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Effects of Two Years of Running Training on Maximum Oxygen Uptake and Running Speed

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The training effects on maximum oxygen uptake (max$\dot{V}O_2$) and performance (running speed of 5000m run) were investigated on twenty-five long distance runners, member of two university track teams. Subjects were divided into three groups based on their initial abilities with respect to maximum oxygen uptake per body weight (max$\dot{V}O_2$/wt) and running speed of 5000m run.

Maximum oxygen uptake was determined by Douglas bag method with progressive treadmill running. Running speed was determined in terms of the best record in official races of 5000m.

As the results, the superior initial value subjects group 1 did not increase in max$\dot{V}O_2$/wt. Subjects in group 2 and 3, whose initial capacity of max$\dot{V}O_2$ and performance were relatively low, showed statistically significant increase in max$\dot{V}O_2$/wt. For all subject, significant negative correlation ($r = -0.77$) was detected between increment of max$\dot{V}O_2$/wt and its initial value. The running speed of 5000m run did not improve in group 1. On the other hand, subjects in group 2 and 3 were found significant improve in running speed. For all subject, significant negative correlation ($r = -0.55$) was found between the initial running speed and the improvement running speed. The resultant vector of increment of max$\dot{V}O_2$/wt and running speed in group 2 and 3 were approximately in parallel with the regression line in our previous study (21).

These results suggests that max$\dot{V}O_2$/wt as a physical resources plays a main factor to determine the running speed. It appears that the effects of training on max$\dot{V}O_2$ affter puberty is distinctive in the subjects with lower initial value of pretraining.

In long distance running, it is pointed out that the capacity of aerobic energy yielding process determines the speed to a high degree (2, 16). Many investigators have indicated that successful distance runners possess a high maximum aerobic work capacity (maximum oxygen uptake) (3, 21, 23, 24, 25, 32) and maximum oxygen uptake per kilogram of body weight (maxVO_2/wt) has been well recognized as index of the aerobic work capacity (4, 16, 19, 20).

It is well known that physical endurance training increases max$\dot{V}O_2$. Furthermore the endurance training and its physiological effects have been quantified as to subjects initial status of fitness, interrelated with age, intensity, duration and frequancy of training, training program and periods of training (6, 22, 27, 28, 30). In the majority of studies were reported that sedentary adult subject increase of max-$\dot{V}O_2$ have been in the range of 10 to 20% for programs of 3–6 months (1, 7, 8, 9, 14). In

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contradiction to the fact, several studies have shown that successful athletes could hardly improved in his work capacity even though hard and long term training (15, 25, 33). The effects of training are necessary to clear based on the various factors.

The present study was intended to examine the effects of hard training in running over two years on maximum oxygen uptake and running speed of the male long distance runners in relation to their initial fitness.

METHOD

Twenty-five male students who were long distance runners of two university track teams volunteered as subjects for this study. They ranged in age from 19 to 23 years at the beginning of the experiment in 1973. They had been conducting training of running every day for 4 to 8 years and participating in official track events before the first experimental year. The subjects were divided into three groups based on their best record of 5000m run and initial values of max$\dot{V}O_2$/wt; the best record of 5000 m for group 1 ranged from 14'00 to 14'59", from 15'00 to 15'59" and from 16'00 to 18'00 in group 2 and 3, respectively. Table 1 shows their anthropometric data and the initial value of max$\dot{V}O_2$/wt before the experiment of each group.

Maximum oxygen uptake was determined by a progressive teadmill running test. The inclination of the treadmill was held constant at angle of 8.6%. During the first two minutes, the treadmill speed was kept at 220m/min for group 1 and 2 and 180m/min for group 3, respectively. After 2 minutes, the speed was increased by 10m/min every succeeding minute until exhaustion. All subjects ran at least five minutes before they reached exhaustion.

Expired air during running was collected in Douglas bags every minute up to exhaustion, at which time the volume was measured by a dry gas meter. Gas samples were analyzed by a Beckman oxygen and carbon dioxide analyzer, the model 160. During each test the ECG revealed the runners heart rate which was used to assure that exhaustion occured.

