

AGE-RELATED DECREASE OF THE INDICES OF AEROBIC CAPACITY IN THE FORMER ELITE ROWERS AND KAYAKERS

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Abstract. Age-dependent changes of the indices of aerobic capacity were estimated in sixty-six former elite rowers and kayakers aged 30 to 67 years who were divided, according to their present recreational physical activity, into the active (A) and less active (LA) groups. The maximal oxygen uptake ($\text{VO}_{2\text{max}}$) was higher in the A than the LA group. Compared to latter group, the former subjects demonstrated faster age-related annual reduction of the maximal oxygen uptake expressed in $\text{l}\cdot\text{min}^{-1}$ (1.4% vs. 0.6%; $p<0.001$), the oxygen uptake at the anaerobic threshold workload (1.1% vs. 0.4%; $p<0.05$), and the maximal oxygen pulse (1.0% vs. 0.4%; $p<0.05$). Also, $\text{VO}_{2\text{max}}$ expressed in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ strongly tended to decline faster with age in the active than the less active subjects (1.2% vs. 0.8%; $p<0.1$). Values of the oxygen pulse at submaximal workload, the PWC_{130} index, the anaerobic threshold expressed as $\% \text{VO}_{2\text{max}}$, and the oxygen cost of work were not significantly affected by age.

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Key words: Aerobic capacity - Aging - Elite athletes

Introduction

Age-dependent changes of the indices of aerobic capacity have been examined by numerous authors who demonstrated that in men the maximal oxygen uptake ($\text{VO}_{2\text{max}}$) expressed in absolute values increased until 16 to 20 years of age proportionally to the growing body mass, whereas when expressed in relation to the body mass it was highest between 12 and 13 years of age [20]. The examined indices usually do not change until the age of 20 to 25 years and then they gradually decline. The age-dependent decrease of the maximal oxygen uptake is associated with the reduced maximal heart rate and maximal stroke volume [7], decreased muscle mass [4], elevated fatty tissue content as well as limited intensity and volume of training [13]. Depending on the report, the rate of this process ranges from almost zero [14,16] to above $1.0 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ per year [12]. The age-

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related reduction of the aerobic capacity was examined mostly in subjects not engaged professionally in sports [2,5,12,21], in the former endurance athletes as well as in “master athletes”, i.e. individuals who, despite being over 40 years of age, are still actively training, mostly endurance sports [1,7,9,12,23]. Reports of the age-dependent changes of the physical fitness indices in the endurance-strength athletes, e.g. rowers and kayakers, are very limited. In fact, the only report we have been able to track down is that of Hagerman *et al.* [8] who investigated a small group of rowers. These authors detected a large decrease of $\text{VO}_{2\text{max}}$ (up to $9.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ per decade) upon termination of a professional career by the tested athletes. Such a profound reduction of $\text{VO}_{2\text{max}}$ could be related to the specific body-build and physical capacity of rowers who, like kayakers, demonstrate a large muscle mass incomparable to that of other endurance athletes as well as a very high aerobic capacity not matched by other strength-trained athletes [6,13].

The aim of the present study was to re-assess, in a larger number of former rowers and kayakers, the rate of the age-related decrease of maximal oxygen consumption and other indices of aerobic capacity, such as anaerobic threshold, oxygen pulse, and PWC_{130} , as well as to investigate the effect on the above rates of the recreational physical activity performed after termination of the career in sports.

Materials and Methods

After preliminary medical examinations and the ensuing doctor’s approval of physical exercising 66 former elite male rowers and kayakers aged between 30 and 67 years were recruited to participate in the investigation. Before obtaining their written consent, all the subjects were informed of the aim, scope, and programme of the study as well as of the possible risks run by middle-aged and older men from exercising at maximal strength. The programme of the investigation was approved by the Research Ethics Committee of the Institute of Sport in Warsaw.

Depending on their recreational physical activity, the subjects were divided into active (group A, composed of individuals who trained at least three times a week for 60 min) or less active (group LA). Owing to the limited number of the former athletes, a more detailed categorization of the physical activity was not possible.

The subjects performed the incremental exercise test on the Jeager ER 900 cycle ergometer. The initial workload equalled to 50 W at the pedalling rhythm of 55 $\text{turns}\cdot\text{min}^{-1}$ and these were gradually increased by 50 W and 5 $\text{turns}\cdot\text{min}^{-1}$, respectively, in the consecutive four-minute exercises. After each workload and at the fourth minute after completion of the test, arterialized blood samples were

collected from the fingertip to estimate the lactate concentration using the enzymatic assay (Boehringer-Mannheim, Germany). The heart rate was continuously registered electrocardiographically, both at rest and during the exercising, using either the computerized Medea Stress Test (Gliwice) or the Marquette Hellige equipment operating in the MemoPort 4000 system.

