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Heikki Rusko, Matti Havu and Esko Karvinen

Muscle Research Center, Department of Biology of Physical Activity and Department of Cell Biology, University of Jyväskylä, Jyväskylä, Finland

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ABSTRACT

Aerobic performance capacity of 84 male and 5 female Finnish athletes practising 11 different sport events as well as 31 reference subjects was studied. The main parameters of aerobic performance capacity were maximal oxygen uptake (max$\dot{V}_{O_2}$) in leg and arm work, succinate dehydrogenase activity (SDH) and percentage of slow twitch fibers (%ST fibers) in m. vastus lateralis (VL), m. gastrocnemius c.l. (GL) and m. deltoideus (D).

The speed skaters (5.58 $l \times min^{-1}$), male cross-country skiers (5.42 $l \times min^{-1}$), canoeists (5.25 $l \times min^{-1}$) and long-distance runners (5.19 $l \times min^{-1}$) had highest max$\dot{V}_{O_2}$ in leg work. In $ml \times kg^{-1} \times min^{-1}$ the male cross-country skiers, long-distance runners, speed skaters and nordic combination skiers had highest mean values (72.8 - 78.3 $ml \times kg^{-1} \times min^{-1}$). In arm work the canoeists had the highest mean value of 4.56 $l \times min^{-1}$. The oxidative capacity of the muscles as judged on the basis of %ST fibers and SDH activity was highest in the long-distance runners.

Maximal oxygen uptake correlated positively with %ST fibers ($r = .56$, $p < .001$) and SDH activity ($r = .38$, $p < .001$) in m. VL. The SDH activity and %ST fibers in m. VL correlated also with one another ($r = .39$, $p < .001$).

It was concluded that the oxidative capacity of the muscles is not the limiting factor for maximal oxygen uptake. The role of the oxidative capacity of the muscles might be important during submaximal work of long duration and when a relatively small muscle mass is activated (long-distance running). Max$\dot{V}_{O_2}$ might be the most important determinant of physical performance when large muscle mass is activated during maximal work of a duration from several minutes up to one hour (cross-country skiing).

INTRODUCTION

During prolonged heavy physical work the individual's performance capacity depends largely on his ability to take up, transport and deliver oxygen to the working muscles. The maximal oxygen uptake is theoretically a good measure of cardio-respiratory performance, since it integrates several processes concerned in the transfer of oxygen from the enviroment to the active tissues. Maximal oxygen uptake has been used extensively as a criterion of performance capacity of endurance athletes (e.g. Hollman et al. 1964, Saltin and Åstrand 1967, Hanson 1973, Bergh 1974). Recently Gollnick et al (1972) have shown that determinants of muscle tissue may also differentiate athletes from one another: the slow twitch muscle fibers predominated in the muscles of endurance athletes and oxidative enzyme activity was highest in those muscles which were extensively engaged in endurance work. The purpose of this investigation was to describe the aerobic performance capacity of top level Finnish athletes and to study further the value of the fiber distribution and enzyme activity as determinants of the adaptive capacity of the muscles.

MATERIAL AND METHODS

Eleven groups of athletes and two groups of reference subjects were employed in the study. The anaerobic performance characteristics of these same athletes have been described previously (Komi et al. 1976). The sport events and physical characteristics of these 89 athletes and 31 reference subjects are seen in Table 1.

Table 1. Physical characteristics of the groups studied.

