Biology of Sport, Vol. 24 N^{o}2, 2007

MAXIMAL HEART RATE IN ATHLETES

J. Faff, D. Sitkowski, M. Ładyga, A. Klusiewicz, L. Borkowski, J. Starczewska-Czapowska
Dept. of Physiology, Institute of Sport, Warsaw, Poland

Abstract: In the present study 1589 male and 1180 female athletes were examined. Depending on the sport they did maximal heart rates were estimated in the subjects during their exercising on the cycle, rowing, kayakers, ski, and treadmill ergometers. Linear regression for HRmax versus age (in years) was calculated for all the subjects exercising on all the ergometers combined (HRmax=208.5-0.8·age), for all the females (HRmax=208.3-0.74·age), and for all the males (HRmax=207.5-0.78·age). In addition, regression of HRmax versus age, separately for males and females, as well as mean HRmax values for the subjects aged 16-24 years exercising on each ergometer were calculated. The results demonstrate, bearing out the findings of other authors in young people of variable physical activities, that in highly trained athletes the widely employed formula HRmax=220–age significantly overestimates the age-predicted maximal heart rate. HRmax differs depending on the type of ergometer on which the exercise is performed: exercising on the rowing ergometer and on the treadmill results in higher HRmax than exercising on the kayakers, cycle, or ski ergometers. Compared to the males, females exercising on the rowing ergometer and on the treadmill exhibit higher HRmax values but no inter-sexual differences were noted when the subjects exercised on the remaining ergometers.

(Biol.Sport 24:129-142, 2007)

Key words: Maximal heart rate - Competition athletes - Inter-sexual differences - The ergometer-depending differences

Introduction

Maximal heart rate (HR_{max}) is an index commonly used for measurements performed in both athletes and individuals not professionally engaged in sports. The directly measured increase of this index during exercising to close to maximum value is one of the indicators of the maximal oxygen uptake (VO_{2max})

Reprint request to: Prof. Jerzy Faff, Dept. of Physiology, Institute of Sport, Trylogii 2/16, 01-982 Warsaw, Poland; E-mail: jerzy.faff@insp.waw.pl

[1]. Extrapolation of the relation between HR and VO_2 during submaximal exercising to the HR_{max} value is one of the means of prediction of VO_{2max} [1]. Similar use is made of the difference between maximal and resting heart rate defined as $HR_{reserve}$ [28]. In athletes, per cent of HR_{max} or per cent of $HR_{reserve}$ are used for determining the training load. In middle-aged, old, and sick people as well as in reconvalescents these values serve as indicators of the optimal intensity of exercising during recreational physical activities and in the exercise-based prophylaxis and therapy of diseases. In studies of physical fitness of older and sick people and in reconvalescents percentages of HR_{max} and $HR_{reserve}$ determine the maximal permissible intensity of exercising (usually 75-85% HR_{max}), i.e., the one which does not markedly jeopardise the life and well-being of the subjects. Obviously, the most accurate value of HR_{max} obtained by a direct measurement during maximal exercise is not always possible. Hence, the age-predicted value of HR_{max} is often employed which has for years been calculated using the formula 220–age (in years) [4,5,6,15,17]. The formula is based on numerous observations indicating that mean HR_{max} values for the tested groups were, respectively to age, close to 220–age [2,3,6,11,21,29]. However, several other authors have shown, based on both direct laboratory measurements and by meta-analysis, that using the 220–age formula results in under- and over-estimation of the HR_{max} values in older and young people, respectively [12,18,26,31]. It was demonstrated that in 18- to 80-year-old healthy men and women linear regression of HR_{max} versus age can be described by the formula where the intercept is lower than 220 and most often ranges from 200 to 214 and the slope is usually less than 1 and most often ranges from 0.6 to 0.8 [9,18,23,26,31,32]. Such values were obtained in men and women of variable level of physical activity who exercised on a treadmill and, in few cases, on a cycle ergometer. To date, however, no data have been published on the regression of HRmax versus age estimated for large groups of people professionally engaged in sports as well as on the differences in the HRmax values resulting from the type of ergometer used. Hence, the present study was undertaken to clarify these issues.

