPD, aerobic (u_1) and anaerobic (u_2) fraction as well as aerobic/anaerobic ratio ($_1/u_2$) O_2 supply.

In Fig. 1, log T has been plotted against log (u_1/u_2) for all the 31 observations on the 13 subjects (solid circles). The correlation appears to be reasonably linear, but to close inspection of the points indicates a slight departure from linearity.

However, Åstrand and Rodahl (4) have reported similar observations on a single subject of athletic type (VO_2 max 5.01/min) with endurance time varying from 1 to 120 min. These data are represented in Table II and the 7 corresponding points (open circles) plotted in Fig. 1 which lie on a smooth curve (hand fitted). The curve clearly shows a slight departure from linearity, and the 31 points from the present study exhibit a very similar trend but mostly lie above the curve.

A simple mathematical approach :

It is well known that from moderately heavy to very heavy work, the endurance time decreases primarily due to a decrease in the aerobic fraction (u_1) of O_2 supply. The anaerobic fraction ($u_1 = 1 - u_1$) increase at the same time, and is likely to reduce the endurance time independently. If that be the case, the slight non-linearity of the curve in Fig. 1 can be easily explained on the basis of the following assumptions :—

(i) Endurance time (T) is determined not by the ratio (u_1/u_2) but by the fractions u_1 and u_2 respectively.

(ii) Relative changes in u_1 and u_2 cause proportional relative changes in T, though in opposite directions.

TABLE I : Aerobic, anaerobic fraction of O_2 utilization of 13 subjects in different endurance tasks.

Sub	*S. No.*	*Endurance time (T)* *min*	*Ex.* $\dot{V}O_2$ l	*Rec.* $\dot{V}O_2$ l	*Total* O_2 *requirement* l	*Aerobic fraction* (u_1)	*Anaerobic fraction* (u_2)	*Aerobic/anaerobic ratio* (u_1/u_2)
AKG	1	12.0	26.08	4.25	30.33	0.86	0.14	6.14
	2	8.0	17.85	5.33	23.18	0.77	0.23	3.35
	3	2.0	3.60	3.71	7.31	0.49	0.51	0.96
MSS	4	19.0	44.04	7.16	51.20	0.86	0.14	6.14
	5	12.0	28.27	5.80	34.07	0.83	0.17	4.88
	6	2.0	3.40	4.69	8.09	0.42	0.58	0.72
SR	7	11.0	23.17	6.92	30.09	0.77	0.23	3.35
	8	6.0	12.97	4.32	17.29	0.75	0.25	3.00
	9	2.0	3.84	3.54	7.38	0.52	0.48	1.08
RS	10	23.0	44.28	3.84	48.12	0.92	0.08	11.50
	11	11.0	25.62	3.29	29.91	0.89	0.11	8.09
DN	12	13.0	29.09	5.14	34.23	0.85	0.15	5.67
	13	2.0	4.13	5.26	9.39	0.44	0.56	0.79
RD	14	23.0	51.36	5.08	56.44	0.91	0.09	10.11
	15	8.0	18.98	8.53	27.51	0.69	0.31	2.23
	16	2.0	3.80	5.71	9.51	0.40	0.60	0.67
NR	17	10.0	19.61	5.21	24.82	0.79	0.21	3.76
	18	2.0	3.30	7.70	11.00	0.30	0.70	0.43
PC	19	8.0	15.70	2.99	18.69	0.84	0.16	5.25
	20	2.0	3.58	5.37	8.95	0.40	0.60	0.67
VP	21	21.0	42.78	3.72	46.50	0.92	0.08	11.50
	22	6.0	13.10	4.13	17.23	0.76	0.24	3.17
	23	2.0	3.89	3.74	7.63	0.51	0.49	1.04
JS	24	16.0	31.22	3.47	34.69	0.90	0.10	9.00
	25	8.0	16.14	6.28	22.42	0.72	0.28	2.57
	26	2.0	3.79	3.94	7.73	0.49	0.51	0.96
BR	27	12.0	29.66	3.67	33.33	0.89	0.11	8.09
	28	2.0	4.04	3.44	7.48	0.54	0.46	1.17
DB	29	31.0	59.61	3.13	62.74	0.95	0.05	19.00
BB	30	19.0	35.15	3.06	38.21	0.92	0.08	11.50
	31	10.5	24.09	3.92	28.01	0.86	0.14	6.14

Assumption (ii) may be mathematically put in the form :—

$$\frac{\delta T}{T} = k_1 \frac{\delta u_1}{u_1} - k_2 \frac{\delta u_2}{u_2} \qquad \ldots.\ (1)$$

where k_1 and k_2 are positive constants.