Group	n	Age yrs	Height cm	Weight kg	FFW[xx] kg	Fat%[x]
Power events, males	6	23.4 4.1	176 5	76.3 6.4	63.1 5.3	13.0 3.4
800 m running, males	6	24.6 2.2	179 4	72.3 4.6	62.9 4.5	12.4 1.4
Skijumping, males	9	22.2 2.4	174 5	69.9 8.5	59.7 5.2	14.3 3.7
Canoeing, males	8	23.7 4.2	182 5	79.6 6.5	68.9 4.4	12.4 2,8
Ice hockey, males	13	22.5 3.5	171 3	77.3 5.7	65.3 4.7	13.0 2.7
Alpine skiing, males	6	21.2 2.4	176 6	70.1 8.0	60.8 5.9	14.1 3.0
Nordic combination, males	5	22.9 2.1	176 5	70.4 5.7	62.0 5.0	11.2 1.4
Cross-country skiing, males	17	25.6 3.2	174 4	69.3 5.2	60.3 4.5	10.2 2.4
Speed skating, males	6	21.0 2.9	181 4	76.5 1.7	65.7 1.7	11.4 2.3
Long-distance running, males	8	26.2 2.8	177 4	66.2 3.2	60.9 3.0	8.4 1.5
Physical education students, males	8	25.6 4.8	178 7	71.7 5.7	62.8 5.0	11.0 2.7
Reference subjects, males	23	30.3 6.5	176 7	75.0 11.8	61.6 8.4	14.4 3.0
Cross-country skiing, females	5	24.3 4.0	163 8	59.1 5.2	47.0 4.8	21.8 3.7

[x] According to Durnin and Rahaman (1967)

[xx] Calculated as a mean of skinfold (Durnin and Rahaman, 1967) and anthropometric (von Döbeln, 1959) measurements.

About half of the athletes were members of the Finnish national teams during the World and European championships in 1973-1974 and Olympic Games in 1972. All of them had been in regular training for several years and some of the endurance athletes had trained for more than ten years. The reference subjects were divided into two groups. The ordinary male reference subjects (23) were policemen, students and members of the university staff and most of them had exercised regularly according to their own fitness programs. The physical education students (8) had trained and competed in their own sport specialties but were not of the top national level.

The variables of aerobic performance capacity were maximal oxygen uptake or maximal aerobic power (max$\dot{V}O_2$), percentage of slow twitch muscle fibers (%ST fibers) and succinate dehydrogenase activity (SDH) of muscle. Max$\dot{V}O_2$ during running on a treadmill was determined for all subjects. After ten minutes' warming up and a short rest the inclination of the treadmill was increased by one degree every second minute until exhaustion occurred. The treadmill speed was selected so that the subjects were able to run for about 8-12 minutes. In some groups whose athletic specialty involved extensive use of the arms, max$\dot{V}O_2$ was also measured while cranking a bicycle with the hands and arms. After ten minutes' warming up and a short rest the subject began to crank the bicycle at 50 rpm and the work load was increased by 150 kpm x min^{-1} every second minute. The first load was selected so that the subjects were exhausted in after about 8-12 minutes. Expired air was collected in Douglas bags and the volume was determined with calibrated dry and wet gas meters. Gas analysis was performed using the Scholander technique. Oxygen consumption was calculated and corrected for STPD according to Consolazio et al (1963). Heart rate was registered every minute during the tests with a one-channel EKG-apparatus.

Muscle fiber composition and SDH activity were assayed from muscle biopsies taken according to Bergström (1962). In most cases a muscle sample was taken from m. vastus lateralis (VL) and in some cases also from m. gastrocnemius c.l. (GL) and m. deltoideus (D). In order to classify the muscle fibers into slow twitch (ST) and fast twitch (FT) types (Gollnick et al. 1972) myosin-ATPase staining was used according to Padykula and Herman (1955). Part of the muscle sample was weighed and used for SDH activity (Pennington 1961) and protein (Lowry 1951) determination. The SDH activity was expressed as nM substrate reduced x mg^{-1} muscle protein x min^{-1} at $37^{\circ}C$ and the error of the method in double determinations (n = 50) of SDH activity was 5,6 %.