The following respiratory gasometric tests were carried out: pulmonary ventilation, oxygen uptake, and excretion of carbon dioxide in the open system with use of the MMC Beckman set. The printouts were obtained every 30 seconds. The following criteria of VO_{2max} attaining were employed:

- VO_2 plateau regardless of the increasing workload;
- blood lactate concentration after the exercise exceeding $8 \text{ mmol}\cdot\text{l}^{-1}$;
- respiratory exchange ratio $RQ > 1.10$;
- arrival at the age-adjusted maximal heart rate according to the formula $HR_{max} = 220 - 0.9 \cdot \text{age}$.

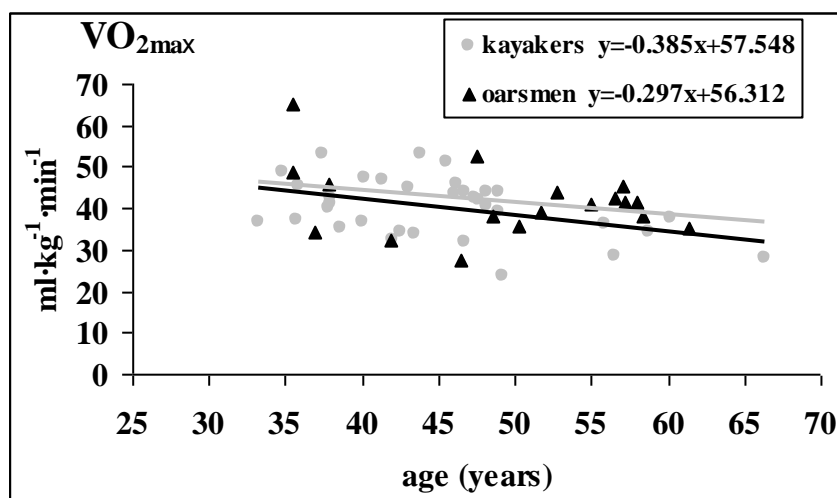
If at least two of the above criteria were met during the exercises, the effort and the oxygen uptake were regarded as maximal.

The obtained results were statistically analysed by calculating the means and standard deviations. Relationship between the indices and the age was assessed using the linear regression analysis and the analysis of the tested indices' mean values in three age compartments. After normality of the distribution was checked by the Kolmogorov-Smirnov test, the indices' values were analyzed using the two-way (age compartment + physical activity) analysis of variance (ANOVA). When the F value was statistically significant, the post-hoc Newman-Keuls test was used to detect significant differences between the groups. In order to compare the regression lines, the differences in the slopes and intercepts were analyzed.

All the calculations and statistical analysis were performed using the computer programs Statistica 5.1 for Windows (StatSoft) and Statgraphics Plus V. 3.0. (Statistical Graphics Corp).

Results

The examined subjects were initially divided into the groups of rowers and kayakers. As exemplified by the VO_{2max} values shown Fig. 1, no significant age-related differences in the tested indices of physical capacity were detected between the two groups of the athletes. Hence, further analyses were performed collectively for the former rowers and the former kayakers. Mean values (\pm SD) of the age and body mass of the subjects divided into three age compartments are presented in Table 1. As indicated, the body mass was not affected by age and physical activity.

**Fig. 1**

Age-related changes of the maximal oxygen uptake in kayakers (n=34) and rowers (n=18); comparison of the regression lines: intercept F=1.90 ns; slope F=0.12 ns

Table 1

Age and body mass of the subjects from various age compartments. Mean values \pm SD are presented

Age compartment	Group	No. of subjects	Age (years)	Body mass (kg)
35-44	A	5	38.7 \pm 3.8	86.2 \pm 7.1
	LA	19	39.3 \pm 3.0	89.7 \pm 10.9
45-55	A	9	48.6 \pm 2.2	88.2 \pm 6.7
	LA	14	48.3 \pm 2.0	88.3 \pm 12.2
>55	A	13	59.2 \pm 2.4	82.1 \pm 8.1
	LA	6	59.9 \pm 3.9	88.2 \pm 6.4
ANOVA	Age		-	ns
	Activity		ns	ns