Materials and Methods

Altogether, 1589 male and 1180 female athletes aged 13-32 years were enrolled in the study. The groups were composed of the national team junior and senior representatives or their immediate backups. All the tested subjects or, in case of the underaged, their administrators, gave their written consent to participate in the examinations which collaterally served as a periodical test of the physical fitness of the athletes. The scheme of the study was approved by the Research Ethics Committee at the Institute of Sport. Some of the subjects were examined twice or thrice at different age with the intervals of at least one year. Consequently, 1766 and 1244 results were obtained in the male and female athletes, respectively, and used for the calculations; these included 1293 and 901 results (i.e., 73% of all) obtained in the males and females aged from 16 to 24 years. After exercising on each ergometer the following numbers of the results were secured:

- on the EK-1 kayak ergometer [33], designed similarly to those used by other authors [20], 918 and 578 results were obtained in the male and female kayakers, respectively;
- on the Concept II rowing ergometer 138 male and 74 female rowers were assayed;
- on the mechanical treadmill 400 results were secured in male athletes (including 113 obtained in tennis players, 204 in orienteers, 66 in modern pentathletes, and 17 in biathletes and cross-country skiers) and 283 results were secured in female athletes (including 88 obtained in tennis players, 134 in orienteers, 39 in pentathletes, and 22 in biathletes and cross-country skiers);
- on the cycle ergometer 293 and 291 results were obtained in male and female judoists, respectively;
- on the ski ergometer 10 male and 13 female biathletes as well as 7 male and 9 female cross country skiers were examined.

During exercising on all the ergometers the heart rates were measured using the Polar Sport Tester (Electro Oy, Finland). The highest value obtained during the test was regarded as HRmax. On the rowing ergometer the test exercise comprised of the simulated rowing with the maximal power on the 2000-meter distance. On the kayak ergometer the test exercise consisted in exercising with maximal power for 4 min in case of men and for 2 min in case of women. The maximal power exercise was preceded by three exercises at approx. 40%, 55%, and 70% of the average power in the maximal exercise for men and approx. 35%, 50%, and 65% of the average power for women. The test exercise on the electrically driven treadmill consisted of running until volitional exhaustion at the speed of the tread increased every 4-5 min by 1.5 to 2.0 $km \cdot h^{-1}$ with the 1-minute intervals between the subsequent stages. The initial speed was individually adjusted so that the incremental exercise until exhaustion could last 15 to 25 min. On the cycle ergometer the test exercise comprised of pedaling at the initial power of 1.25 $W \cdot kg^{-1}$ in case of men and at 1.0 $W \cdot kg^{-1}$ in case of women with the power increased every 4 min by 0.75 $W \cdot kg^{-1}$ until exhaustion. On the ski ergometer, which imitated the work of arms during the ski run, the test exercise consisted of exercising at the initial power of 1 W·kg^{-1} for men or 0.8 W·kg^{-1} for women with the power increased every 3 min by 0.6 W·kg^{-1} and 0.4 W·kg^{-1} for men and women, respectively, with the 1-minute intervals between the stages, until exhaustion.

Mean HRmax for the athletes 16-24 years old (73% of the tested subjects fell within this age range) were calculated separately for males and females exercising on different ergometers. Consequently, the obtained results allowed for the direct comparison of the mean HRmax values obtained in people of similar average age using the data derived from the majority of the tested subjects. After checking for the normality of distribution (with use of the Kolmogorov-Smirnow test) the values of the tested indices were statistically evaluated using the bivariate (sex, type of ergometer) analysis of variance. When the obtained F value was significant the significance of the differences between the means was estimated using the post-hoc Newman-Keuls test. Linear regression of HRmax versus age was calculated for exercises on different ergometers and, in addition, separately for the males and the females as well as for the males and the females combined. In the last three cases comparisons were made between the directly measured mean values of HRmax±SD and those predicted from the estimated regression of HRmax versus age and the most commonly employed formula in the literature, HRmax = 220 – age. For this purpose, differences between the measured and predicted mean HRmax values (MD), the Pearson's simple correlation coefficients (r), standard estimation errors (SEE), and total errors (TE) were calculated.

SEE were estimated based on the formula:

$$SEE = SDp \times \sqrt{1 - r^2}$$

where SDp is standard deviation of the mean HRmax value predicted by the given formula, and r is the coefficient of correlation between the measured and predicted values of HRmax.

Total error was calculated using the formula:

$$TE = \sqrt{\frac{\sum (HR_{\max m} - HR_{\max p})^2}{n}}$$

where HRmax m and HRmax p refer to the measured and predicted HRmax, respectively, and n is the number of the results.