Integration of eqn (1) finally leads to

$$T = A \quad (u_1^{k_1}/u_2^{k_2}) \qquad \ldots.\ (2)$$

It may be noted that in the special case when $k_1 = k_2 = k$, eqn (2) reduces to

$$T = A\ (u_1/u_2)^k \qquad \ldots.\ (3)$$

in which case alone, log T will be linearly related to log (aerobic/anaerobic ratio).

It may be concluded, therfore, that the non-linearity of the curve in Fig. 1 is because $k_1/k_2 \neq 1$.

Statistical analysis ;

From eqn (2) we have

$$\text{Log } T = \text{Log } A + k_1 \log u_1 - k_2 \log u_2 \qquad \ldots.\ (4)$$

which is of the form :

$$Y = a + b_1 x_1 + b_2 x_2 \qquad \ldots.\ (5)$$

where $Y = \log T$, $x_1 = \log u_1$, $x_2 = \log u_2$, $a = \log A$, $b_1 = k_1$ $b_2 = -k_2$.

Eqn (5) was fitted to the data of Table II by the method of least squares and the values obtained for the constants were :

$$a = 0.3971,\ b_1 = 1.1087 \text{ and } b_2 = -0.7631 \qquad \ldots.\ (6)$$

which were found to be highly significant ($P < 0.001$). The standard error of the estimate was 0.0268. The coefficient of correlation (r) between observed and estimated log T was 0.9996 indicating almost a perfect linear relationship.

Similar analysis was performed with the present data on Indian subjects (Table I). It was found that the constant b_1 and b_2 do not change significantly while the constant 'a' differs significantly ($P < 0.05$) from that in (6) being equal to 0.5184. The coefficient of correlation (r) between observed and estimated log T for this set of data was 0.9640.

The equations fitting the two sets of data (Table ; I and II) with the constants noted above are :—

$$T = 3.30\ (u_1^{1.1087}/u_2^{0.7631}) \qquad \ldots.\ (7)$$

(Present data on 13 Indian Subjects)

and

$$T = 2.50 \quad (u_1^{\,1.1087}/u_2^{\,0.7631}) \qquad \ldots\ldots (8)$$

(Data of Åstrand and Rodahl (4) on one subject)

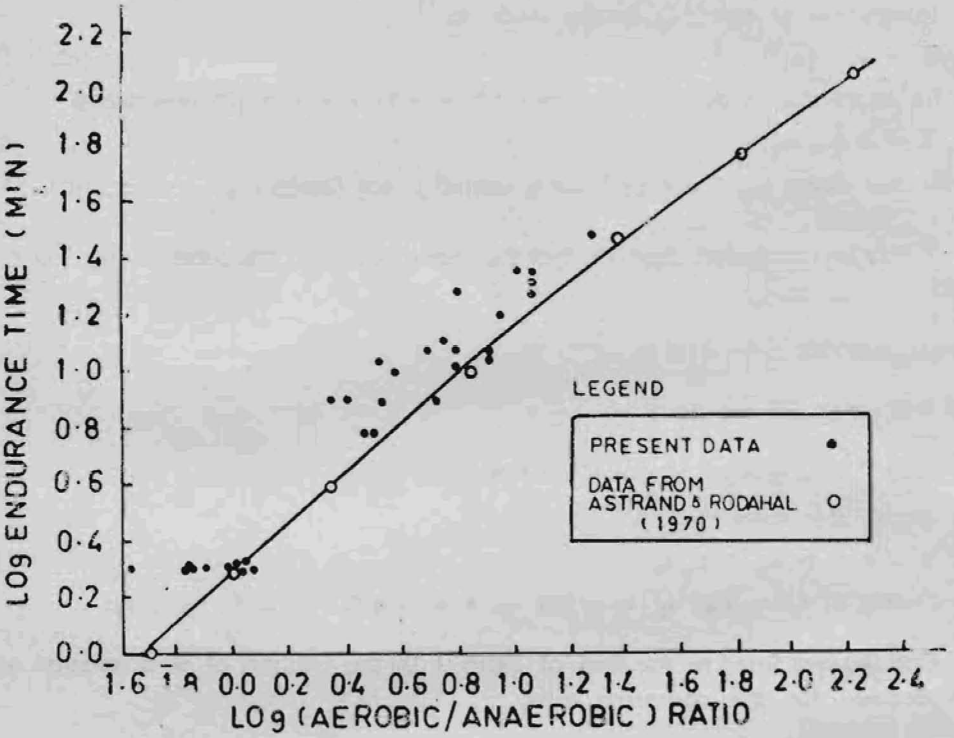

Fig 1 : Relationship between endurance time and aerobic-anaerobic ratio of oxygen supply.

