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HEIKKI RUSKO

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UNIVERSITY OF JYVÄSKYLÄ, JYVÄSKYLÄ 1976

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CONTENTS

PREFACE

The present publication is based on studies reported in the following papers, which are being referred to by their Roman numerals:

I Komi, P., Rusko, H., Vos, J. and Vihko, V., Anaerobic performance capacity in athletes. Research reports from the Department of Biology of Physical Activity, No 8. University of Jyväskylä, Jyväskylä 1976.

II Rusko, H., Havu, M. and Karvinen, E., Aerobic performance capacity in athletes. Research reports from the Department of Biology of Physical Activity, No 9. University of Jyväskylä, Jyväskylä 1976.

III Arstila, A. and Rusko, H., Fitness profiles of elite Finnish athletes. Research reports from the Department of Biology of Physical Activity, No 10. University of Jyväskylä, Jyväskylä 1976.

IV Rusko, H., Arstila, A. and Hirsimäki, Y., Aerobic and anaerobic performance capacity of junior athletes. Research reports from the Department of Biology of Physical Activity, No 11. University of Jyväskylä, Jyväskylä 1976.

V Rusko, H., Vihko, V. and Komi, P., Seasonal and annual changes in physical performance capacity of elite athletes. Research reports from the Department of Biology of Physical Acitivity, No 12. University of Jyväskylä, Jyväskylä 1976.

The studies were carried out at Muscle Research Center, Department of Biology of Physical Activity and Department of Cell Biology, University of Jyväskylä, Finland. The studies are the result of extensive and stimulating teamwork and there are several persons to whom I wish to express my sincere gratitude:

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Jyväskylä, June 1976

Heikki Rusko

1. INTRODUCTION

The studies of various characteristics of athletic populations have had two main lines: morphological description of the athletes (body size and type, amount of body fat, heart size, blood properties, muscle fiber composition, etc.)and functional analysis of the athletes (oxygen uptake, cardiac output, lactate production, phosphagen depletion, muscle force etc.). It is obvious that the physical performance of the athlete depends on a variety of factors, which "operate" at the whole body level, at the level of organs and at the level of tissues and cells. Åstrand and Rodahl (1970) have classified the determinants of physical performance into energy output (aerobic and anaerobic), neuromuscular function (strength and technique) and psychological factors. With respect to athletic training physiological studies should clarify which are the requirements of different sports, how the athletes fit to these requirements and what kind of training programs change the performance characteristics of the athletes in the desired directions.

During prolonged heavy physical work the athlete's performance depends largely on his ability to take up, transport and deliver oxygen to the working muscles. The maximal oxygen uptake or maximal aerobic power is theoretically a good measure of cardiorespiratory performance because it integrates all processes concerned in the oxygen transfer. It has also been used to study aerobic performance capacity of the athletes (e.g. Hollman et al. 1964; Saltin and Åstrand 1967). The prolonged work capacity of the athletes might also include the availability of substrates in the working muscles and in blood and the proper regulation of various functions of the body (for ref. see Åstrand and Rodahl 1970). Recently Gollnick et al. (1972) have shown that the determinants of muscle tissue and muscle fibers may also differentiate the athletes from one another: the endurance athletes have predominantly slow twitch fibers and high oxidative enzyme acitivities in their muscles, whereas the "power athletes" have more fast twitch fibers in their muscles. In actual sport performances these fibers may also be selectively recruited (e.g. Saltin 1973).

During high intensity work of short duration the athlete's performance depends on the anaerobic energy output including depletion of phosphagen stores and anaerobic glycolysis (e.g. Margaria et al. 1933; Margaria 1967; Hultman et al. 1967; Karlsson 1971). Although the breakdown of glycogen to pyruvic and lactic acid might be very important in fierce competitions, only little information exists on the anaerobic power and capacity of the athletes (Hermansen 1969; Karlsson et al. 1972).

From the neuromuscular factors strength is not particularly difficult to measure and relatively much information has been gathered on different athletic populations with respect to muscle strength. However, because of the different methods of measurement the results can seldom be compared.

The purpose of the present study is to develop a versatile battery of tests in order to characterize the various determinants of physical performance in elite Finnish athletes. More specifically the aims may be summarized as follows:

1. to evaluate the physical performance characteristics of elite athletes and to study the relationships between these characteristics.
2. to analyze the physiological requirements of different sport events.
3. to evaluate the physical performance characteristics of elite junior athletes.
4. to follow-up the seasonal and annual changes in the physical performance characteristics of elite athletes during their normal course of training.

In general, problem No 1 is dealt with in papers I, II and III, problem No 2 in paper III, problem No 3 in paper IV and problem No 4 in paper V.

2. RESEARCH METHODS

2.1. Subjects

The subjects were 89 adult and 58 junior athletes and 38 reference subjects. Fifty athletes participated in the follow-up study described in paper V. The sport events and physical characteristics of these subjects are seen in Table 1. Many of the athletes were members of the Finnish national teams in the Olympic Games, in World Championships and in European Championships between 1972 and 1976. All of the adult athletes have been in regular training for several years and some of them for more than ten years. Large individual differences were observed in the quantity and quality of training of the junior athletes. The athletes were chosen by national sport federations and recommended to the tests by the Finnish Olympic Committee. Thus the athletes were judged to represent the best Finnish athletes in their own sport events.

Only the best adult athletes were included in the calculations of the fitness profiles (problem No 2, paper III). These athletes were as follows: four male and five female cross-country skiers, four skijumpers, four canoeists, four nordic combination skiers, six ice hockey players, four long-distance runners, six 800 m runners, six alpine skiers, six power athletes and six speed skaters. These athletes were among the best of Finnish athletes in their own particular sport event. Almost all of them had belonged to the Finnish national teams and most of them had been successful in international competitions.