Table 2
Maximal values of the oxygen uptake (VO_{2max}), heart rate (HR_{max}), minute pulmonary ventilation (VE_{max}), oxygen equivalent ($VE_{max} \cdot VO_{2max}^{-1}$) and oxygen pulse ($O_2 \text{ pulse}_{max}$). Mean values \pm SD are presented

Index	Age compartment						ANOVA (p)
	35-44		45-55		>55		
	A	LA	A	LA	A	LA	Age Activity
VO_{2max} ($l \cdot min^{-1}$)	4.55 \pm 0.70	3.46 \pm 0.40***	3.85 \pm 0.26 ^a	3.25 \pm 0.34*	3.27 \pm 0.31 ^{ab}	2.93 \pm 0.37	0.0000
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	53.0 \pm 7.2	39.5 \pm 5.6***	43.7 \pm 4.5 ^a	37.5 \pm 8.1	40.8 \pm 3.3 ^a	32.9 \pm 4.4	0.0006
HR_{max} ($b \cdot min^{-1}$)	182 \pm 6	180 \pm 11	177 \pm 8	175 \pm 16	177 \pm 17	168 \pm 16	ns
$O_2 \text{ pulse}_{max}$ ($ml \cdot kg^{-1} \cdot b^{-1}$)	0.29 \pm 0.04	0.22 \pm 0.03	0.25 \pm 0.03 ^a	0.22 \pm 0.05	0.23 \pm 0.02 ^a	0.20 \pm 0.04	0.0102
VE_{max} ($l \cdot min^{-1}$)	166.0 \pm 27.3	130.9 \pm 21.8*	138.9 \pm 26.8 ^a	124.5 \pm 21.2	124.5 \pm 32.8 ^a	113.0 \pm 21.2	0.0111
$VE_{max} \cdot VO_{2max}^{-1}$	36.2 \pm 3.8	37.7 \pm 4.0	35.7 \pm 7.7	38.4 \pm 5.5	37.6 \pm 7.8	38.6 \pm 4.6	ns

statistically significant differences from mean in the active group: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$;
a – statistically significant differences from the respective mean in age compartment of 35-44 years;
b – statistically significant differences from the respective mean in age compartment of 45-55 years

Table 3
 Oxygen uptake ($\dot{V}O_{2AT}$) and power output (P_{AT}) at the lactate threshold and power output at $130 \text{ b} \cdot \text{min}^{-1}$ heart rate (PWC-130);
 Mean values \pm SD are presented

Index	Age compartment						ANOVA (p)
	35-44		45-55		>55		
	A n=5	L.A n=19	A n=9	L.A n=14	A n=13	L.A n=6	Activity
$\dot{V}O_{2AT}$ ($\text{l} \cdot \text{min}^{-1}$)	3.12 \pm 0.41	2.09 \pm 0.32***	2.67 \pm 0.38 ^a	2.15 \pm 0.30***	2.18 \pm 0.27 ^{ab}	1.81 \pm 0.21	0.0000
$\dot{V}O_{2AT}$ ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	36.2 \pm 3.6	23.5 \pm 4.0***	30.3 \pm 4.8 ^a	24.7 \pm 4.0**	26.7 \pm 4.2 ^a	20.7 \pm 3.1*	0.0000
$\dot{V}O_{2AT}$ ($\% \dot{V}O_{2max}$)	68 \pm 5	60 \pm 3	67 \pm 7	65 \pm 2	66 \pm 9	63 \pm 4	0.0452
P_{AT} (W)	231 \pm 43	160 \pm 32***	199 \pm 32 ^a	157 \pm 27*	159 \pm 23 ^{ab}	130 \pm 21	0.0000
P_{AT} ($\text{W} \cdot \text{kg}^{-1}$)	2.72 \pm 0.40	1.80 \pm 0.34***	2.26 \pm 0.40 ^a	1.83 \pm 0.33*	1.95 \pm 0.35 ^a	1.49 \pm 0.30*	0.0000
PWC-130 ($\text{W} \cdot \text{kg}^{-1}$)	2.23 \pm 0.15	1.61 \pm 0.39	1.88 \pm 0.23	1.70 \pm 0.65	1.82 \pm 0.44	1.49 \pm 0.54	0.0035

statistically significant differences from mean in the active group: * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$;
 a – statistically significant differences from the respective mean in age compartment of 35-44 years;
 b – statistically significant differences from the respective mean in age compartment of 45-55 years.