Results

Table 1
Formulas of the linear regression of HRmax versus age

All ergometers	Females	HRmax = 208.3 - 0.74·age (yrs)
combined	Males	HRmax = 207.5 - 0.78·age (yrs)
	Females and males	HRmax = 208.5 - 0.8·age (yrs)
Treadmill	Females	HRmax = 213.8 - 0.81·age (yrs) 1.3.5.
	Males	HRmax = 209.9 - 0.73·age (yrs) 3.
Bicycle	Females	HRmax = 211.6 - 0.88·age (yrs) 1.3.5.
ergometer	Males	HRmax = 204.4 - 0.72·age (yrs 4.
Kayakers	Females	HRmax = 205.1 - 0.68·age (yrs)
ergometer	Males	HRmax = 206.7 - 0.81·age (yrs
Rowing	Females	HRmax = 206.1 - 0.50·age (yrs)
ergometer	Males	HRmax = 207.5 - 0.64·age (yrs)
Ski	Females	HRmax = 194.3 - 0.31·age (yrs) 2.
ergometer	Males	HRmax = 197.7 - 0.42·age (yrs) 2.

Statistically significant differences in the values of the intercept (see also text):
1. relative to the males; $p<0.001$
2. relative to the remaining ergometers; $p<0.001$
3. relative to the kayakers ergometer; $p<0.001$
4. relative to the treadmill; $p<0.001$
5. relative to the rowing ergometer; $p<0.001$

Regression formulas for HRmax versus age are shown in Table 1. Noticeably, the formula obtained for the two groups of male and female athletes combined was similar to those obtained when these two groups of the subjects were analysed separately and the formula obtained for the females did not significantly differ from that obtained for the males. In fact, the respective slopes were practically identical and only minor differences between the intercepts were noted. Nevertheless, significant sex-dependent differences were detected in the intercept values in the formulas of regression obtained after exercising on the treadmill ($F=15.6$; $p<0.001$) and on the cycle ergometer ($F=39.1$; $p<0.001$); in both cases higher values were noted in the females. Moreover, significant differences between the intercepts appeared to be related to the type of ergometer. In the tested female athletes lower intercept values were found in the regression formulas obtained from exercising on the kayak compared to the cycle ergometer (F=22.9; p<0.001), from exercising on the kayak ergometer compared to the treadmill (F=150.9; p<0.001), and from exercising on the ski ergometer compared to all the remaining ergometers (F>16.0; p<0.001). In the male athletes, significantly lower intercepts occurred in the formulas obtained after exercising on the kayak ergometer compared to the treadmill (F=100.1; p<0.001), after exercising on the cycle ergometer compared to the treadmill (F=75.5; p<0.001), and after exercising on the ski ergometer compared to the remaining ergometers (F>8.0; p<0.01).

Table 2
Mean HRmax values obtained for the male and female athletes aged 16-24 years during exercising on different ergometers

Ergometer	Females		Males	
	Age	HRmax	Age	HRmax
Bicycle	20.1±1.9 n=217	193.7±7.6 1.4.	20.9±1.8 n=258	189.1±7.4
Treadmill	18.7±1.9 n=168	198.7±7.3 1.2.3.	19.2±1.9 n=282	195.8±8.2 2.
Kayakers	18.6±1.9 n=379	192.3±7.0 5.	18.6±2.0 n=661	192.0±7.6
Rowing	18.6±1.4 n=75	196.4±6.8 2.	19.7±1.6 n=120	195.2±7.8 2.
Ski	19.1±1.6 n=21	188.2±8.7	20.1±1.6 n=13	189.5±8.9

Statistically significant differences (see also text):
1. relative to the males; p<0.001
2. relative to the cycle, kayakers, and ski ergometer; p<0.001
3. relative to the rowing ergometer; p<0.05
4. relative to the kayakers and ski ergometer; p<0.05
5. relative to the ski ergometer; p<0.05