The reference subjects were divided into three groups. The 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

TABLE 1. Physical characteristics of the groups studied (mean and standard deviation)

Group	n	Age yrs	Height cm	Weight kg	FFW[xx] kg	Fat%[x]
I ADULT SUBJECTS						
Power events,	6	23.4	176	76.3	63.1	13.0
males		4.1	5	6.4	5.3	3.4
800 m running,	6	24.6	179	72.3	62.9	12.4
males		2.2	4	4.6	4.5	1.4
Skijumping,	9	22.2	174	69.9	59.7	14.3
males		2.4	5	8.5	5.2	3.7
Canoeing,	8	23.7	182	79.6	68.9	12.4
males		4.2	5	6.5	4.4	2.8
Ice hockey,	13	22.5	171	77.3	65.3	13.0
males		3.5	3	5.7	4.7	2.7
Alpine skiing,	6	21.2	176	70.1	60.8	14.1
males		2.4	6	8.0	5.9	3.0
Nordic combination,	5	22.9	176	70.4	62.0	11.2
males		2.1	5	5.7	5.0	1.4
Cross-country skiing,	17	25.6	174	69.3	60.3	10.2
males		3.2	4	5.2	4.5	2.4
Speed skating,	6	21.0	181	76.5	65.7	11.4
males		2.9	4	1.7	1.7	2.3
Long-distance running,	8	26.2	177	66.2	60.9	8.4
males		2.8	4	3.2	3.0	1.5
Physical education	8	25.6	178	71.7	62.8	11.0
students, males		4.8	7	5.7	5.0	2.7
Reference subjects,	23	30.3	176	75.0	61.6	14.4
males		6.5	7	11.8	8.4	3.0
Cross-country skiing,	5	24.3	163	59.1	47.0	21.8
females		4.0	8	5.2	4.8	3.7
Reference subjects	7	24.8	164	57.5	45.6	22.8
females		6.0	7	5.5	3.3	2.4
II JUNIOR ATHLETES						
Cross-country skiing,	31	18.7	177.3	66.6	59.9	10.2
males		1.8	5.0	6.4	4.6	1.9
Long distance running,	10	18.8	177.8	63.0	57.2	9.3
males		1.9	6.1	6.4	5.3	1.7
Short distance running,	12	18.0	177.3	65.0	58.0	10.4
males		1.9	6.3	6.2	5.8	1.8
Skijumping,	3	17.9	175.0	67.5	59.1	10.7
males		1.9	5.2	2.5	3.3	1.5
Cross-country skiing,	7	18.3	165.2	56.9	44.6	21.8
females		1.4	7.2	8.6	5.4	2.2

x According to Durnin and Rahaman (1967).

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

education students (8) had trained and competed without any special success in their own sport specialities. The female reference subjects (7) were three physical education students, two physiotherapists, one dentist and one clerical worker and all of them had trained regularly according to their own fitness programs.

2.2. Methods and procedures

The measurements of this study were made between the spring of 1973 and the winter of 1976. The yearly measurement times were in the spring during May-June, in the autumn during September-October and in the winter during January-February-March. These times correspond to the beginning of the basic training period (spring), a change from basic trainig period to special training period (autumn) and to the competitive season (winter). Thus altogether 9 test occasions were organized and the athletes visited the laboratory and were tested from 1 to 6 times.

The following parameters were investigated on most of the subjects: maximal aerobic power or maximal oxygen uptake (max $\dot{V}O_2$) and maximal heart rate during and blood lactate after treadmill running and arm ergometer work on a mechanically braked bicycle ergometer, vertical velocity (V_v) and muscular power (MP) during running up the stairs, total and relative leg and arm forces, percentage of slow twitch fibers (%ST fibers) and activity of succinate dehydrogenase (SDH), lactate dehydrogenase (LDH) and creatine phosphokinase (CPK) in skeletal muscle tissue. Furthermore, the following anthropometric variables were determined: height, weight, fat-free body weight (FFW) calculated as a mean of skeletal and skinfold estimations (von Döbeln 1959; Durnin and Rahaman 1967) and the percentage and total amount of body fat from subscapular, triceps, biceps and suprailiac skinfolds (Durnin and Rahaman 1967).

The treadmill running and arm ergometer work were performed in a special laboratory where the temperature and humidity could be controlled between 18-21 °C and 40-60 %, respectively. Maximal oxygen uptake during running on a treadmill was determined for all subjects. After ten minutes of warming up and short rest the inclination of the treadmill was increased by one degree every two minutes until exhaustion. For subjects with high aerobic capacity steps of two degrees were used to start with. The treadmill speed was selected according to the fitness of the subjects so that they were exhausted in after about 8-12 minutes. In some groups whose athletic speciality involved extensive use of the arms the maximal oxygen uptake was measured also while cranking a bicycle ergometer with the hands and the arms. After ten minutes' warming up and short rest the subject began to crank the bicycle at 50 rpm and the work load was increased every two minutes by 150 kpm x min^{-1}. The first work load was selected so that the subjects became exhausted in after about 8-12 minutes.

Oxygen uptake was measured during the last two or three working minutes by using the Douglas bag method. The subjects breathed through an Otis-McKerrow respiratory valve. The connecting tube between the valve and the stopcock of Douglas bags was smooth and not corrugated, with an inner diameter of 35 mm. The inner diameters of the stopcocks and tubes of the Douglas bags were 25 mm. The volume of the expired air was determined with calibrated dry and wet gas meters. The gas analyses were performed with the Scholander technique. Oxygen consumption was calculated and corrected for STPD according to Consolazio et al. (1963). The highest oxygen uptake value was recorded as max $\dot{V}_{O_2}$ in each test. The error of the method in double determinations of maximal aerobic power was calculated earlier (Rusko 1972) on 15 physical education students and it was 0.12 l x min^{-1} or 2.9 %.

Heart rate was registered with a one-channel electrocardiograph throughout the treadmill running and arm ergometer tests at the end of each minute and at exhaustion. The heart rates were calculated from ten heart beats and the highest value was recorded as maximal heart rate.

Blood lactate concentration was measured from two capillary blood samples taken from a fingertip about 3 and 5 minutes after maximal treadmill running and arm ergometer tests, and the highest values were selected to represent the maximal blood lactate concentrations. The enzymatic method with reagents and instructions of Biochemica Boehringer was used. The error of the method in double determinations of maximal blood lactate from duplicate blood samples was 5,2 % (Rusko 1972).

Vertical velocity of the subjects was measured according to the method of Margaria et al. (1966). The subjects ran up the stairs two steps at a time at their maximal speed. The running velocity was recorded using photocells and an electronic timer when a steady speed was achieved after four steps. The recorded speed was converted to vertical velocity ($m \times sec^{-1}$) and muscular power ($kg \times m \times sec^{-1}$). The relative power index (RPI) was obtained by dividing the estimated theoretical oxygen cost of running by the measured maximal aerobic power (Margaria et al. 1966).