The heart rate of each subject was over 185 beats/min before exhaustion. It was, therefore, assumed that the subjects maximal level of oxygen uptake was attained. Respireatory rate was recorded with the aid of a thermister attached to the inside of the mask. The treadmill test was administered in each May or June for three years from 1973 to 1975.

Since the subjects had about 20 chances of participating in official running races of 5000m every year, the running speed was determined in terms of the best record of 5000m in each year.

The training program consisted of interval running, repetition running, speed play, endurance running and time trial etc. The training was supervised by their coaches. Group 1 and 2 trained regularly twice a day for 6 days in every week. Group 3 trained once a day for 5 days in every week. In group 1 and 2, mean running distance of each month during a year was 454 km/month (18.92km/day). In group 3, it was 257km/month (12.85km/day). There were almost same in monthly running distance between the first and second experimental year.

Table 1. Anthropometric data, running speed and physiological responses to the maximum work loard before and after two years training

		Group 1 (n=11)			Group 2 (n=6)			Group 3 (n=8)		
		before	after	Diff.	before	after	Diff.	before	after	Diff.
Height (cm)	X	170.0	170.6	0.6	167.0	167.1	0.1	165.6	166.1	0.5
	S.D.	5.40	5.21		3.22	3.34		4.74	4.69	
Weight (kg)	X	57.2	57.6	0.4	55.4	55.3	−0.1	55.3	55.8	0.5
	S.D.	3.89	4.27		3.58	4.06		5.43	4.81	
Mean Speed of 5000m Run	X	5.64	5.66	0.2	5.42	5.57*	0.15	4.75	5.00*	0.25
(m/sec)	S.D.	0.08	0.08		0.49	0.52		0.19	0.11	
max$\dot{V}O_2$ (STPD)	X	3.94	4.02	0.08	3.72	3.88*	0.16	3.32	3.65**	0.33
(1/min)	S.D.	0.24	0.46		0.33	0.27		0.31	0.34	
max$\dot{V}O_2$/wt (STPD)	X	69.1	70.2	0.9	66.9	70.2*	3.3	60.2	65.6**	5.4
(ml/min · kg)	S.D.	4.56	4.55		2.40	0.57		2.49	4.41	
max$\dot{V}E$ (STPD)	X	115.1	123.6*	8.5	109.6	118.9	9.3	99.2	117.3**	18.1
(1/min)	S.D.	9.75	9.69		6.34	14.9		11.2	15.9	
max. Heart Rate	X	187	185	−2	189	182	−7	188	192	4
(beats/min)	S.D.	12.1	8.0		5.8	5.6		11.4	4.8	
Resp. Rate	X	64	64	0	67	62	−5	63	65	2
(freq./min)	S.D.	6.0	10.9		6.7	6.1		9.4	8.2	
Tidal Volume	X	1.79	1.93	0.14	1.63	1.92	0.29	1.57	1.81	0.24
(1/breath)	S.D.	0.21	0.28		0.23	0.13		0.23	0.29	
O_2 Pulse	X	21.2	21.8	0.6	19.8	21.3	1.5	17.8	19.1	1.3
(ml/beat)	S.D.	1.62	1.40		2.11	1.68		1.98	1.94	
Venti. equiv.	X	29.2	30.7	1.5	29.5	30.5	1.0	29.9	32.0	2.1
(ml$\dot{V}E$/ml$\dot{V}O_2$)	S.D.	1.70	1.87		1.34	1.74		2.75	2.78	

* Significant at $P < 0.05$ ** Significant at $P < 0.01$

RESULTS

Table 1 shows mean values of body height, weight, running speed of 5000m and physiological responses of each group before and after training. The mean values of height and weight after training were not changed for every group in compariosn with those before training.

In group 1, mean running speed and mean values of max$\dot{V}O_2$/wt did not improve after training, however, maximum pulmonary ventilation (max$\dot{V}E$) only increased significantly. Mean running speed in group 2 improved 0.15 m/sec (2.8%) and mean values of max$\dot{V}O_2$/wt was also increased 3.3ml/min·kg (4.3%). These increments by training are statistically significant at 5% level. In group 3, running speed, mean max$\dot{V}O_2$/wt and max$\dot{V}E$ were significantly 0.25m/sec (5.3%), 5.4ml/min · kg (9.1%), and 18.1 l/min (18.2%), respectively. These increments indicated greater value than the other two groups. Other physiological

Table 2. Individual values before and after training on maximum oxygen uptake, maximum oxygen uptake per kilogram of body weight and running speed of 5000m run.