Table 2 shows mean HRmax values obtained in the male and female athletes aged 16-24 years after their exercising on different ergometers. As indicated, compared to the males significantly higher (p<0.001) HRmax values were demonstrated by the female athletes exercising on the treadmill and the cycle ergometer (by 2.9 and 5.4, respectively). Noteworthy, in both cases the mean age of the males was by 6 months higher than that of the females: the difference of minor importance in terms of its effect on the detected variation in the obtained mean values, but which - according to the regression formula - could change the difference in HRmax by as little as 0.4 beats·min^{-1}. In order to minimize the difference in the mean age within the groups under comparison the results obtained in 15 males picked at random from the 30 oldest athletes who exercised on the cycle ergometer and on the treadmill were discarded. Consequently, mean age values obtained for the male groups exercising on these ergometers equaled to 20.3±1.6 and 18.7±1.6, respectively, and were almost identical to those obtained in the females. In spite of this, mean HRmax obtained in the males exercising on the cycle ergometer and on the treadmill amounted to 189.5±6.9 and 196.1±8.0, respectively, and remained significantly lower ($p<0.001$ and $p<0.005$, respectively) than in the females. No significant differences between HRmax values obtained in the male and female athletes were detected after exercising of the subjects on the remaining ergometers.

In both the females and the males tested the highest mean HRmax values were recorded after exercising on the treadmill and the rowing ergometer. These mean values significantly differed from the means obtained on the cycle, kayakers, and ski ergometers ($p<0.001$). Although the mean age of the males exercising on the cycle ergometer was by 1.7 years lower than that of those exercising on the treadmill and by 1.2 years lower than that of those exercising on the rowing ergometer this - according to the regression formula - could result in the difference in the mean HRmax only by about 1 beat·min^{-1}, whereas the recorded differences between the means obtained on the cycle ergometer versus those obtained on the treadmill and the rowing ergometer equaled to 6.7 and 6.1 beats·min^{-1}, respectively. No significant differences were noted between the means calculated for the male athletes exercising on the rowing ergometer and on the treadmill, but in the females exercising on the former ergometer the significantly higher ($p<0.05$) HRmax was detected compared to that obtained after exercising on the latter ergometer. In addition, the mean value obtained by the females on the cycle ergometer was significantly higher than those obtained on the ski and kayakers ergometers ($p<0.01$ and $p<0.05$ respectively); in turn, the mean value obtained on the latter was higher ($p<0.05$) than the one obtained on the former ergometer. In case of the males, no differences in the mean HRmax values were noted when these athletes exercised on the cycle and ski ergometers; the values obtained on these ergometers were lower compared to the values obtained on the kayakers ergometer, but in view of the lowest mean age of the athletes exercising on the latter ergometer the recorded differences were not significant.

In Table 3 the directly measured mean HRmax values are compared with the ones predicted based on the formula HRmax=220–age as well as those predicted from the regressions calculated (Table 1) for the female athletes' group, for the male athletes' group and for both groups combined. As indicated, for all the groups the HRmax values predicted using the 220–age formula are markedly overestimated. The means predicted from the remaining formulas do not differ from the measured values. The coefficients of correlation of HRmax versus age do not vary depending on the formula employed but the SEE and TE values are clearly the highest when the 220–age formula is used indicating that in the latter case adjustment of the regression line to the results is the least accurate. Noteworthy, precision of the formula set out for the male and female groups combined, when used separately for the two groups, only slightly differs from the precision of the formulas defined for each of these groups alone; the detected differences in the MD, SEE, and TE values are practically negligible.

Table 3
Comparison of the directly measured mean HRmax values with the values predicted from the given formulas of regression of HRmax versus age. Differences between the measured and predicted mean HRmax values (MD), correlation coefficients (r), standard estimation errors (SEE), and total errors (TE) are also indicated

Group	Regression formula	HRmax±SD	MD±SD	R	SEE	TE
Females	Measured	194.5±7.9				
	220 - age	201.2±3.4	-6.7±7.6^{xx}	0.31^{xx}	3.2	10.1
N=1244	208.5 - 0.8 age[1]	193.5±2.7	1.0±7.5^{x}	0.31^{xx}	2.6	7.6
	208.3 - 0.74 age[2]	194.4±2.5	0.0±7.5	0.31^{xx}	2.4	7.5
Males	Measured	192.0±8.1				
N=1766	220 - age	200.3±3.7	-8.2±8.0^{xx}	0.34^{xx}	3.5	11.4
	208.5 - 0.8 age[1]	192.7±2.9	-0.7±7.9	0.34^{xx}	2.7	7.9
	207.5 - 0.78 age[2]	192.1±2.9	0.0±7.9	0.34^{xx}	2.7	7.9
Females	Measured	193.1±8.3				
and	220 - age	200.7±3.6	-7.6±7.8^{xx}	0.34^{xx}	3.4	10.9
Males	208.5 - 0.8 age[2]	193.1±2.9	0.0±7.8	0.34^{xx}	2.7	7.8
N=3010						