RESULTS

The max$\dot{V}_{O_2}$ of speed skaters, male cross-country skiers, canoeists, long-distance runners, nordic combination skiers and 800 m runners exceeded 5,0 l x min^{-1}, Table 2. The ice hockey players (4,75 l x min^{-1}) also had a significantly higher max$\dot{V}_{O_2}$ than the male reference subjects (4,06 l x min^{-1}). When max$\dot{V}_{O_2}$ was expressed in ml x kg^{-1} x min^{-1} the male cross-country skiers (78,3) and long-distance runners (78,1) had significantly higher means than any other athletic group. The max$\dot{V}_{O_2}$ of the speed skaters and nordic combination skiers was also higher than 70 ml x kg^{-1} x min^{-1}. The skijumpers and power athletes had practically the same max$\dot{V}_{O_2}$ both in l x min^{-1} and in ml x kg^{-1} x min^{-1} as the reference groups. The female cross-country skiers had the lowest max$\dot{V}_{O_2}$ of 4,03 l x min^{-1} but when calculated in ml x kg^{-1} fat free weight x min^{-1} they ranked second to the male skiers and above the long-distance runners and the speed skaters (Table 2).

Table 2. Aerobic performance characteristics of the legs (means and standard deviations).

Group	n	Maximal oxygen uptake (STPD) $l \times min^{-1}$	$ml \times kg^{-1} \times min^{-1}$	$ml \times kg^{-1} FFW \times min^{-1}$	%ST fibers m.VL	m.GL	SDH activity $nM \times mg^{-1} prot \times min^{-1}$ m.VL	m.GL	Maximal heart rate
Long-distance running, males	8	5.19	78.1	85.3	78	88	44.6	53.1	192
		0.33	3.5	4.6	6	15	8.2	6.4	14
Speed skating, males	6	5.58	72.9	85.0	69	63	25.1	31.1	197
		0.37	4.3	6.3	13	9	4.7	7.8	5
Cross-country skiing, males	17	5.42	78.3	89.8	63	72	27.0	27.7	191
		0.42	4.0	5.3	9	13	5.3	4.2	9
Nordic combination, males	5	5.12	72.8	82.7	63	74	21.8	26.9	194
		0.27	2.5	3.1	5	13	3.5	4.9	8
Alpine skiing, males	6	4.45	63.8	73.5	63	-	24.3	-	199
		0.35	4.5	5.1	8		-		8
Ice hockey, males	13	4.75	61.5	72.7	61	-	31.8	-	200
		0.42	4.2	4.7	12		5.2		6
Canoeing, males	8	5.25	66.1	76.3	58	-	15.5	-	195
		0.36	4.4	4.4	9		0.5		8
Skijumping, males	9	4.25	61.3	71.3	55	-	19.0	-	199
		0.37	4.3	3.0	8		1.2		8
800 m running, males	6	5.04	69.8	80.2	45	-	32.5		203
		0.37	4.5	4.2	16		-		11
Power events, males	6	4.33	57.1	68.7	37	46	27.2	29.4	200
		0.50	8.4	7.7	18	20	8.8	10.4	6
Physical education students, males	8	4.65	65.1	74.4	53	-	27.1	-	193
		0.55	9.2	10.1	12		11.5		9
Reference subjects, males	23	4.06	55.1	66.4	47	62	21.4	29.8	193
		0.54	7.4	8.7	13	17	5.5	8.7	8
Cross-country skiing, females	5	4.03	68.2	86.4	60	61	27.7	29.8	195
		0.15	3.9	9.1	13	4	7.3	9.4	10

With regard to %ST fiber distribution the long-distance runners had the highest mean values of 78 % and 88 % in m. VL and m. GL, respectively. In m. VL the %ST fiber distributions of male and female skiers, speed skaters, nordic combination skiers, canoeists, alpine skiers and ice hockey players were also higher ($p < .05$) as compared to the ordinary reference subjects. The mean values of the skijumpers, 800 m runners and power athletes did not differ significantly from the %ST fiber distribution of the reference subjects.

The SDH activity in m. VL and m. GL of the long-distance runners was higher ($p < .01$) than the mean values of any other group. In addition, only the ice hockey players had, on the average, a higher SDH activity in m. VL than the reference subjects.

The max$\dot{V}_{O_2}$, SDH activity and %ST fiber distribution in m. VL of those reference subjects who were not regularly engaged in physical training were in the mean 49 ml x kg^{-1} x min^{-1}, 17 nM x mg^{-1} prot x min^{-1} and 46 %, respectively.

