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RELATIONS OF FIVE KILOMETER PERFORMANCE, ENERGY COST OF RUNNING AND PREDICTED VELOCITY AT $\dot{V}O_{2max}$ IN TRAINED MALE RUNNERS

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Energy cost of running has been reported to correlate either negatively, positively or insignificantly with maximal oxygen intake per body weight ($\dot{V}O_{2max}$/wt). On the other hand, predicted velocity at $\dot{V}O_{2max}$ (v$\dot{V}O_{2max}$) has been shown as an index of long-distance running performance. The purpose of this study was to compare the relationships of 5 km running performance, energy cost of running and v$\dot{V}O_{2max}$. Subjects of the present study were six long-distance runners aged 22-33 years old. They have been trained for more than eight years and are skillful in treadmill running. These subjects performed 5 km running tests on a treadmill at different 3-5 speeds between 238 and 313 m/min. The coefficients of variance (CV) of total oxygen consumptions at the different running speeds were only 2.0 to 3.6%. This reveals similarity of the total oxygen consumptions in spite of the difference of running speeds, agreeing with the results reported by Margaria et al.[14]. There were significant and positive correlations between v$\dot{V}O_{2max}$ and 5 km running performance (the best record in this season). But there were no significant correlations of 5 km performances, energy costs, $\dot{V}O_{2max}$/wt and velocities at the blood lactate concentration of 4 and 7 mM, and of v$\dot{V}O_{2max}$ and other parameters except 5 km running performance. These results led to conclusions: The v$\dot{V}O_{2max}$ is a useful index for 5 km performance in well-trained runners, but $\dot{V}O_{2max}$/wt and energy cost of running are not.

Key words: Lactate, Maximal oxygen intake, Running economy, Long distance running

Introduction

The relation of oxygen consumption and running speed has long been studied, but is not yet well understood. Trained long-distance runners are reported to show smaller oxygen intakes than those of non-long-distance runners, provided that running speed is

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the same[2,4,6]. However, Morgan et al.[16] have reported that, even when the rate of oxygen consumption is higher at a same running speed, time required for 10 km running is shorter for runners with larger maximal oxygen intake ($\dot{V}O_{2max}$). For this reason, the running speed at the maximum rate of oxygen intake (v$\dot{V}O_{2max}$) has been regarded as an index of running performance.

One of the studies reports that oxygen consumption for covering a same distance at varied running speed is constant in each individual[14]. This has led to a concept of 'energy cost' of running, which is net oxygen consumption for running above that at rest. Comparing different subjects with various exercise performances, di Prampero et al.[7] have reported that correlation of the energy cost and $\dot{V}O_{2max}$ per body mass ($\dot{V}O_{2max}$/wt) is not significant. In contrast, another study shows a negative correlation of the two parameters[3] and implies that athletes with larger $\dot{V}O_{2max}$/wt can cover a certain running distance with smaller oxygen consumption per body mass. Therefore, the reported results on the correlation of the energy cost and $\dot{V}O_{2max}$/wt are not consistent. On the other hand, the concentration of blood lactate measured at a same running speed or at a same exercise intensity is reported to be lower in trained than in untrained subjects. The similar decrease in blood lactate is also observed after training[5,10]. The decrease in blood lactate may be related to increase in oxygen intake, because the increase would suppress lactate production and activate lactate clearance[8,9,15]. These lead to a possibility that the lower lactate concentration in trained athletes at a same running speed results from larger oxygten consumption due to larger $\dot{V}O_{2max}$/wt. Aerobic training is accepted to increase $\dot{V}O_{2max}$/wt[1], which would contribute to convert anaerobic energy production system in part to more efficient aerobic system. The training is important for gaining metabolic characteristics suitable for endurance exercise[5,11]. If $\dot{V}O_{2max}$/wt is larger, then the rate of oxygen consumption will be greater at a same running speed, leading to larger oxygen consumption for covering a certain distance.