Muscle force of extensor muscles of both legs and in some cases of the right elbow were measured isometrically in standard positions using special dynamometers (Komi 1973 a, b). The angles of the knees and the elbow were 107 and 94 degrees, respectively. The relative leg force was calculated by dividing the total force by body weight.

Muscle fiber composition and enzyme activities were assayed in muscle biopsies taken according to Bergström (1962) in most cases from m. vastus lateralis (VL) and in some cases also from m. gastrocnemius c.l. (GL) and m. deltoideus (D). For classification of muscle fibers into slow twitch (ST) and fast twitch (FT) types myosin ATPase staining was used according to Padykula and Herman (1955) and Gollnick et al. (1972). The percentage of ST fibers (%ST fibers) was calculated from the numbers of ST and FT fibers and usually 200-300 fibers were counted. Part of the muscle sample was weighed, homogenized and used for SDH activity (Pennington 1961), LDH activity (Kornberg 1955), CPK activity (Biochemica Boehringer test combination 1972) and protein content (Lowry et al. 1951) determinations. SDH activity was expressed as nM substrate reduced x mg^{-1} muscle protein x min^{-1} at 37 °C and LDH and CPK activities as µM substrate oxidized x mg^{-1} muscle protein x min^{-1} at 22 °C.

2.3. Statistics

Ordinary statistical methods were used to calculate mean, SD and SE. The error of the methods was estimated from SD of a single experiment as calculated from duplicate determinations. The product-moment correlation coefficients and least squares' regression lines were calculated when the relationships between different parameters were studied.

The statistical significance was tested by means of Student's t-test for paired and unpaired samples and for correlation coefficients. The level of significance is indicated with p-values.

3. RESULTS

3.1. The performance characteristics and their relationships in top level athletes (paper I, II, III)

The means values for the main variables in the different groups of adult subjects are seen in Figure 1 and 2. Both the male cross-country skiers and the long-distance runners had the highest max $\dot{V}O_2$ of 78 ml x kg^{-1} x min^{-1} in leg work. The female cross-country skiers had 13 % lower mean value

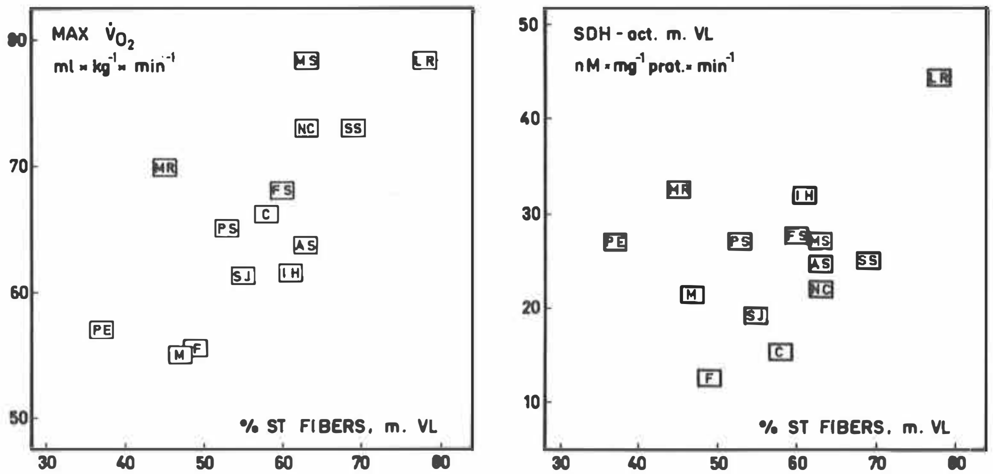

FIGURE 1. The mean values for maximal oxygen uptake and %ST fibers in m. VL (left) and for SDH activity and %ST fibers in m. VL (right) in the different groups studied.

The letters inside the symbols denote power events (PE), 800 m running (MR), skijumping (SJ), canoeing (C), ice hockey (IH), alpine skiing (AS), nordic combination (NC), male cross-country skiing (MS), speed skating (SS), long-distance running (LR), physical education students (PS), male reference subjects (M), female cross-country skiing (FS) and female reference subjects (F).

than the above groups, but when max $\dot{V}O_2$ was expressed in ml x kg^{-1}FFW x min^{-1} the female skiers ranked second after male cross-country skiers and before long-distance runners and other male athlete groups. The skijumpers and power athletes had practically the same max $\dot{V}O_2$ as the male reference subjects (55-61 ml x kg^{-1} x min).

The %ST fibers in m. VL (78 %) and m. GL (88 %) of the long-distance runners were recorded highest. The male cross-country skiers, speed skaters, nordic combination skiers, canoeists, alpine skiers and ice hockey players (58-69 %) had also significantly higher %ST fibers in m. VL than the male reference subjests. The power athletes had lowest mean value of 37 % but it did not differ significantly from the mean %ST fibers of the male reference subjects (47 %).

The SDH activities in m. VL and m. GL of the long-distance runners (44.6 and 53.1 nM x mg^{-1}prot x min^{-1}) were significantly higher than the mean values in any other group (Figure 1). In addition, only the ice hockey players (31.8 nM) and the female cross-country skiers (27.7 nM) had, on the average, higher SDH activity in m. VL than the male (21.4 nM) or female (12.5 nM) reference subjects.

In arm work the canoeists had the highest max $\dot{V}O_2$ of 4.56 l x min^{-1} (88 % of that in leg work) and they had also the highest %ST fibers in m. D, 71 %. The %ST fibers and SDH activities in m. D of the groups studied did not differ significantly from one another.

The mean vertical velocity of the power athletes, ice hockey players and speed skaters exceeded 1.50 m x sec^{-1} and was significantly higher than the mean value of the male reference subjects (1.32 m x sec^{-1}). The cross-country skiers, long-distance runners and nordic combination skiers had lower mean values as compared with the male reference subjects (Figure 2). The muscular power demonstrated a similar pattern. The power athletes and ice hockey players had slightly higher RPI and the above endurance oriented athletes significantly lower RPI than the male reference subjects.