TABLE II : Aerobic, anaerobic fraction of O_2 utilization of one subject in different endurance tasks (Data from Åstrand and Rodahl, 1970)

S. No.	*Endurance time (T)* *min*	*Ex.* $\dot{V}O_2$ 1	*Rec.* $\dot{V}O_2$ 1	*Total* O_2 *requirement* 1	*Aerobic fraction* (u_1)	*Anaerobic fraction* (u_2)	*Aerobic / anaerobic ratio* (u_1/u_2)
1	120	480	3	483	0.994	0.006	166
2	60	260	4	264	0.985	0.015	65.7
3	30	140	6	146	0.959	0.041	23.4
4	10	50	7	57	0.877	0.123	7.13
5	4	20	9	29	0.690	0.310	2.23
6	2	9	9	18	0.500	0.500	1.00
7	1	4	8	12	0.333	0.667	0.50

Observed and estimated endurance time for both sets of data have been compared in Fig. 2 using respective constants as given in eqns (7) and (8).

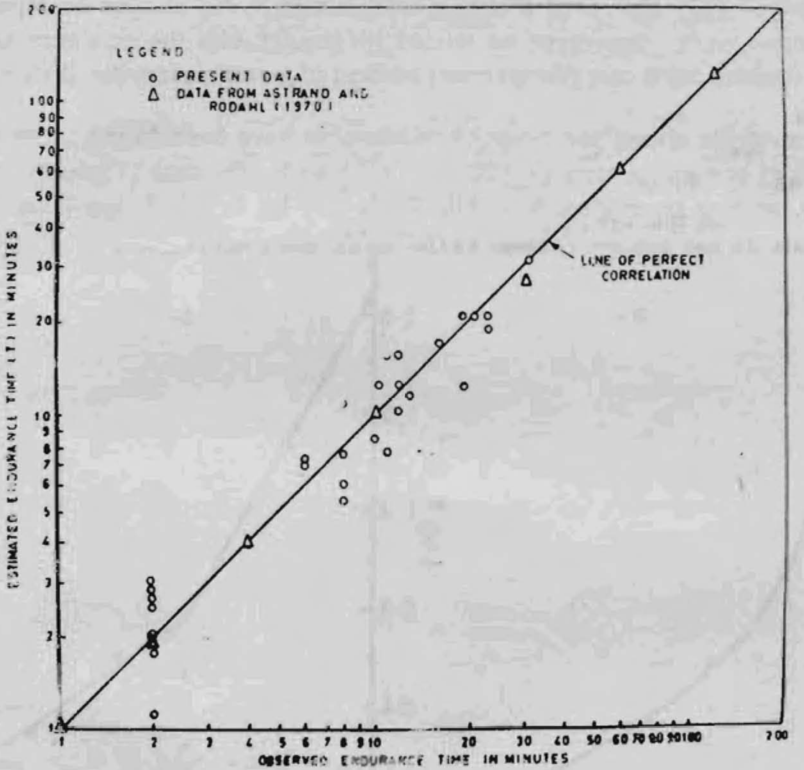

Fig. 2: Relationship between observed endurance time with estimated endurance time.

DISCUSSION

Limited information is available in the literature on estimation of endurance time for continuous heavy physical effort, in terms of work load relative to individual VO_2 max (2,22). Bink (6) and Bonjer(7,8) proposed an exponential equation connecting endurance time and work load which reduces to a linear relationship between log T and work load. Recently, Gleser and Vogel (12) also derived a similar equation on the basis of data obtained with eight subjects of a average fitness both before and after 4 weeks of physical training. Training has been shown to effect the constants of the equation significantly, despite the fact that work load was expressed relative to the individual $\dot{V}O_2$ max which is, by itself, a measure of the degree of training.

Gross-Lordemann and Muller (15) on the other hand, have used the general hyperbolic equation which is equivalent to a linear relationship between log T and log (work load). Tornvall (27) also used a similar relationship in his studies on capacity for short and prolonged work. However, he related his results with the maximum work rate that could be sustained for 6 min (Wmax/min) instead of aerobic capacity ($\dot{V}O_2$ max).