[1]Formula set out for the females and males combined;
[2]Formula set out for the given group; $^{x}p<0.01$ $^{xx}p<0.001$

Discussion

The most important finding of the present study consists in the demonstration that in individuals professionally engaged in sports the course of linear regression of the maximal heart rate versus age is, to a large extent, similar to that described by other authors for people of variable physical activity; there are, however, sex-related differences between the HRmax values obtained on the cycle ergometer versus the treadmill as well as differences in these values depending of the type of ergometer.

As pointed out in the introduction, HRmax is one of the most frequently utilized indicators of maximal exercises. Nevertheless, the influence of the type of physical activity on this index is often questioned. One reason for this controversy may be the relatively large dispersion of individual HRmax results around the mean value. Some authors indicated the tendency of this index to decrease in the endurance-trained athletes [2,14]. On the other hand, there are reports indicating the markedly slower decline of HRmax with age in physically active individuals which should be reflected in higher values of this index [10,22]. In most of the hitherto reported studies no effect of physical training has been detected on the age-related rate of decrease of the maximal heart rate [3,7,19,26]. Indeed, physical activity has not been shown to affect the formulas of regression of HRmax versus age [26]. In some studies, the intercept in the regression formulas was higher in the less physically active individuals [25,32], whereas other authors detected higher intercept values in the more physically fit people [18].

The results obtained in the present study indicate that in people professionally engaged in sports the relation of HRmax to age is similar to that in individuals from the general population characterized by largely varied physical activity. This conclusion is supported by the finding that formulas of regression of HRmax versus age obtained for the tested female athletes (208.3 - 0.74·age), male athletes (207.5 - 0.78·age), and all of the athletes (208.5 - 0.8·age) are almost identical to those of Tanaka *et al.* [26] obtained after exercising on a treadmill and a cycle ergometer with use of the meta-analysis (208.1 - 0.77·age, 208.7 - 0.73·age, and 208.0 - 0.7·age, respectively) and direct laboratory measurements (207.2 - 0.65·age, 209.6 - 0.72·age, and 209.0 – 0.7·age, respectively). The values of the intercept and the slope of the regression line calculated in the present study for the tested athletes after their exercising on the treadmill are similar to the respective mean values obtained by other authors for people of variable physical activity aged between 14 and 80 years. This is illustrated by the data from the literature shown in Table 4 on the regression of HRmax versus age during exercising on a treadmill.

Table 4

Formulas of the regression of HRmax versus age obtained by other authors after exercising on a treadmill

Subjects	Regression formula	Ref. no.
Sedentary women	HRmax = 207.0 - 0.6 ·age (yrs)	25
Endurance-trained women	HRmax = 199.9 - 0.56·age (yrs)	25
Caucasian women	HRmax = 207.0 - 0.62·age (yrs)	23
Hispanic women	HRmax = 213.7 - 0.75·age (yrs)	23
Women	HRmax = 208.8 - 0.72·age (yrs)	31
Female athletes from this study	HRmax = 213.8 - 0.81·age (yrs)	
Sedentary men	HRmax = 211.9 - 0.51·age (yrs)	32
Physically active men	HRmax = 206.8 - 0.67·age (yrs)	32
Endurance-trained men	HRmax = 205.6 - 0.65·age (yrs)	32
Sedentary men	HRmax = 205.2 - 0.66·age (yrs)	18
Endurance-trained men	HRmax = 211.6 - 0.88·age (yrs)	18
Men	HRmax = 213.6 - 0.79·age (yrs)	31
Men	HRmax = 205.8 - 0.69·age (yrs)	9
Male athletes from this study	HRmax = 209.9 - 0.73·age (yrs)	

In comparison to the widely used by most of the authors formula HRmax=220–age (see introduction) the regression formulas obtained in the present investigation much better describe the relation of HRmax to age in the group of females, in the group of males, and in all the tested athletes. This is indicated by the markedly lower differences between the HRmax values estimated directly and indirectly using the obtained formulas versus the formula 220–age, by the markedly lower standard estimation errors, and - most of all - by the markedly lower total errors. Similarly to the reports of other authors [26] as well as to the indications from our previous paper [12] the use of the formula HRmax=220–age for tests performed in young individuals resulted in overestimation of HRmax.