This study was intended to examine correlations of energy cost of running, v$\dot{V}O_{2max}$, the blood lactate concentration and $\dot{V}O_{2max}$/wt in long-distance (5 km) running.

Methods

Subjects were six male runners aged 22-33 years old, who have been trained for more than 8 years as long-distance runners. Before tests of the present study we obtained their written informed consent to be subjects. Characteristics and aerobic capacities of the subjects are listed in Table 1.

Five of the subjects performed five types of 5 km running tests on a treadmill at different running speeds, while one did three types of the similar tests. The speeds were assigned to individual subjects referring to their best records of 5000 m running time (5 km RT) in the tested season and the mean speed of 5000 m running (v5 km) was calculated from the 5 kmRT. Experimental protocols of all subjects are shown in Table 2.

Electrocardiogram (ECG) was continuously monitored with an electrocardiograph

Table 1. Characteristics and aerobic capacities of subjects.

Subj.	Age (yrs)	Height (cm)	Weight (kg)	5 kmRT (min	: sec)	$\dot{V}O_{2max}$ (mℓ/kg/min)	HRmax (bts/min)
1	23	173	56.1	15	44	67.1	189
2	24	164	54.6	15	48	77.8	195
3	22	168	52.4	15	52	77.9	181
4	33	165	61.2	17	13	64.6	201
5	31	177	63.0	16	01	71.8	188
6	22	173	55.0	16	38	70.4	192

5 kmRT, The best record of 5000 m running time in this season:
$\dot{V}O_{2max}$, Maximal oxygen intake per body weight;
HRmax, Maximal heart rate.

Table 2. Experimental protocol (5 km running on a treadmill)

	Speeds of 5 km running in m/min (Duration in minute)					
Subj.	238 (21)	250 (20)	263 (19)	278 (18)	294 (17)	313 (16)
1		C	C	C	C	C
2		C	C	C	C	N
3		C	C	C	C	C
4	C	C	C	C	N	
5		C	C	C	C	N
6	C		C		C	

Running was completed for C but not for N

(NEC San-ei, Japan) by a dipole chest lead during the tests and recorded for 10 sec every minute to calculate the heart rate.

Oxygen intake was determined with standard techniques of open circuit spirometry. Respired qases were sampled continuously through a low-resistance breathing mask. Oxygen intake and carbon dioxide production were computed and analyzed once every 30 sec during the tests with a gas analyzer (Aerobicsprocessor 391, NEC San-ei, Japan). the maximum tests for determining $\dot{V}O_{2max}$ took place on the last day of series of the tests. Mean oxygen intakes per minute at different running speeds were calculated from the intakes during the last 5 min of the 5 km running tests. Total oxygen consumptions for the 5 km running was calculated as the product of mean oxygen intake per minute and 5 km running time at each speed. Energy cost of running was net oxygen consumption above resting value expressed in mℓ/kg/km and estimated by total oxygen consumption and 5 km running time at 280 m/min. The speed of 280 m/min was near the highest speed at which all subjects could complete 5 km running.

Blood was sampled from the antecubital veins between 2 and 3 min after the end of the running, promptly deproteinized and used for assaying lactate by an enzymatic method with a commercial kit (Lactate Test, Boehringer, Germany). Running speeds