Table 4

Annual age-related reduction of the examined indices expressed in the measurement units and in percentages of the value predicted for the age of 35 years

Index	Group	Annual decrease
VO _{2max}	A	0.069 l·min ⁻¹ ; 1.4%
	LA	0.022 l·min ⁻¹ ; 0.6%
VO _{2max}	A	0.65 ml·kg ⁻¹ ·min ⁻¹ ; 1.2%
	LA	0.33 ml·kg ⁻¹ ·min ⁻¹ ; 0.8%
HR _{max}	A	0.255 b·min ⁻¹ ; 0.1%
	LA	0.604 b·min ⁻¹ ; 0.3%
VO _{2AT}	A	0.041 l·min ⁻¹ ; 1.3%
	LA	0.008 l·min ⁻¹ ; 0.4%
VO _{2AT}	A	0.39 ml·kg ⁻¹ ·min ⁻¹ ; 1.1%
	LA	0.11 ml·kg ⁻¹ ·min ⁻¹ ; 0.4%
P _{AT}	A	3.36 W; 4%
	LA	1.00 W; 0.4%
P _{AT}	A	0.032 W·kg ⁻¹ ; 1.2%
	LA	0.013 W·kg ⁻¹ ; 0.4%
O ₂ pulse _{max}	A	0.003 ml·kg ⁻¹ ·b ⁻¹ ; 1.0%
	LA	0.001 ml·kg ⁻¹ ·b ⁻¹ ; 0.4%
O ₂ pulse (150 W)	A	0.000 ml·kg ⁻¹ ·b ⁻¹ ; 0%
	LA	0.000 ml·kg ⁻¹ ·b ⁻¹ ; 0%

As shown in Table 2 and Figs. 2 and 3, the maximal oxygen uptake was higher in the A than the LA group (Table 2, Figs. 2 and 3). Compared to the latter group, the slopes of the regression lines for VO_{2max} expressed in l·min⁻¹ and in ml·kg⁻¹·min⁻¹ against age were markedly higher or strongly tended to be higher, respectively, in subjects from the A group. As a result, the rate (in percentages) of the decrease of the examined indices with age was higher in subjects from group A (Table 4). No statistically significant differences between the groups were recorded for the maximal heart rate, although the subjects from group A tended to have higher mean values of HR_{max} (Table 2). The maximal oxygen pulse was markedly higher in the A than the LA group (Table 2, Fig. 4). As in the case of VO_{2max}, the greatest differences in this parameter between the groups were found in the 35-45-year age compartment. Statistically significant age-related changes of the maximal oxygen pulse were detected only in subjects from group A. The oxygen pulse at

submaximal workload (150 W) was also higher in this group and, as demonstrated by ANOVA, did not depend on age (Fig. 5). As in the case of VO_{2max} , the maximal effort pulmonary ventilation (VE_{max}) decreased with age. According to the analysis of variance the ratio of the maximal effort ventilation to the maximal oxygen uptake was not affected by the age and the level of physical activity (Table 2).

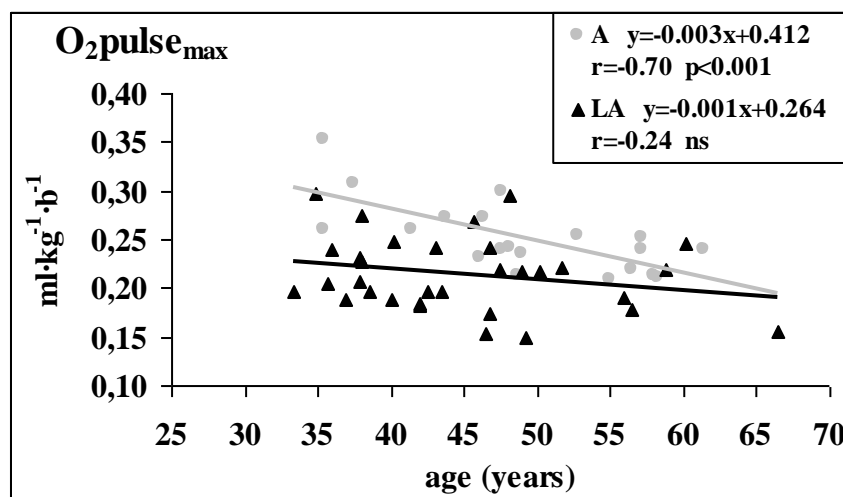
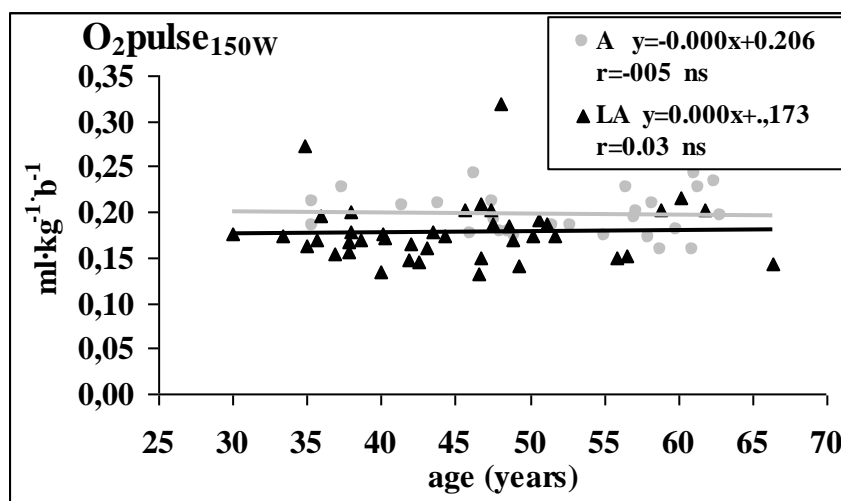