In the present study the highest HRmax values in both the females and the males were detected after exercising on the treadmill and the rowing ergometer and lower values were obtained on the cycle, kayakers, and ski ergometers. In contrast, Tanaka *et al.* [26] did not detect differences between the HRmax values obtained during exercising on the treadmill and the cycle ergometer. However, Londeree and Moeschberger [14] after reviewing a large body of literature concluded that maximal heart rate during treadmill running is higher than that obtained on a cycle ergometer. Indeed, numerous authors have reported that exercising on a treadmill is associated with higher VO_{2max} than exercising on a cycle ergometer [8,16]. It is possible that a greater maximal energy expenditure during treadmill running compared to that obtained upon pedaling the ergometer results in the higher HRmax value. Likewise, the high HRmax detected by us during exercising on the rowing ergometer can be explained by the engagement of large groups of muscles, both from the upper and lower parts of the body, what - in case of the well trained athletes - is associated with the very high VO_{2max} [13]. The significantly lower HRmax obtained on the ski and kayakers ergometers may be associated with the very large contribution of the work of arms, especially during exercising on the ski ergometer. Noteworthy, some authors [24] claim that during exercising with upper limbs the heart rate does not reach the HRmax level.

Similar to the results of others [26], in the present study the formula of regression of HRmax versus age for the whole female group resembles that obtained for the whole male group. However, our careful analysis of this index obtained during exercising on different ergometers revealed the inter-sexual differences which have not been detected earlier by other authors. These differences occurred when the subjects pedaled the cycle ergometer or ran on the treadmill. In both cases, the significantly elevated intercept values and higher mean HRmax values were found for the tested females aged 16-24 years. Although the detected differences in the mean values are not large they are statistically significant. Exercising on the remaining ergometers was not associated with any inter-sexual differences in the HRmax values obtained for the group of the 16-24-year-old athletes nor were such differences noted in the regression formulas. In contrast to our results, Tanaka *et al.* [26] were not able to detect inter-sexual differences in the regression of HRmax versus age resulting from exercising on a cycle ergometer or on a treadmill. In turn, Whaley *et al.* [31] reported that during running on a treadmill the intercept in the regression of HRmax versus age tended to be higher in men than in women. However, the cited authors did not test professional athletes. Generally, in a group of people composed of young, middle-aged, and older individuals, women are less physically activity than men. As a result, the former more often than the latter exhibit local fatigue of the muscles resulting in cessation of exercising before the maximal heart rate has been attained. Presumably, this effect did not occur in the female athletes tested in the present study who had regularly trained with the relative intensity similar to that of the males. In addition, all the examined athletes were highly motivated to exert maximal effort during the investigation, which also served as a test of their exercise capacities. Such high a motivation can hardly be achieved in a population whose members exhibit different physical activities, especially older women. Interestingly, the inter-sexual differences in HRmax were detected only during treadmill running and upon pedaling the cycle ergometer. To some extent this can be explained by the fact that average physiological differences between men and women in the strength of the lower body muscles are less pronounced than the differences in the strength of the muscles from the upper part of the body [30]. Of the ergometers employed in the present investigation it is a treadmill and a cycle ergometer that most profoundly engage muscles of the lower part of the body enabling women to achieve the relatively high maximal energy expenditure. In case of a rowing ergometer, the strength of the upper extremities plays an important role. Even more important is the strength of upper limbs during exercising on kayakers and ski ergometers.

In summary, the obtained results indicate that, similar to the findings by other authors who tested young people of variable physical activities, application of the widely used formula HRmax=220–age for evaluation of the maximal heart rates in professional athletes leads to overestimation of the seeked values. HRmax differs depending on the type of ergometer on which the exercise is performed. Hence, exercising on a rowing ergometer and on a treadmill results in higher HRmax than exercising on kayakers, bicycle, or ski ergometers. Female athletes exercising on a cycle ergometer and on a treadmill exhibit higher HRmax values than their male counterparts. No inter-sexual differences in the HRmax values were detected during exercising on the remaining ergometers used in the present investigation.