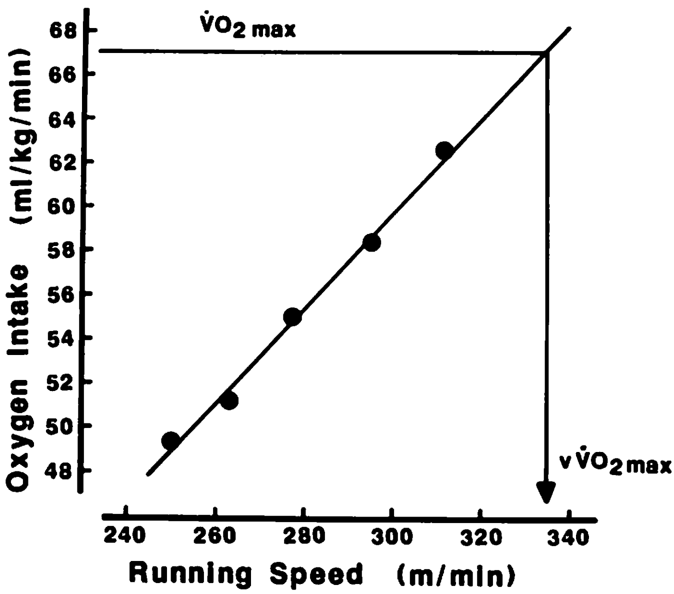

Fig. 1 Relation between oxygen intake and running speed of a subject. The running speed for $\dot{V}O_{2max}$ is the predicted velocity at $\dot{V}O_{2max}$ (v$\dot{V}O_{2max}$).

corresponding to the blood lactate concentrations of 4 and 7 mM (vLa 4 and vLa 7) were estimated from the non-linear regression equation describing the relation between running speed and the blood lactate concentration.

The velocity at $\dot{V}O_{2max}$ of each subject (v$\dot{V}O_{2max}$) was predicted from $\dot{V}O_{2max}$ and oxygen intake values. Initially, the linear regression equation expressing the relation between oxygen intake and treadmill velocity was derived for each subject (Fig. 1). Then, the running velocity associated with $\dot{V}O_{2max}$ was calculated by entering $\dot{V}O_{2max}$ value into the regression equation.

Values obtained by the running tests were expressed as means and SD. Correlations between any two of the parameters such as the energy cost, $\dot{V}O_{2max}$/wt, and running speeds were analyzed by the linear regression, and the Pearson's coefficients of correlation (r) were calculated. When p was less than 0.05, the correlation was regarded to be significant.

Results

Percentages of oxygen intakes on the maximal oxygen intakes (%$\dot{V}O_{2max}$) of 6 subjects in 5 km running's at the different speeds were 68.5-79.6% for the lowest speeds and 88.4-97.4% for the highest speeds. The heart rates increased with time during 5 km running and reached near maxima at the highest speeds in all cases.

Total oxygen consumptions in 5 km running at 3-5 different speeds were determined in each subject. Mean and SD of values of the consumptions in all subjects are shown

Table 3. Means, SD's and coefficients of variance (CV) of total oxygen consumptions in 5 km running at different 3-5 speeds.

Subj.	Mean liter	SD liter	CV %
1	55.0	1.98	3.6
2	63.7	2.15	3.4
3	57.4	1.17	2.0
4	62.8	1.73	2.8
5	70.5	1.54	2.2
6	59.4	1.77	3.0