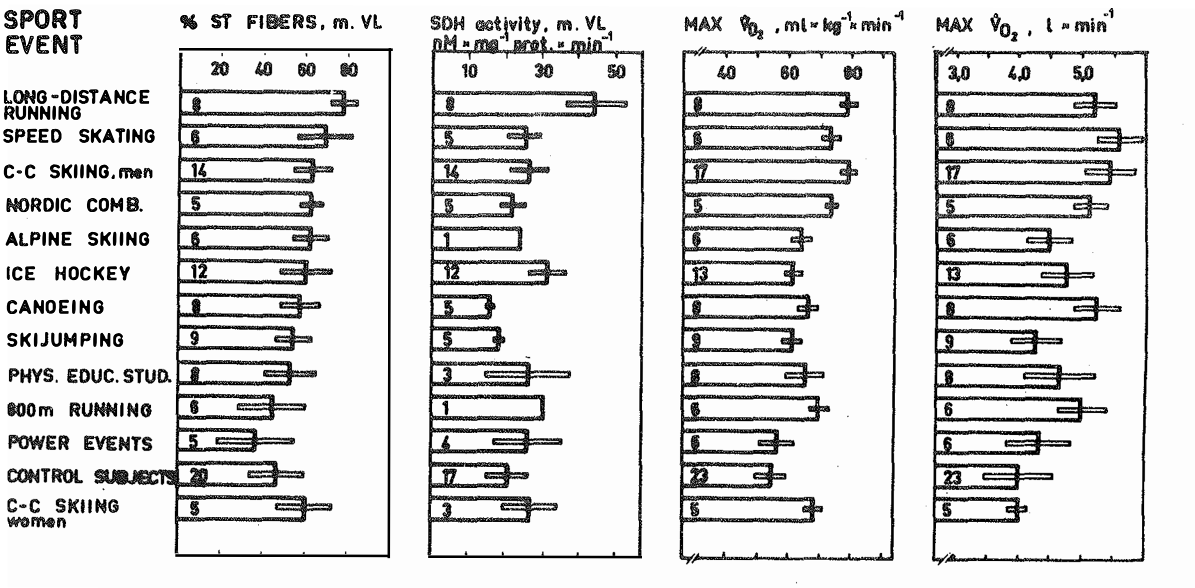
In arm work, the canoeists had the highest max$\dot{V}_{O_2}$ of 4,56 l x min^{-1} and also highest %ST fiber distribution of 71 % in m. deltoideus. The %ST fibers and SDH activity in m. D of the groups studied did not differ significantly from each other (Table 3).

Table 3. Aerobic performance characteristics of the arms (means and standard deviations).

Group	n	Maximal oxygen uptake (STPD) $l x min^{-1}$	Maximal oxygen uptake (STPD) $ml x kg^{-1} x min^{-1}$	%ST fibers in m. D	SDH activity $nM x mg^{-1} prot x min^{-1}$ in m. D	Maximal heart rate	Max$\dot{V}O_2$ %, $\frac{arm}{leg}$x100
Canoeing, males	8	4.56 0.32	59.3 4.5	71 9	20.7 2.5	188 7	88 4
Cross-country skiing, males	17	4.09 0.36	59.0 3.9	69 12	22.7 5.4	184 9	76 5
Nordic combination, males	5	3.54 0.36	50.3 2.5	70 12	19.4 2.3	181 5	69 5
Physical education students, males	3	3.26 0.36	47.7 2.6	57 -	-	187 5	76 5
Reference subjects, males	13	3.00 0.53	38.9 5.5	60 9	17.6 6.3	184 10	73 6
Cross-country skiing, females	5	2.93 0.27	49.8 7.2	69 12	20.7 6.3	187 12	73 9

Figure 1 shows that a relatively good relationship exists between the mean values of max$\dot{V}_{O_2}$, %ST fiber distribution and SDH activity. When calculated from the results of all male subjects the correlations between these variables were as follows: max$\dot{V}_{O_2}$ - %ST fibers $r = .56$ ($p < .001$), max$\dot{V}_{O_2}$ - SDH activity $r = .38$ ($p < .001$) and SDH activity - %ST fibers $r = .39$ ($p < .001$). Within the largest groups (n ≧ 8) the correlations between max$\dot{V}_{O_2}$ and %ST fiber distribution were systematically positive although significantly only in the long-distance runners.