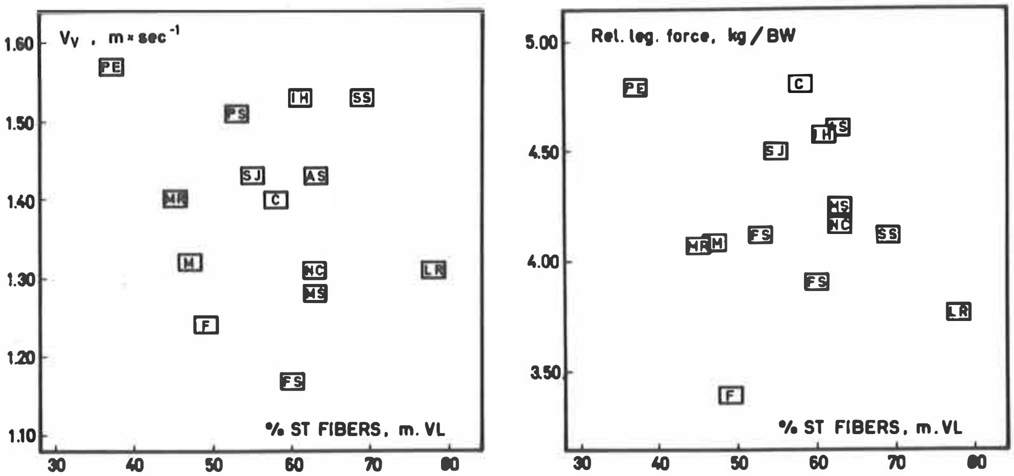

FIGURE 2. The mean values for vertical velocity and %ST fibers in m. VL (left) and for relative leg force and %ST fibers in m. VL (right) in the **different** groups studied. The letters inside the symbols denote the different groups of subjects, see Figure 1.

The total and relative leg forces were recorded highest in power athletes, canoeists, ice hockey players, skijumpers and alpine skiers (Figure 2).

Power athletes, 800 m runners, canoeists and alpine skiers had highest and almost equal blood lactate concentrations (13.2-13.8 mM) after the maximal treadmill running test. The mean values for the other groups ranged from 9.0-11.8 mM.

When the performance characteristics of the male athletes were intercorrelated (see also Figures 1 and 2) following significant correlations were found between the various parameters of aerobic performance capacity: max $\dot{V}O_2$ correlated with %ST fibers in m. VL ($r = .48$, $p < .001$) and with SDH activity in m. VL ($r = .38$, $p < .001$) and SDH activity correlated with %ST fibers ($r = .39$, $p < .001$).

When the different variables of anaerobic performance capacity were intercorrelated it was observed that both vertical velocity and relative leg force correlated with %FT fibers in m. VL ($r = .37$, $p < .001$ and $r = .38$, $p < .001$, respectively). Vertical velocity demonstrated also significant relationships with the enzymes LDH ($r = .43$, $p < .01$) and CPK ($r = .34$, $p < .05$) in the subgroup of skijumpers, alpine skiers, nordic combination skiers and male cross-country skiers. In addition to these correlations, blood lactate after maximal treadmill running correlated significantly with the %FT fibers in the male athletes ($r = .24$, $p < .05$).

From the variables between aerobic and anaerobic performance capacity max $\dot{V}O_2$ correlated negatively with vertical velocity ($r = -.55$, $p < .001$), relative leg force ($r = -.26$, $p < .05$) and LDH activity ($r = -.52$, $p < .01$). Furthermore, SDH activity correlated negatively with relative leg force ($r = -.30$, $p < .05$), and LDH activity ($r = -.42$, $p < .05$). The relative power index correlated with %ST fibers ($r = -.38$, $p < .001$).

3.2. The physiological requirements of the different sport events (paper III)

The best male cross-country skiers and long-distance runners had almost equal fitness profiles. They differed from the male reference subjects by having slightly smaller body weights and 20-60 % smaller fat depots. With respect to the anaerobic and neuromuscular variables, these two athlete groups had practically the same values as compared with the reference subjects: only the leg forces of the athletes tended to be lower than the mean values of the reference subjects. The male cross-country skiers and the long-distance runners had 30-60 % higher values in maximal oxygen uptake than the reference subjects and the skiers tended to have a little higher values than the runners. With respect to the %ST fibers and SDH activity in m. VL, the best long-distance runners had higher values than the best male skiers, who also had higher mean values as compared with the reference subjects. The RPI was in both groups smaller than the mean value of the reference subjects. In arm work the maximal oxygen uptake of the male cross-country skiers was 30-60 % higher than that of the reference subjects.

The profile of the best nordic combination skiers agreed fairly well with the profiles of the above endurance athlete groups. The nordic combination skiers had slightly higher fat depots, smaller maximal oxygen uptake both in leg and arm work, lower %ST fibers and lower SDH activity in m. VL than the best male cross-country skiers and long-distance runners.

The profile of the female cross-country skiers was compared with the profile of the male cross-country skiers. With respect to the percentage and total amount of body fat, maximal aerobic power both in leg and arm work and %ST fibers in m. VL the female skiers differed less from the female reference subjects than the male skiers from the male reference subjects. On the contrary, the SDH activity in m. VL of the female skiers differed much more than that of the male skiers from the values of their reference subjects.

The best ice hockey players were characterized by high leg forces, vertical velocity and muscular power. They also had higher maximal oxygen uptake and SDH activity in m. VL than the reference subjects.

The best speed skaters differed from the reference subjects by having higher vertical velocity and muscular power as well as higher maximal oxygen uptake and %ST fibers in m. VL. Their body fat, blood lactate and relative power index were slightly lower than those of the reference subjects.

The best canoeists differed from the reference subjects in several characteristics. Their height, weight, fat-free weight, leg forces, muscular power and blood lactate values as well as %ST fibers and relative power index differentiated them from the reference subjects. Furthermore, their maximal oxygen uptake exceeded the corresponding value of the reference subjects both in leg and especially in arm work.

The 800 m runners had higher blood lactate, maximal oxygen uptake and SDH activity in m. VL and lower RPI than the reference subjects. The runners also tended to have lower fat depots, higher vertical velocity and higher maximal heart rate than the reference subjects.

The alpine skiers differed from the reference subjects mainly by having higher vertical velocity, blood lactate, maximal oxygen uptake and %ST fibers.

The power athletes and skijumpers had higher vertical velocity than reference subjects.

3.3. The junior athletes (paper IV)

In cross-country skiing (Table 2) the male juniors did not differ significantly from the adult male skiers with respect to the relative leg force, max $\dot{V}_{O_2}$ in arm work and SDH activity in m. VL. Instead, the juniors had significantly lower %ST fibers in m. VL and max $\dot{V}_{O_2}$ in leg work than the adult skiers. In vertical velocity the juniors had 9.8 % higher mean value than the adult male cross-country skiers. The mean values of the female juniors in the main parameters were 79.0-105.6 % from the corresponding values of the adult female cross-country skiers but the differences were not significant.