Group	No.	Subj.	max$\dot{V}O_2$ (ml/min)		max$\dot{V}O_2$/wt (ml/min · kg)		Running Speed (m/sec)	
			Before	After	Before	After	Before	After
1	1	T.I.	4.27	4.45	79.1	80.9	5.83	5.88
	2	M.S.	3.86	3.81	70.8	68.0	5.70	5.64
	3	O.K.	3.81	3.90	67.4	71.6	5.66	5.62
	4	K.O.	3.64	3.92	68.7	72.6	5.65	5.68
	5	S.K.	3.84	3.82	68.6	68.2	5.63	5.63
	6	R.Y.	3.48	3.73	63.8	69.6	5.63	5.63
	7	K.Y.	3.92	4.14	68.8	70.2	5.61	5.56
	8	N.O.	4.16	4.34	64.0	67.2	5.59	5.57
	9	Y.M.	3.99	3.84	63.5	61.9	5.57	5.68
	10	T.S.	4.13	4.15	70.0	68.0	5.57	5.57
	11	I.Y.	4.28	4.18	75.1	73.9	5.63	5.63
		Average	3.94	4.02	69.1	70.2	5.64	5.66
		S.D.	0.24	0.46	4.56	4.55	0.08	0.08
2	1	M.T.	4.40	4.36	70.4	69.2	5.52	5.52
	2	M.S.	3.66	4.13	64.2	70.9	5.42	5.57
	3	T.F.	3.62	3.67	67.6	70.6	5.40	5.58
	4	K.H.	3.34	3.73	63.6	70.4	5.40	5.52
	5	T.S.	3.58	3.66	68.8	69.7	5.38	5.67
	6	Y.N.	3.70	3.73	66.7	70.4	5.37	5.53
		Average	3.72	3.88	66.9	70.2	5.42	5.57
		S.D.	0.33	0.27	2.40	0.57	0.49	0.52
3	1	T.S.	3.14	3.57	60.4	71.4	4.96	5.09
	2	O.K.	3.59	3.79	62.0	65.0	4.88	4.98
	3	M.K.	2.96	3.41	56.9	59.3	4.82	4.82
	4	S.K.	3.29	3.54	58.8	63.8	4.85	4.95
	5	H.M.	3.54	3.61	58.0	59.2	4.84	5.05
	6	K.O.	3.11	3.19	65.5	67.1	4.70	5.00
	7	S.K.	3.91	4.44	60.2	71.0	4.59	5.22
	8	T.Y.	3.03	3.68	59.4	68.1	4.34	4.92
		Average	3.32	3.65	60.2	65.6	4.75	5.00
		S.D.	0.31	0.34	2.49	4.41	0.19	0.11

responses, i.e. maximum heart rate, respiration rate (resp. rate), tidal volume, oxygen pulse (O_2 pulse) and ventilation equivalent (venti, equiv.) for each group did not change significantly over the training period.

Table 2 present all individual and mean values from the experiment before and after training. Figure 1 illustrates the individual improvement on running speed expressed in relation to the initial mean speed of 5000m run.

As clear from this figure, the superior the

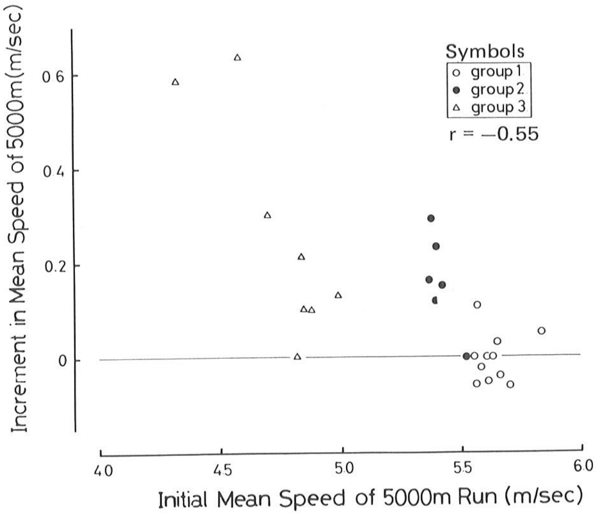

Fig. 1. The individual improvement on running speed in relation to be the initial mean speed of 5000m run.