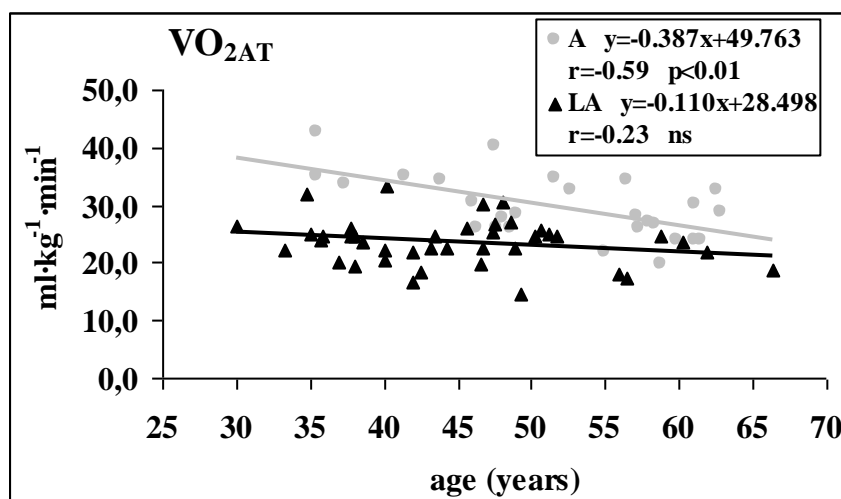
Fig. 4

Age-related changes of the maximal oxygen pulse; comparison of the regression lines: intercept $F=18.89$, $p<0.0001$; slope $F=2.92$ ns

Values of the threshold oxygen uptake (VO_{2AT}) and the threshold power output (P_{AT}) as well as reduction with age of these indices were all markedly higher in the A than the LA group of the subjects (Table 3, Figs. 6-8). In the former group, the relatively steady decreases of VO_{2AT} and P_{AT} were registered in all the age compartments, whereas reduction of these indices in the LA group was detectable only in subjects who were more than 55 years old. The VO_{2AT} value expressed in the percentage of VO_{2max} was higher in the A than the LA group. No relationship between this index and age was detected by the analysis of variance (Table 3). Significantly higher values of PWC-130 were also detected in subjects from group A, even though no age-dependent changes of this index were noted (Table 3). The oxygen cost of work was comparable in the two groups of the subjects and slightly increased with age (Fig. 8).

**Fig. 5**

Age-related changes of the oxygen pulse at the 150 W workload; comparison of the regression lines: intercept $F = 5.28$, $p < 0.05$; slope $F = 0.06$ ns

**Fig. 6**

Age-related changes of the threshold oxygen uptake; comparison of the regression lines: intercept $F = 47.62$, $p < 0.0000$; slope $F = 4.83$, $p < 0.05$