The junior long-distance runners had significantly lower %ST fibers and SDH activity in m. VL than adult runners. With respect to the other main parameters the differences were small and insignificant.

The junior short-distance runners did not differ significantly from the adult 800 m runners although their mean values ranged from 85.2 % to 112.2 % from the corresponding mean values of the adult runners.

TABLE 2. Physical performance characteristics in junior and adult athletes (mean and standard deviation)

Groups		n	Vertical velocity $m \times sec^{-1}$		Relative leg force kg/BW		Max $\dot{V}O_2$ $ml \times kg^{-1} \times min^{-1}$ legs		arms		%ST fibers m. VL		SDH act. m.VL $nM \times mg^{-1}$ prot $\times min^{-1}$	
			$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Cross-country	adults	17	1.28	0.11	4.24	0.57	78.3	4.0	59.0	3.9	63.4	9.2	27.0	5.3
skiing, males	juniors	31	1.40^x	0.09	4.13	0.95	74.6^x	6.6	57.3	7.8	57.7^x	9.8	26.4	9.5
Cross-country	adults	5	1.17	0.07	3.90	1.28	68.2	3.9	49.8	7.2	60.0	12.9	27.7	7.3
skiing, females	juniors	7	1.17	0.17	3.46	0.60	67.2	3.8	49.5	4.2	63.4	4.6	21.9	7.5
Long-distance	adults	8	1.31	0.07	3.77	0.59	78.1	3.5	-	-	78.5	5.8	44.6	8.2
running, males	juniors	10	1.35	0.09	3.63	0.74	75.0	4.6	-	-	65.7^x	7.7	31.0^x	9.6
800 m running	adults	6	1.40	0.20	4.06	1.06	69.8	4.5	-	-	45.3	16.9	32.5	-
Short-distance running, males	juniors	12	1.47	0.08	3.80	0.79	69.7	4.2	-	-	50.5	11.5	27.7	9.4
Skijumping,	adults	9	1.43	0.10	4.49	0.59	61.3	4.3	-	-	55.4	8.0	19.0	1.2
males	juniors	3	1.33	0.19	5.88^x	0.65	58.5	8.8	-	-	52.3	7.4	26.7	11.0

x significant difference between adult and junior athletes.

The junior skijumpers had significantly higher relative leg force than the adult skijumpers. The SDH activity in m. VL of the junior skijumpers differed also considerably from the SDH activity in the adult skijumpers, but because of large standard deviation the difference was not significant.

In correlation analysis it was found that the age of the male junior athletes correlated significantly with the maximal oxygen uptake in $ml \times kg^{-1} \times min^{-1}$ ($r = .39$, $p < .01$), %ST fibers in m. VL ($r = .25$, $p < .05$), SDH activity in m. VL ($r = -.29$, $p < .05$) and with the relative power index ($r = .28$, $p < .05$). When the age of the juniors was kept constant using the partial correlation methods it was found that the relative leg force correlated negatively with the maximal oxygen uptake ($r = -.37$, $p < .05$) and positively with the relative power index ($r = .33$, $p < .05$).

The relationship between age and %ST fibers was studied in more detail by including all endurance oriented athletes or short performance athletes studied in the calculations. The correlation between age and %ST fibers in m. VL of the endurance oriented athletes (male and female cross-country skiers and long-distance runners) was .46 ($p < .001$), among the short performance athletes (running 800 m or shorter distances, skijumpers, jumpers, throwers) the same correlation was -.39 ($p < .05$).

3.4. The annual and seasonal changes (paper V)

In adult male skiers the following significant changes were observed after one year of training: increase in fat-free weight, maximal oxygen uptake in arm work, SDH activity in m. VL and decrease in the fat percentage of the body. In addition, after two years of training, body weight, maximal oxygen uptake in leg work, max $\dot{V}O_2$ ratio (arms/legs), maximal heart rate in arm and leg work and muscular power had increased and the amount of body fat had decreased significantly. In female skiers the significant changes after one or two years of training were increase in height, body weight and fat-free body weight as well as decrease in the fat percentage and maximal heart rate during arm work. The male junior skiers had significantly higher height, body weight, fat-free weight, maximal oxygen uptake in leg work, SDH activity in m. VL, total and relative leg force , vertical velocity and muscular power after one year of training. After two years of training the same trend continued. The nordic combination skiers had increased significantly their total and relative leg force , vertical velocity, muscular power, relative power index and SDH activity in m. VL during one year of training, and after two years of training their fat-free weight had increased, too. After one year of training the skijumpers had significantly higher total and relative leg force , vertical velocity, muscular power and relative power index.

The mean seasonal and annual changes in percents for the main parameters (Table 3) show that the maximal oxygen uptake of the cross-country skier groups had increased by 4.7-9.9 % in leg work and by 5.6-17.0 % in arm work from spring to winter. The mean annual increases were 3.1-4.6 % and 3.9-5.9 %, in leg max $\dot{V}O_2$ and arm max $\dot{V}O_2$, respectively. The SDH activity in m. VL of the male and female cross-country skiers increased by 32.7 % and 40.3 %, from spring to winter, respectively. The female, adult male, male junior and nordic combination skiers increased their SDH acitivity in m. VL annually by 16.2 %, 29.8 %, 35.9 % and 42.5 %, respectively. No significant changes were observed in %ST fiber distribution in m. VL during the investigation period.

TABLE 3. The mean percentage seasonal (S, from spring to winter) and annual (A) changes in maximal oxygen uptake (max $\dot{V}O_2$, l x min^{-1}) in arm and leg work, vertical velocity (V_v, m x sec^{-1}), total leg force (kg) and SDH activity in m. VL (nM x mg^{-1}prot x min^{-1})

	Percentage change in									
	Max $\dot{V}O_2$ legs		Max $\dot{V}O_2$ arms		V_v		Total leg force		SDH act., m. VL	
	S	A	S	A	S	A	S	A	S	A
Male cross-country skiers	4.7	3.3	5.6	5.9	2.5	4.2	2.3	4.9	32.7	29.8
Female cross-country skiers	6.7	3.1	6.7	4.2	7.3	1.7	20.5	9.1	40.3	16.2
Junior male cross-country skiers	9.9	4.6	17.0	3.9	1.9	4.5	17.3	14.9	-	35.0
Nordic combination skiers	-	1.7	-	5.7	-	16.1	-	24.8	-	42.5
Skijumpers	-	-0.8	-	-	-	8.3	-	29.1	-	-

The nordic combination skiers and skijumpers increased annually their vertical velocity by 16.1 % and 8.3 %, respectively. The annual changes in total leg force of the nordic combination skiers and skijumpers were 24.8 % and

29.1 %, respectively. The total leg forces of the female and male junior cross-country skiers increased both from spring to winter (20.5 % and 17.3 %, respectively) and annually (9.1 % and 14.9 %, respectively).