Figure 1. The mean values (±SD) of the main parameters of aerobic performance capacity for the different subject groups.



DISCUSSION

Athletes often have to train for many different functions: e.g. aerobic and anaerobic power, technique. The training of the endurance athletes improves mainly the aerobic components of energy production. The present results show that the max$\dot{V}_{O_2}$ in ml x kg^{-1} x min^{-1} of the pure endurance athletes, male cross-country skiers and long-distance runners, is superior as compared to the other groups.

Because of the smaller body weights and larger fat depots female skiers had a lower max$\dot{V}_{O_2}$ than male reference subjects. When these two factors were "eliminated" by dividing the max$\dot{V}_{O_2}$ by fat-free weight, female skiers had only a 4 % lower mean value than male skiers. This difference is mainly due to the lower hemoglobin values of women (von Döbeln 1956). The SDH activity of male and female skiers were almost equal, too, and these results agree quite well with the observation that the best Finnish female skiers train almost as much as their male colleagues.

In some sport events the weight of the athlete may have a positive effect on the performance in that particular event, because the proportion of work against gravity is relatively small. Max$\dot{V}_{O_2}$ of these athletes (canoeists) is relatively higher in $l \times min^{-1}$ than in $ml \times kg^{-1} \times min^{-1}$. In the present study the correlation coefficients between max$\dot{V}_{O_2}$ and body weight ranged from .53 to .82 within the largest groups ($n \geq 8$), which shows a close relationship between the amount of muscle mass and max$\dot{V}_{O_2}$ also among elite athletes as has been shown with other mostly untrained subjects (e.g. Åstrand 1952, Hermansen 1973). This should be taken into account in the selection of a sport event.

Maximal aerobic power of athletes in different sport events

In previous studies (Hollmann et al. 1964, Saltin and Åstrand 1967, Hermansen 1973) the max$\dot{V}_{O_2}$ of various athletic groups have been higher, as high as or lower than observed in this study. However, the comparisons are not clear because of the differences in the sizes of the groups, in the selection of the athletes and in the timing of the measurements. In this study the athletes were usually tested at the beginning and at the end of the basic training period and a few of them also 1-2 months after the top competitions.

Five of the 17 male cross-country skiers belonged to the Finnish national team in the 1974 World Championships and their max$\dot{V}_{O_2}$ was in the mean 5,65 l x min^{-1} and 82 ml x kg^{-1} x min^{-1}. These values are practically the same as those of 5 Swedish skiers reported by Saltin and Åstrand (1967) and a little higher than the max$\dot{V}_{O_2}$ of 10 Norwegian skiers (Hermansen 1973). Recently Bergh (1974) has reported higher values for Swedish skiers at the time of the Sapporo Olympic Games. According to Hanson (1973) the max$\dot{V}_{O_2}$ of the best American skier is 6,2 l x min^{-1} and 88 ml x kg^{-1} x min^{-1}. The differences are partly due to seasonal variation. For instance the max$\dot{V}_{O_2}$ of one Finnish skier during the investigation period was in the mean 6,3 l x min^{-1} and 88,5 ml x kg^{-1} x min^{-1} but one month after the World Championship in Falun in 1974 his max$\dot{V}_{O_2}$ was 6,5 l x min^{-1} and 92 ml x kg^{-1} x min^{-1}.

The Finnish female skiers had higher max$\dot{V}_{O_2}$ than their Swedish or Norwegian competitors (Saltin and Åstrand 1967, Hermansen 1973, Bergh 1974). The best Finnish man and woman skier during the investigation period were not tested in the present study; they were in similar tests in March 1973 in Stockholm and their max$\dot{V}_{O_2}$ was then 7,4 l x min^{-1} and 77 ml x kg^{-1} x min^{-1} for the male skier and 4,4 l x min^{-1} and 75 ml x kg^{-1} x min^{-1} for the female skier (Bergh 1974). The highest individual value for female skiers in the present study was 4,3 l x min^{-1} and 75 ml x kg^{-1} x min^{-1}.