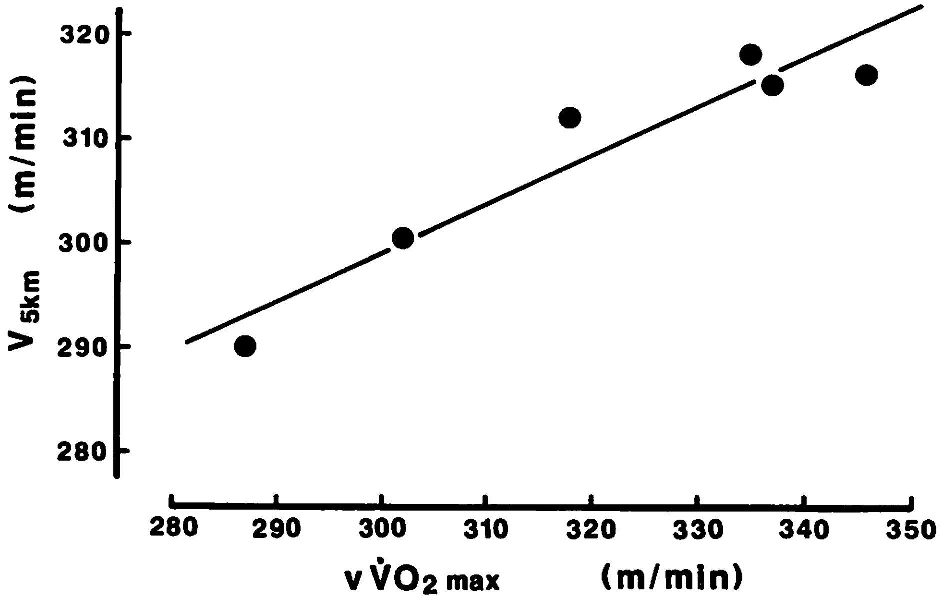

Fig. 2 Relation between mean velocity of 5 km running (V5 km) and predicted velocity at $\dot{V}O_{2max}$ ($v\dot{V}O_{2max}$) in well-trained male runners. $r=.95$, $P<.01$.

in Table 3, indicating small values of SD. The coefficient of variance (CV) was estimated to range from only 2.0 to 3.6%, suggestive of very similar total oxygen consumptions irrespective of difference of running speeds. Mean (±SD) of energy cost of running at the speed of 280 m/min was 205.3 (±11.7) mℓ/kg/km.

A significant positive correlation was demonstrated between the v5 km and $v\dot{V}O_{2max}$ ($p<.01$) (Fig. 2). However, there were no significant correlations among the energy cost, $\dot{V}O_{2max}$/wt, v5 km, $v\dot{V}O_{2max}$, vLa 4, and vLa 7 except the relationships between v5 km and $v\dot{V}O_{2max}$ and between vLa 4 and vLa 7.

Discussion

There were differences of the subjects in mean of total oxygen consumptions in 5 km running's at different 3-5 speeds, but SD was small in each subject. This indicate that total energy requirement in a same distance running is very similar though running speedd is different. These results coincide with result reported by Margaria et al.[14]

As already pointed out by Morgan et al.[17], results on energy cost or running economy are markedly influenced by homogeneity of subjects in a tested group whether it consists of subjects with similar $\dot{V}O_{2max}$/wt and running performance. In addition, skill in treadmill test and running form are known to affect oxygen intake. Hence, these points should be taken into consideration in discussing results.

The maximal oxygen intake of subjects in the present study were 64.6-77.9 mℓ/kg/min, suggesting heterogeneity of subjects in the present study. But, running skill of these subjects seemed to be similar, because all of them were trained as long-distance runners for more than 8 years.

Banc and Heller[3] have shown that energy cost and $\dot{V}O_{2max}$/wt are negatively correlated. In contrast, we speculated that, if $\dot{V}O_{2max}$/wt is larger, then energy cost will be larger. Because large $\dot{V}O_{2max}$/wt indicates excellent aerobic metabolism during exercise. However, different from the speculation, our result did not show significant correlation between these parameters. The disagreement between the two results would depend on running techniques of subjects. Subjects used in their study are adult young runners and canoeists of male and female and there seems to be a possibility that skill of the subjects in running on a treadmill differs. Therefore, there might be variance of mechanical work efficiency of the subjects, e. g. difference of running technique judged from vertical body movement causes the variance.

Moreover, there was no significant correlation between the energy cost and v5 km as an index of running performance. Lacour et al.[12,13] have reported that energy cost of running is not correlated with running performance, provided that running distance is longer than 1.5 km. The result is consistent with our result showing the absence of significant correlation between energy cost and v5 km. These results on the insignificant correlations of the energy cost with $\dot{V}O_{2max}$/wt and running performance would reveal that the energy cost cannot be an index of physical resource or performance.

There was a significant correlation only between v$\dot{V}O_{2max}$ and v 5 km in the present study. Morgan et al.[16] have reported that ten kilometer performance is significantly correlated to v$\dot{V}O_{2max}$, also consistent with our result.

Although meaning of the energy cost of running and the reason for the high correlation of v$\dot{V}O_{2max}$ with running performance are unclear, results of this study reveal that the predicted velocity at $\dot{V}O_{2max}$ is a useful index of long-distance running performance.

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