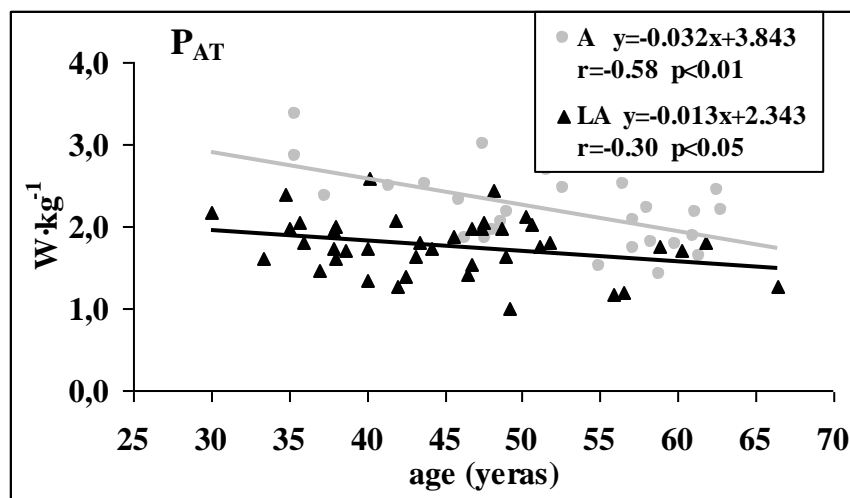


Fig. 7
Age-related changes of the threshold power output; comparison of the regression lines: intercept $F=35.73$, $p < 0.0000$; slope $F=3.08$ ns

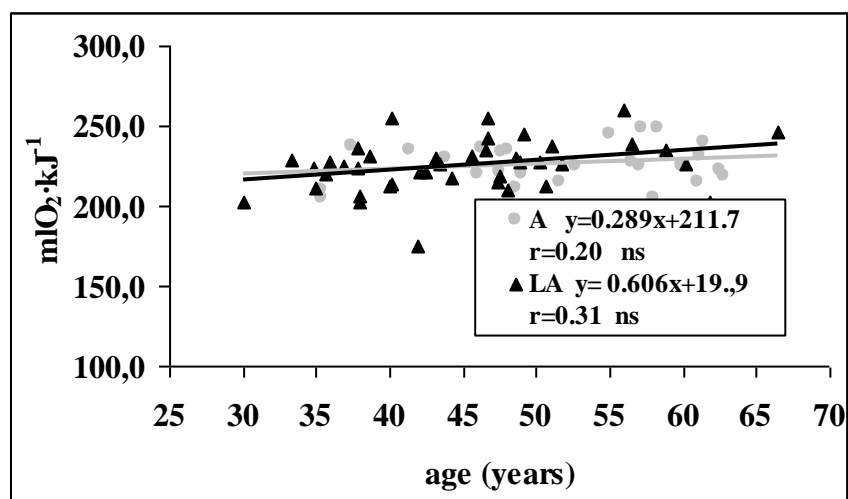


Fig. 8
Age-related changes of the oxygen cost at the anaerobic threshold; comparison of the regression lines: intercept $F=0.23$ ns; slope $F=0.54$ ns

Discussion

The original finding of the present investigation is the faster reduction with age of the indices of aerobic capacity in the physically active compared to the less active former elite rowers and kayakers aged between 30 and 67 years. Compared to the results obtained by other authors who tested endurance athletes or physically inactive subjects, the rate of the $\text{VO}_{2\text{max}}$ decline with age was generally slower in the less active former athletes investigated in the present study.

The former rowers and kayakers examined in the present investigation exhibited a very high physical capacity. According to the norms calculated by Shvartz and Reibold [20] the $\text{VO}_{2\text{max}}$ means determined by us for groups A and LA and expressed in absolute values correspond to the excellent and very good capacities, respectively. If the values of $\text{VO}_{2\text{max}}$ were expressed in $\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, the fitness of the athletes would be classified as slightly lower owing to the large body mass of the examined subjects. Such physical fitness would be regarded as very good/excellent and average/good in the A and LA groups, respectively. These fitness levels are markedly higher than the average determined in men from the corresponding age compartments sampled from the Polish population [2].

Compared to the results obtained by us in subjects from group A, similar or slightly lower mean values of $\text{VO}_{2\text{max}}$ (relative to age) expressed in absolute values and similar or slightly higher values of $\text{VO}_{2\text{max}}$ (relative to body mass) were obtained, for example, by Wiswell *et al.* [22] in track athletes and by Wollein *et al.* [23] in cyclists. Hagerman *et al.* [8] investigated former Olympic silver medallists in rowing aged around 44 years whose mean $\text{VO}_{2\text{max}}$ values equalled to $46.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. This result is very close to that observed by us in subjects from the respective age compartment of the A group.