None of the above two types of relationship have been found to be valid over the entire range of endurance time (1-120 min) covered by the data (Table II) of Astrand and Rodahl (4), as may be evident from Fig. 3 (a and b), in which log T has been plotted against relative work load ($\dot{V}O_2/\dot{V}O_2$ max) and its logarithm respectively. Both the curves are resonably linear down to about 6-8 min, corresponding to a relative work load of about 1.2. The graph with respect to log ($\dot{V}O_2/\dot{V}O_2$ max) actually consists of two linear portions with different slopes, meeting at a point where T is about 6 min. This suggests the existence of two distinct ranges (viz., submaximal and supermaximal) of work load which are satisfied by general hyperbolic equations (15) with different constants. In the lower range (T < 6 min), endurance is primarily limited by anaerobic power which is not adequately reflected in either of the two relationships mentioned above

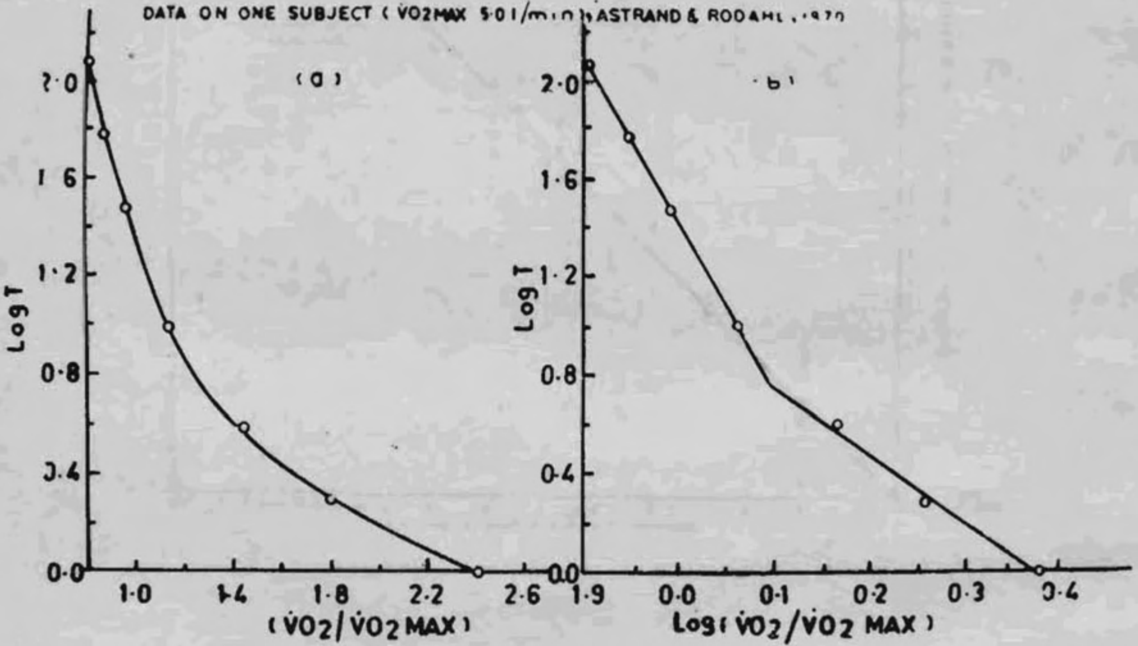

Fig. 3: Relationship between log endurance time with relative work load and log relative work load.

That aerobic capacity alone is not a reliable index of endurance performance has been well demonstrated by observations on long-distance and marathon runners (9,10,11).

The present approach based on aerobic and anaerobic fractions of O_2 supply, has been found to be quite satisfactory in so far as a single equation (No. 8) fits the data of Åstrand and Rodahl (4) almost perfectly over the entire range of T (1-120 min). An equation of the same type (No. 7) fits the present data reasonably well ($r=0.9640$), the observed scatter (Fig. 2) being mainly due to individual difference among the 13 subjects and possible errors in O_2 estimations, particularly for $u_1 > 0.9$. The values of T are, on the average, 32% higher than those reported by Astrand and Rodahl (Fig.1). The latter data pertain to an athletic subject ($\dot{V}O_2$ max$=5.0$ 1/min), whereas the Indian subjects of the present study are of average fitness (mean $\dot{V}O_2$ max $= 2.38$ 1/min). Any possible effect of training on the proposed equation can, therefore, be safely ruled out. The unexpected difference in T for the same aerobic fraction of O_2 supply for the two sets of data (Tables I and II) may be possibly due to superior thermoregulatory mechanism of the heat-acclimatised Indian subjects. However, no definite conclusion in this regard, can be drawn from the present study, particularly because the data of Åstrand and Rodahl pertain to a single individual.

In view of the high degree of correlation between observed and estimated log T on the basis of aerobic and anaerobic fraction of O_2 supply ($r=0.9996$ and 0.9640 for the two sets of data), it appears that this index in terms of a single physiological parameter is quite suitable for the assessment of endurance capacity. However, it will be interesting to study the effect of various other factors limiting endurance of this index. Some of these are, initial glycogen level in muscles (1) hyperthermia and dehydration (24,29) and relative distribution of ST fibers (11,13,14).

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