The effects of %ST fibers and initial level of each performance characteristics were studied by dividing each group of athletes into two subgroups on the basis of the following: those whose values were below group average and those whose values were above average. The initial level of maximal oxygen uptake, vertical velocity, total and relative leg force, and SDH activity in m. VL had no significant relationship to the annual increases in each parameter. Instead, those whose %ST fibers in m. VL were above average were able to increase their maximal oxygen uptake annually more ($p < .05$) than those whose %ST fibers were below average in each group. When only athletes competing in cross-country skiing were included the tendency was the same.

4. DISCUSSION

In order to attain some of the goals set for the study an extensive battery of tests was selected to describe the various characteristics of physical performance capacity.

The results of the best athletes in each sport event were used the analyze the requirements of the different sport events. The correlation coefficients between the various performance characteristics and ranking order in actual sport performance were also calculated (paper III). On the basis of these results each sport event seemed to have its own specific requirements. For instance, even the pure endurance events, cross-country skiing and long-distance running, seemed to differ from each other: the maximal oxygen uptake was a characteristic required especially in cross-country skiing whereas the oxidative capacity of the muscles was needed more in long-distance running more than in cross-country skiing.

Inspite of the specific demands of the different sports, the events could be classified into four subgroups. The "aerobic endurance" events include cross-country skiing, long-distance running and nordic combination. They are all characterized by high demands for the aerobic performance capacity but by no extra demands for the neuromuscular or anaerobic components of performance capacity. At the end of the investigation period the nordic combination skiers had improved their leg force and vertical velocity so much that their sport event might more likely be classified into "speed-endurance" events. The canoeists, 800 m runners and alpine skiers might be classified into "anaerobic endurance" athletes. They attained high blood lactate concentration in the maximal treadmill running test and, furthermore, they had high aerobic performance capacity. The third group of events, ice hockey and speed skating, were classified into "speed-endurance" events. The vertical velocity and muscular power differentiated them from the reference group as well as some characteristics of the aerobic performance capacity. The skijumpers and the power athletes form the fourth group of events: power events. Only the anaerobic-neuromuscular factors tended to differentiate these athletes from the reference subjects.

If the above classification is applied to training it could be interpreted so that the basic principles of training might be the same in each group of events. However, the specific demands of each sport event should be taken into account especially during the special training period. Although the selected battery of tests is rather manysided, one should remember that there are several important determinants of physical performance which were not measured in this study.

The mean values of the different groups and the correlation coefficients between various parameters suggest that the neuromuscular factors are opposite characteristics of aerobic performance capacity both at whole body level and at muscle tissue level. An explanation to this might be the specificity of training in each sport event, which improves the trained characteristics while the others remain unchanged. The untrained characteristics may also weaken as a result of specialized training (Gordon 1967). The low LDH activity, leg force and vertical velocity values of the endurance athletes support this hypothesis. Previous studies have also confirmed that the endurance athletes may have lower total LDH activity than untrained subjects (Karlsson et al. 1974 ; Suominen and Heikkinen 1975) and that "aerobic" training may lead to a decrease in total LDH activity and to changes in LDH isozyme pattern (Sjödin et al. 1976). In some sport events several aspects of physical performance capacity are needed. The most prominent examples in this study were canoeing, ice hockey and at the end of the study also nordic combination, which all were characterized by high muscle force and vertical velocity as well as by high aerobic power.

All main parameters describing the neuromuscular, anaerobic and aerobic aspects of physical performance capacity at whole body level were related to the %ST fiber distribution of thigh muscle. Among the neuromuscular factors the running velocity seems to be more clearly than muscle strength influenced by activity of enzymes involved in rapid ATP resynthesis (present study, Komi et al. 1973 and 1976; Thorstensson et al. 1975). However, strength training may also increase enzyme acitivity (Thorstensson and Karlsson 1974) but they possibly remain proportional to the increases in contractile proteins in the muscle (e.g. Gordon 1967).

The parameters of aerobic energy output (max $\dot{V}O_2$, %ST fibers, SDH activity) were all related to one another and the correlation was highest between max $\dot{V}O_2$ and %ST fibers. This is in agreement with the previous results of Gollnick et al. (1972) and Forsberg et al. (1975) and it might indicate that the same genetic factors determine both of these characteristics.

However, the two determinants of the oxidative capacity of the muscles could explain only 15-30 % of the total variance in max $\dot{V}_{O2}$, which might then more closely be relatd to the factors of circulation. The determinants of the oxidative capacity of the muscles are probably more important during prolonged submaximal work when a relatively small muscle mass is working (long-distance running). On the contrary, maximal oxygen uptake might be more important during maximal work of several minutes' duration when a relatively large muscle mass is working (cross-country skiing). The SDH actitivy of the muscles has been estimated to be sufficient for attaining high maximal oxygen uptake (Gollnick et al. 1972) and the increases in SDH activity during training have been shown to exceed the increases in max $\dot{V}_{O_2}$ (present study, Gollnick et al. 1973). However, as discussed by Holloszy (1973), a relatively higher increase in enzyme activity is needed if the muscles are hypoxic during work and if the hypoxia becomes more marked after training.