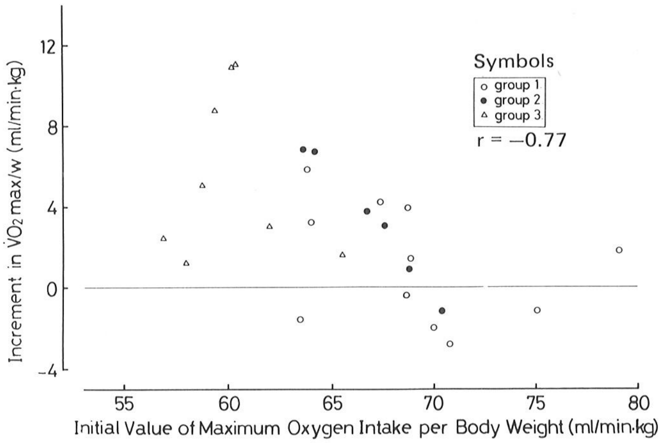

Fig. 2. The individual increase of max$\dot{V}O_2$/wt after training in relation to the initial value for their max$\dot{V}O_2$/wt.

subject's initial mean speed was, the less the improvement by training was observed. There are negative correlation (r = −0.55) between the initial running speed and improved running speed.

Figure 2 illustrates individual increase of max$\dot{V}O_2$/wt after training in relation to the initial value for their max$\dot{V}O_2$/wt. The superior the subject's initial value was, the less the increase was found and also the inferior the subjects value was, the greater the increase was recognized as well as in the case of running speed. Therefore, there was a negative correlation (r = −0.77) between the increment in max$\dot{V}O_2$/wt and the initial value of max$\dot{V}O_2$/wt.

DISCUSSION

In evaluating effects of training, one must consider several factors, that is, modes of training (training program), differences in intensity. duration and frequency of training, periods of training, initial status of fitness and inter-related with age (6, 7, 10, 22, 29, 30, 31).

It is well known that the values of max$\dot{V}O_2$ for Japanese males increased with age until 18 years old (11, 17 18). These results suggested that in this study the influence of growth to evaluate training effects will be excluded because our subjects were between 19 to 23 years of age.

Many studies have reported that sedentary adult subject improved in their aerobic work capacity by 10–20% for programs of 3–6 months (1, 7, 8, 9, 14). The percentage of improvement attained in max$\dot{V}O_2$ is related to one's initial degree of fitness (26, 29). Åstrand (2) pointed out about intensity of training that one should train at approximately above 50% of his maximum oxygen uptake, which is in agreement with Karvonen (12). Duration for improvements in max$\dot{V}O_2$ have been found at least 5 to 10 minutes a day (1, 7, 29). Another investigation found the longer duration to produce more significant inprovements (5, 27). Numerous studies have sought to evaluate frequancy of training (6, 22, 26, 28, 29). These investigations generally showed that effects the training 2 or 3 days per week for sendentary subject.

The subjects in this study had conducted their training for two years, hard and regularly according to the various programs scheduled by their coaches. Training programs consisted of interval running, repetition running, speed play, endurance running, time trials, etc. Average running distance per day for group 1 and 2 were 18.92km and it was 12.85km for group 3. Such a training might give an approximately maximum load for each subject from the view point of their running schedule and distance.