In the present investigation, the rate of decrease of $\text{VO}_{2\text{max}}$ in the LA group equalled to approx. $0.33 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (0.8%) per year. In view of the reported data, this is a rather slow rate of the fitness reduction in the moderately active subjects. Indeed, few reports demonstrated a similar rate of reduction of $\text{VO}_{2\text{max}}$ with age [17] and in the majority of other reports a markedly higher reduction rate (between 0.42 and $0.54 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ per year) was presented [19,20,21]. Results obtained in statistical samples of the Polish population also fit in this latter range [2]. Nevertheless, numerous reports indicated that the annual $\text{VO}_{2\text{max}}$ decrease exceeded $0.65 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ [15,16].

In subjects from group A, the reduction rate of $\text{VO}_{2\text{max}}$ ($0.65 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1} = 1.2\%$ per year) was twice as high as in the those from the LA group. This rate approaches the average value reported in the literature. Notably, some authors have

not registered any decrease in aerobic capacity in the physically active subjects tested for several years [14,16]. However, other studies of the physically active individuals demonstrated a rate of the VO_{2max} decrease exceeding $0.9 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ per year [1,8,12].

The available results of investigations of the effect of physical activity on the age-dependent changes of fitness are inconsistent. For example, Rogers *et al.* [19] demonstrated that the decline of VO_{2max} with age was lower in the intensively training runners than in the not very active men (0.5% vs. 1.0% per year). Similar results were also obtained by other authors [15]. A few longitudinal studies of the strenuously training middle-aged or older men demonstrated no significant changes in the maximal oxygen uptake over 10 to 15 years of life [14,16]. In contrast, numerous authors [9,21] did not detect any differences in the physical activity-related decline of VO_{2max} with age in the tested subjects. Other studies [1,8,12] of the physically active men exhibited a large ($>0.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) annual reduction in VO_{2max} . Hagerman *et al.* [8] showed that the decrease of the maximal oxygen uptake in nine former elite rowers equalled to $0.94 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ (1.0%) per year. Interestingly, Katznel *et al.* [12] in cross-sectional studies found no differences in the activity-related rate of the VO_{2max} decline, whereas in longitudinal investigations the decline was almost three-fold higher in active middle-aged and old athletes than in sedentary men. When the athletes were further divided into subgroups according to the intensity of the continued training, the detected annual decrease in VO_{2max} ranged from insignificant (0.28%) in the intensively training subjects to very high in the moderately or minimally training subjects (2.6% and 4.6%, respectively). The slight decline in the maximal oxygen consumption detected in longitudinal studies in the strenuously training subjects may possibly be explained by the increased intensity and regularity of the training following the initial examination. This increase might be induced spontaneously in subjects who knew that their capacity would be checked or result from the investigator's intention of testing the regularly and intensively training individuals. Consequently, after the initial up-regulation of VO_{2max} triggered by the enhanced physical activity, a decrease of this parameter with age may ensue.

In spite of the more rapid decline of all the tested indices of physical capacity in subjects from group A, mean values of these indices were higher in the A than the LA group. This apparent inconsistency may be easily explained using the changes in VO_{2max} as an example. It is highly probable that mean values of the maximal oxygen uptake measured in the examined athletes during their professional career were similar in the two groups. This suggestion stems from the fact that the subjects from both groups used to be members of the Polish National Team and

that a comparable number of athletes from each group had had remarkable achievements in sports. As indicated by the studies of Klusiewicz *et al.* [13], the mean value of $\text{VO}_{2\text{max}}$ in Polish rowers successful in international competition was about $64.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$, whereas in members of the National Team and of its direct backup the respective values were 63.3 and $61.4 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$. The men examined in the present investigation completed their career in sports at the age of 27 ± 4.7 years. Putting this value into the regression formula of $\text{VO}_{2\text{max}}$ against age obtained from the results of the examined athletes (aged 35 to above 55 years), the calculated $\text{VO}_{2\text{max}}$ of $59.8 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ closely resembles that determined for the active National Team athletes. Thus, we may assume that the rate of decrease of the maximal oxygen uptake in subjects from group A during the first period after termination of their career in sports was similar to that detected in subjects aged 35 to above 55 years. This reduction may be related to aging as well as to the gradually reduced intensity and volume of training. When, unlike in group A, the regression line of $\text{VO}_{2\text{max}}$ against age in the LA group is extrapolated up to 27 years of age, the obtained $\text{VO}_{2\text{max}}$ value is markedly lower (only $43.7 \text{ ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$) than the one expected for the National Team athletes. This may be explained by the rapid decrease of this index in subjects from the LA group during the first period after termination of their career in sports. Presumably, this phenomenon is associated with the sudden reduction of the power and work output after cessation of the regular training. Therefore, the rate of decline of the tested indices of aerobic capacity in subjects from the examined age compartment was faster in group A than in group LA, but the mean reduction of the tested indices of aerobic capacity measured from the time of termination of the athletic career until any of the age ranges used in the present study was higher in the latter group. This points to the fact that mean values of the indices of aerobic capacity were lower or strongly tended to be lower in each age compartment in subjects from group LA than in those from group A.