Previous studies have shown that the %ST fibers does not change after short periods of endurance (Eriksson 1972; Gollnick et al. 1973; Kiessling et al. 1975), strength (Thorstensson and Karlsson 1974) and sprint training (Thorstensson et al. 1975). In the present study one or two years of training, either endurance type (cross-country skiing) or strength type (skijumping, nordic combination), did not change the %ST fibers of the athletes. Recently, Komi et al. (1976) have shown that the fiber composition of skeletal muscles is determined solely by heredity. Because max $\dot{V}_{O_2}$ and running velocity are also influenced by genetic factors (Klissouras 1971; Komi et al. 1973 and 1976), the top level athletes are most likely products of strong genetic selection. In childhood and during adolescence a natural selection of junior athletes occurs on the basis of one or more "favourable" characteristics related to the performance in the specific sport events. In national level competitions and in sport events which require several components of performance capacity the athletes with weaker genetic potentials may complete succesfully. However, on international level the athletes must possess all possible genetic endowments. This is especially true in sport events which require specific components of neuromuscular or energy yielding process. Thus with respect to the muscle fiber distribution a superclass sprinter, jumper and thrower should have 70-90 % FT fibers and a superclass endurance runner and cross-country skier 70-90 % ST fibers in their muscles (paper I, II, III, and Gollnick et al. 1972). The correlation between age and %ST fibers among both endurance athletes and "power athletes" (paper IV) further support the hypothesis of genetic selection and the need for extreme characteristics in some sport events.

The role of the muscle fiber distribution might be pronounced in endurance sport events because, in addition to maximal oxygen uptake, the annual increases in maximal oxygen uptake were significantly related to %ST fibers. On the contrary, one junior skier has been able to compensate his low %ST fiber (50 %) by proper individual training. Consequently, his SDH activity and maximal oxygen uptake have increased to very high level and he became a medalist in European Junior Championships in 1976, The annual increases in vertical velocity and leg force were not related to muscle fiber distribution. It might be explained with the low initial levels and high increases of skijumpers and nordic combination skiers in these parameters.

Most of the adult athletes were able to improve their test results and, as expected, the cross-country skiers improved mainly their maximal oxygen uptake and SDH activity and the skijumpers and nordic combination skiers their muscle strength and running velocity. No definite ceiling of maximal oxygen uptake was observed in the cross-country skiers, although some female and one male junior skier demonstrated a slight decrease in their maximal oxygen uptake. It is suggested that the ceiling of maximal oxygen uptake (Saltin and Åstrand 1967; Ekblom 1969; Klissouras 1971) is perhaps related to the levelling off in the quantity and intensity of training. In the present study the training of the cross-country skiers was intensified both with respect to quantity and intensity after the poor success of the Finnish athletes in the Olympic Games in Sapporo in 1972. This might have been reflected also in the tendency to attain higher maximal heart rate in the maximal treadmill running test after two years of training.

The parameter which improved most during the two years of training was SDH activity in m. VL. Thus it was surprising to find that the youngest male junior skiers (15-16 years of age) had almost as high SDH activities as the adult skiers after two years of training. Previously Eriksson (1972) has shown that the 11-16 year old boys have higher SDH activity than untrained men and after a short period of training the SDH activity has increased by 30 %. These high values might be related to growth and maturation during which a relatively greater increase occurs in the other muscle tissue components, such as the contractile proteins or/and connective tissue elements, as compared with the increases in enzyme activities.

In the present study the battery of the tests was strongest in describing the aerobic performance capacity of the subjects. The leg force and vertical velocity were thought to reflect the neuromuscular factors but they did not differentiate systematically the short performance sport events from the other sport events. This might be explained with the lower values than expected in some athletes (skijumpers, 800 m runners, nordic combination skiers). However, together with the %FT fibers these parameters might describe sufficiently the neuromuscular performance capacity. The selected parameters were weakest in describing the anaerobic energy yielding processes. The blood lactate concentration after maximal treadmill running test was the only parameter obtained from all athletes. However, it differentiated the expected "anaerobic event" (running 800 m or shorter distances, canoeing and alpine skiing) from the other events, and furthermore the blood lactate correlated significantly with the %FT fibers. Because the anaerobic energy output might be a decisive factor in the hardest competitions it should be studied more extensively in future studies, for instance by assaying glycolytic enzyme activities from muscle samples and by measuring oxygen debt after maximal work tests.

TIIVISTELMÄ

Suomalaisten urheilijoiden fyysinen suorituskyky

Tutkimuksen tavoitteena oli muodostaa testipatteristo, jonka avulla mahdollisimman monipuolisesti voitaisiin kuvata ja seurata huippu-urheilijoiden fyysistä suorituskykyä ja sen muutoksia. Ongelma-alueittain tarkoituksena oli

1. arvioida suomalaisten urheilijoiden fyysistä suorituskykyä sekä tutkia suorituskyvyn osatekijöiden välisiä yhteyksiä,
2. analysoida eri urheilulajien fysiologisia vaatimuksia,
3. arvioida junioriurheilijoiden fyysistä suorituskykyä,
4. selvittää mitä kausiluonteisia ja vuosittaisia muutoksia urheilijoiden fyysisessä suorituskyvyssä tapahtuu normaalin harjoittelun aikana.

Raportissa kuvataan 89 mies- ja naisurheilijan, 58 junioriurheilijan ja 38 verrokin fyysistä suorituskykyä sekä kuvataan 80 urheilijan suorituskyvyn muutoksia kahden vuoden harjoittelujakson aikana.

Fyysistä suorituskykyä tutkittiin suorittamalla mittauksia koko elimistön tasolla, elinten ja lihasryhmien tasolla sekä lihaskudoksen ja solujen tasolla. Seuraavat muuttujat mitattiin useimmilta tutkituilta: pituus, paino, rasvaton kehonpaino, kehon rasvaprosentti ja rasvan kokonaismäärä, porrasjuoksunopeus, jalkojen ja oikean käden isometrinen ojennusvoima, maksimaalinen hapenotto ja maksimaalinen työsyke juoksumatto- ja käsiergometrikuormituksessa sekä veren maitohappopitoisuus em. kuormitusten jälkeen, reisilihaksen ja joissakin tapauksissa pohje- ja hartialihaksen solurakenne(%hitaita lihassoluja) sekä samojen lihasten SDH entsyymin aktiivisuus (sukkinaattidehydrogenaasi).