In the case of long-term training for athletes, Saltin and Åstrand (25) reported that a world class cross-country skier who had training almost daily during the intervening eight years and successfully participated in two Olympic games and two world championship had almost same value of max$\dot{V}O_2$ of 5.48 l/min when he was tested in 1955 and 1963. Kollias (15) have found that max$\dot{V}O_2$/wt of five members of the university track team was either slightly improved or unchanged after a series of treadmill training during a season, while four runners improved their out-door running time by the training. Yamaji and Miyashita (33) also reported that the recordes of 5000m run were improved by 5.6% for 14 runners after three years of training without any increase of max$\dot{V}O_2$.

Daniels and Oldridge (5) pointed out that an attempt to explain the significant improvement in running performance the several factors which might contribute to running performance should be considered: 1. An increase in max$\dot{V}O_2$/wt. 2. A decrease in the oxygen demand of running at any given velocity (increase efficiency). 3. Working closer to max$\dot{V}O_2$ for a greater portion of the race. 4. Greater anaerobic involvement, which is likely a function of working closer to max$\dot{V}O_2$. Yamaji and Miyashita (33) suggested that improvement of the record of 5000m may be due to these factors, that is, (1)) increase in oxygen debt, (2) the improved ability to run at high percentage of max$\dot{V}O_2$, (3) more efficient running movement.

In this study it was found that the max$\dot{V}O_2$/wt and mean speed of 5000m in group 2 and 3 were increased after training but it did not change in group 1. It was observed in our previous study (20) that there was close relationship between max$\dot{V}O_2$/wt and running speed of 5000m, and its regression equation was as follow: $\hat{Y} = 0.0431X + 2.50$. In order to analyze the effect of training in every group, this regression line was showed in Figure 3: in this figure, the improvement in running speed is shown as the component of a vector Y, and the increase in the max$\dot{V}O_2$/wt is shown as the component of a vector X. Thus resultant vector can be composed of those X–Y vectors. As shown in Figure 3, group 2 and 3 improved in both running speed and max$\dot{V}O_2$/wt. Both resultant vectors for group 2 and 3 are approximately in parallel with regression line calculated on 60 long distance runners. This result might indicate that on average group 2 and 3 increases running speed mainly with the increase of max$\dot{V}O_2$/wt. This finding suggests that sufficiently trained runners during adolescence must to enhance more efficient running motion and develop ability to run at a high percentage of max$\dot{V}O_2$.

The records of 5000m run for the subjects of group 1 were within the 50th ranking in Japan before the experiment. This means that they had been sufficiently trained during adolescence, that is, 7 to 8 years training before the experiment. Klissouras (13) pointed out the fact that an individual's increase of max$\dot{V}O_2$ can be improved substantially by physical training, but its ceiling is set by the genotype. Furthermore, Saltin and Åstrand (2) stated that there were limits individual's ability to improve his max$\dot{V}O_2$ and therefore the natural endowment was important. Accordingly one of the reason of no increase of max$\dot{V}O_2$/wt in group 1 may be to get to the ultimate level of max$\dot{V}O_2$ determined by upper limit of genetic factors before they entered into the universities.

On the other hand, max$\dot{V}O_2$/wt in group 2 and 3 increased after training. As shown in Figure 2, that the increase in max$\dot{V}O_2$/wt was greater in the subjects of low initial value than

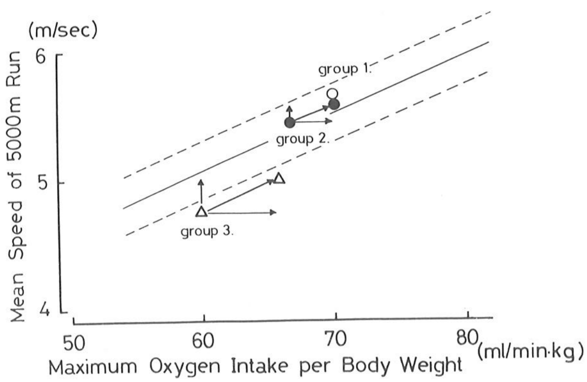

Fig. 3. Training effects over two years on running speed and max$\dot{V}O_2$/wt for each group.
The regression equation and its standard deviation were calculated on 60 long distance runners in our previous study.
The regression equation was as follows: $\hat{Y} = 0.0431X + 2.50 \pm 0.232$
The resultant vectors for group 2 and 3 are approximately in palallel with regression line.