The rate of the age-dependent decrease of the maximal oxygen pulse was similar to the results obtained for $\text{VO}_{2\text{max}}$. This finding corroborates the results of other authors [5]. The reduction of this index, similarly to the maximal oxygen uptake, was faster in group A than in the LA group, although the value of oxygen pulse in each of the examined age compartments was higher in the former group. This finding can be explained similarly to that detected for $\text{VO}_{2\text{max}}$. The age-related decrease of oxygen uptake at the anaerobic threshold ($\text{VO}_{2\text{AT}}$) in the examined former athletes depended on their physical activity. In subjects from group A, reduction of this index (in percentages) was similar to the decline of $\text{VO}_{2\text{max}}$ and occurred uniformly in the whole examined age compartment, whereas the decrease

of VO_{2AT} in the LA group was significantly slower than that of VO_{2max} and occurred only subjects over 55 years old. Similar differences between the A and LA groups were noted with respect to the threshold power and PWC-130. The hitherto published data on the age-dependent changes of the threshold indices are inconsistent. For example, Posner *et al.* [17] demonstrated a generally steady decrease with age of the ventilatory threshold in healthy men aged 20 to over 89 years, a finding in agreement with that detected by us in subjects from group A. In contrast, other authors reported that anaerobic [11] or ventilatory [3] thresholds decreased with age more slowly than did VO_{2max} , the observations resembling our present results obtained in subjects from group LA.

Both VO_{2max} and threshold indices hinge primarily on the function of the cardiovascular system and aerobic metabolism of the muscles, while the values of the latter indices, as compared to VO_{2max} , to greater extent depend on the peripheral factors affecting aerobic metabolism of the working muscles. Increment in the blood lactate concentration and, consequently, workload at the lactate and other threshold values occurs during sub-maximal activity of the cardiovascular system. As indicated by the obtained results, the oxygen pulse during submaximal exercising did not change with age. Other authors [18] did not detect any effect of aging on the heart ejection volume during sub-maximal exercising. Hence, the age-dependent decrease of the threshold values may be explained by the reduced mass of the skeletal muscles and the number of the motor units, the effects which build up especially after 50 years of age [5]. The faster decrease of the threshold indices observed in subjects from group A can be explained, as in the case of VO_{2max} .

The oxygen cost of work was similar in both groups of the subjects and did not depend on age. This observation indicates that in the well-trained former athletes the inevitable decline with aging of movement coordination only slightly affects the tested index. In subjects from group A, maximal pulmonary ventilation was higher than that in LA but proportionally to the higher energy expenditure at maximal workload, as indicated by the lack of marked differences between the groups with respect to the oxygen equivalent.

Conclusions

Reduction of the indices of aerobic capacity (VO_{2max} , VO_{2AT} , oxygen pulse) in the former elite rowers and kayakers aged 30 to 67 years is faster in the physically active (A) than the less active (LA) subjects. Nevertheless, the values of these indices are higher in the former subjects. Compared to the results obtained by other

authors in endurance athletes and sedentary individuals, the VO_{2max} decrease with age detected in the present investigation in subjects from the LA group was generally slower.

No significant differences between the groups were demonstrated for values of the maximal heart rate. Similarly to the VO_{2max} reduction, the maximal pulmonary ventilation (VE_{max}) declined with age. The ratio of VE_{max} to VO_{2max} was age- and physical activity-independent. The oxygen pulse at sub-maximal workload (150 W) as well as the value of VO_{2AT} expressed in percentages of VO_{2max} were age-independent and higher in the A than the LA group. Also, the markedly higher values of PWC-130 were registered in the former, compared to the latter group. However, no significant age-dependent changes in this index could be found. The oxygen cost of work was age-independent and comparable in the two groups of the tested subjects.

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