Mieshiihtäjät ja kestävyysjuoksijat saavuttivat suurimman maksimaalisen hapenoton juoksumattotestissä (78 ml x kg x min). Naishiihtäjien maksimaalinen hapenotto oli pienin, mutta kun se lakettiin suhteessa rasvattomaan kehonpainoon, oli naishiihtäjien maksimaalinen hapenotto suurempi kuin kestävyysjuoksijoiden ja lähes yhtä suuri kuin mieshiihtäjien. Solurakenteen ja SDH aktiivisuuden perusteella arvioituna oli kestävyysjuoksijoiden lihasten oksidatiivinen kapasiteetti suurin. Lisäksi hiihtäjien, pikaluistelijoiden, yhdistetyn hiihtäjien, melojien, pujottelijoiden ja jääkiekkoilijoiden reisilihaksissa oli merkitsevästi enemmän hitaita lihassoluja kuin verrokkiryhmän henkilöiden lihaksissa. Pikajuoksijoiden, hyppääjien ja heittäjien reisilihaksessa sen sijaan oli jonkin verran vähemmän em. hitaita lihassoluja kuin verrokkiryhmällä. Käsiergometrikuormituksessa melojat saavuttivat suurimman maksimaalisen hapenoton (4.56 l x min^{-1}).

Pikajuoksijoiden, hyppääjien ja heittäjien sekä jääkiekkoilijoiden ja pikaluistelijoiden porrasjuoksunopeus oli yli 1.50 m x sec^{-1}. Kestävyysurheilijoiden porrasjuoksunopeudet olivat vähän pienemmät kuin verrokkien (1.32 m x sec^{-1}). Pikajuoksijoiden, heittäjien ja hyppääjien sekä melojien, jääkiekkoilijoiden, mäkihyppääjien ja pujottelijoiden jalkojen lihasvoimat olivat suurimmat. Veren maitohappopitoisuus juoksumattokokeen jälkeen oli suurin 800 m juoksijoilla, melojilla, pujottelijoilla sekä pikajuoksijoilla, hyppääjillä ja heittäjillä.

Junioriurheilijoiden keskiarvot olivat lähes kaikissa muuttujissa yhtä suuret kuin aikuisten urheilijain. Merkitsevät erot olivat seuraavat: juniorimäkihyppääjien jalkavoima oli suurempi kuin mieshyppääjien ja juniorikestävyysjuoksijoiden hitaiden solujen määrä ja SDH-aktiivisuus reisilihaksessa olivat pienemmät kuin miesjuoksijoiden. Juniorihiihtäjien maksimaalinen hapenotto (juoksumatto) ja hitaiden solujen määrä olivat pienemmät kuin mieshiihtäjillä.

Siirryttäessä peruskuntokaudesta kilpailukauteen kykenivät mies- ja naishiihtäjät sekä juniorihiihtäjät lisäämään maksimaalista hapenottoaan 4.7-9.9 % juoksumattokuormituksessa sekä 5.6-17.0 % käsiergometrikuormituksessa. Vuosittaiset muutokset olivat 3.1-4.6 % (juoksumatto) ja 3.9-5.9 % (käsiergometri). Mies- ja naishiihtäjien reisilihaksen SDH-aktiivisuus lisääntyi 32.7 ja 40.3 %, vastaavasti, siirryttäessä peruskuntokaudesta talveen. Vuosittainen SDH-aktiivisuuden lisäys oli mieshiihtäjillä 29.8 %, naishiihtäjillä 16.2 %, juniorihiihtäjillä 35.0 % ja yhdistetyn hiihtäjillä 42.5 %. Mäkihyppääjien ja yhdistetyn hiihtäjien vuosittainen jalkavoiman lisäys oli 29.1 ja 24.8 %, ja vastaavasti porrasjuoksutestissä näiden kahden ryhmän tulokset paranivat 8.3 % ja 16.1 %. Tutkittaessa lihasten solurakenteen merkitystä harjoittelun kannalta todettiin, että urheilijat, joiden reisilihaksessa oli runsaasti hitaita lihassoluja kykenivät lisäämään hapenottoaan vuosittain enemmän kuin ne, joilla oli vähän hitaita lihassoluja lihaksissa. Lisäksi maksimaalinen hapenotto, porrasjuoksunopeus ja jalkojen voima korreloivat merkitsevästi lihasten solurakenteeseen.

Tutkimuksen perusteella voitiin vetää se johtopäätös, että kullakin urheilulajilla on omat erikoisvaatimuksensa, jotka heijastuvat myös testituloksissa. Urheilulajien välisistä eroista huolimatta voitiin tutkitut lajit luokitella neljään ryhmään niiden osittain samanlaisten vaatimusten perusteella. Aerobisia kestävyyslajeja ovat hiihto ja kestävyysjuoksu sekä osittain yhdistetty. Anaerobiset kestävyyslajit ovat melonta, 800 m juoksu ja pujottelu. Nopeus-kestävyyslajeja ovat tulosten mukaan jääkiekko ja pikaluistelu sekä teholajeja mäkihyppy, pikajuoksu, hypyt ja heitot.

Koska sekä tämän että muiden tutkimusten tulokset osoittavat, että lihasten solurakenne on muuttumaton ja eräiden tutkimusten mukaan kokonaan perintötekijöistä määräytyvä, ovat huippu-urheilijat todennäköisesti geneettisen valikoitumisen tuotteita. Junioriurheilussa ja kansallisen tason kilpailuissa voivat menestyä ne urheilijat, joilla on joitakin "hyödyllisiä" perittyjä ominaisuuksia, mutta kansainvälisellä huipputasolla täytyy urheilijalla kuitenkin olla kaikki mahdolliset positiiviset perintötekijät voidakseen menestyä.

Aerobisen suorituskyvyn osatekijöiden merkitystä arvioitaessa todettiin, että lihasten oksidatiivinen kapasiteetti on todennäköisesti ratkaiseva ominaisuus pitkäkestoisissa submaksimaalisissa suorituksissa, joissa suhteellisen pieni osa kehon lihaksista on toiminnassa. Maksimaalinen hapenotto puolestaan on ratkaiseva ominaisuus maksimaalisissa muutamia minuutteja tai muutamia kymmeniä minuutteja kestävissä suorituksissa, joissa suuri osa kehon lihaksista on toiminnassa. Tulosten perusteella näyttää todennäköiseltä, että maksimaalista hapenottoa rajoittavat pikemminkin verenkierron tekijät kuin lihasten oksidatiivinen kapasiteetti.

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E R R A T A

On page	The..th line from top	Instead of	Please read
7	23	Acitivity	Activity
11	3	58	63
25	10	acitivity	activity
25	11	35.9	35.0
28	28	acitivity	activity
29	10	acititivy	activity
30	1	complete	compete
31	34	event	events
33	14	58	63
34	1	lakettiin	laskettiin