The max$\dot{V}_{O_2}$ of the long-distance runners is in agreement with the results of best runners in the world, but the 800 m runners seem to have definitely lower max$\dot{V}_{O_2}$ than for instance American and Swedish runners (Saltin and Åstrand 1967, Karlsson et al. 1972, Daniels and Oldridge 1970). Admittedly, the performance level of the Finnish 800 m runners studied was not very high.

The crew of four Finnish canoeists (7th in München 1972) had a mean max$\dot{V}_{O_2}$ of 5,5 l x min^{-1} which is higher than reported for German or Swedish canoeists (Hollmann et al. 1964, Saltin and Åstrand 1967, Gollnick et al. 1972). Speed skaters and ice hockey players seem to have little lower or as high max$\dot{V}_{O_2}$ as compared with values reported in the literature (e.g. Saltin and Åstrand 1967, Seliger et al. 1972, Ekblom et al. 1967, Hermansen 1973).

Maximal aerobic power and oxidative capacity of muscle

On the average, the determinants of oxidative capacity of the muscles (%ST fibers and SDH activity) were highest in those groups whose max$\dot{V}_{O_2}$ was highest (figure 1). This is in agreement with the results of Gollnick et al. (1972). However, based on the correlation coefficients the two muscular factors could explain only 15-30 % of the total variance in max$\dot{V}_{O_2}$ and several exceptions from the general tendency were found both at group and at individual level. For instance, the male skiers and long-distance runners had equal max$\dot{V}_{O_2}$ although their %ST fiber distribution and SDH activity were significantly different. The difference in fiber compositions was even more pronounced between the speed skaters and 800 m runners but nevertheless their max$\dot{V}_{O_2}$ values were practically the same. Ice hockey players had a twofold SDH activity and higher %ST fibers in m. VL as compared with canoeists; however, they had lower max$\dot{V}_{O_2}$ than canoeists.

These results seem to support the hypothesis that the oxidative capacity of the muscles is not the limiting factor for maximal oxygen uptake, which might then more likely be limited by central or local factors of circulation. Gollnick et al. (1972 and 1973) have shown that differences in enzyme activity of skeletal muscles due to endurance training are not in proportion to differences in max$\dot{V}_{O_2}$ and that changes in enzyme activity occur after a relatively short period (5 months) of training. According to Holloszy et al. (1967) and Holloszy (1973) the changes in oxidative capacity are probably more important during submaximal than maximal work and they may contribute to a greater oxidation of fat and lower production of lactate as a result of endurance training. The high SDH activity and %ST fiber distribution of the long-distance runners partly support this hypothesis. On the contrary, the SDH activity of the cross-country skiers was relatively low, which might be interpreted as follows. When a relatively small muscle mass is activated the role of local factors of aerobic performance capacity is pronounced (runners) whereas when almost all muscles are working (cross-country skiing) the factors of circulation and max$\dot{V}_{O_2}$ become increasingly more important (e.g. Gleser et al. 1974).

The correlation between %ST fiber distribution and SDH activity in the whole sample of male subjects was significantly positive. However, none of the correlations in the largest groups of athletes were significant. Indirectly this indicates a high SDH activity both in ST and in FT fibers as suggested also by Gollnick et al. (1974). In long-distance runners and ice hockey players the correlations were slightly negative which might indicate even higher oxidative capacity in FT fibers. The FT fibers may be recruited and activated either during long-lasting and exhaustive submaximal exercises or during short maximal bursts of activity (e.g. Saltin 1973, Piehl 1974) and the training of long-distance runners and ice hockey players agrees quite well with these two exercise regimens. The oxidative capacity of the whole muscle and especially of the FT fibers could thus be increased by at least two types of training programs and the amount of work done by the muscle might be the most important factor.

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