References

1. American College of Sports Medicine. ACSM’s Quidelines for Exercise Testing and Prescription (2000). 6th Ed. Lippincott Wiliams & Wilkins, Baltimore, MD

2. Andersen K.L., L.Hermansen (1965) Aerobic work capacity in middle-aged Norwegian men. *J.Appl.Physiol*. 20:432-436

3. Åstrand I. (1960) Aerobic work capacity in men and women with special reference to age. *Acta Physiol.Scand*. 49(Suppl.169):1-92

4. Fox E.L. (1984) Physiology of exercise and physical fitness. In: R.H.Strauss (ed.) Sports Medicine. W.B.Saunders Co., pp. 381-456

5. Fox S.M., W.L.Haskell (1970) The exercise test: needs for standardization. In: M.Eliakim, H.N.Neufeld (Eds.) Cardiology: Current Topics and Progress. Acad. Press, New York, pp. 149-154

6. Hanson P. (1984) Clinical exercise testing. In: R.H.Strauss (ed.) Sports Medicine. W.B.Saunders Co. pp. 13-40

7. Hawkins S., R.Wiswell (2003) Rate and mechanism of maximal oxygen consumption decline with aging: implications for exercise training. *Sports Med.* 33:877-888

8. Hermansen L., B.Saltin (1972) Oxygen uptake during maximal treadmill and bicycle exercise. *J.Appl.Physiol*. 26:31-37

9. Inbar O., A.Oren, M.Scheinowitz, A.Rodstein, R.Dlin, R.Casaburi (1994) Normal cardiopulmonary responses during incremental exercise in 20-to 70-yr-old men. *Med.Sci.Sports Exerc*. 26:538-546

10. Kasch F.W., J.L.Boyer, S.VanCamp, F.Nettl, L.S.Verity, J.P.Wallace (1995) Cardiovascular changes with age and exercise. *Scand.J.Med.Sci.Sports* 5:147-151

11. Kasch F.W., J.P.Wallace (1976) Physiological variables during 10 years of endurance exercise. *Med.Sci.Sports* 8:5-8

12. Klusiewicz A., J.Faff (2003) Indirect methods of estimating maximal oxygen uptake on the rowing ergometer. *Biol.Sport* 20:181-194

13. Klusiewicz A., J.Faff, R.Zdanowicz (1999) Diagnostic value of indices derived from specific laboratory tests for rovers. *Biol.Sport* 16:39-50

14. Londeree B.R., M.L.Moeschberger (1984) Influence of age and other factors on maximal heart rate. *J.Cardiac.Rehab.* 4:44-49

15. Marti B., H.Howald (1990) Long-term effects of physical training on aerobic capacity. Controlled study of former elite athletes *J.Appl.Physiol*. 69:1451-1459

16. McKay G.A., E.W.Bannister (1976) A comparison of maximum oxygen uptake determination by bicycle ergometry at various pedaling frequencies and by treadmill running at various speeds. *Eur.J.Appl.Physiol*. 35:191-200

17. Mesquita A., M.Trabulo, M.Mendes, J.F.Viana, R.Seabra-Gomez (1996) The maximum heart rate in the exercise test: the 220-age formula or Sheffield's table. *Rev.Port.Cardiol.* 15:139-144

18. Pimentel A.E., C.L.Gentile, H.Tanaka, D.R.Seals, P.E.Gates (2003) Greater rate of decline in maximal aerobic capacity with age in endurance-trained than in sedentary men. *J.Appl.Physiol* 94:2406-2413

19. Pollock M., L.J.Mengelkoch, J.E.Graves, D.T.Lowenthal, M.C.Limacher, C.Foster, J.H.Wilmore (1997) Twenty-year follow-up of aerobic power and body-composition of older track athletes. *J.Appl.Physiol*. 82:1508-1516

20. Ridge B.R., F.S.Pyke, A.D.Roberts (1976) Response to kayak ergometer performance after kayak and bicycle ergometer training. *Med.Sci.Sports Exerc*. 8:18-22

21. Rivera A.M.,A.E.Pels III, S.P.Sady, M.A.Sady, E.M.Cullinane, P.D.Thompson (1989) Physiological factors associated with the lower maximal oxygen consumption of master runners. *J.Appl.Physiol*. 66:949-954

22. Rogers M.A., J.M.Hagberg, H.M.III Wade, A.A.Ehsani, J.O.Holloszy (1990) Decline in VO_{2max} with aging in master athletes and sedentary men. *J.Appl.Physiol*. 68:2195-2199

23. Schiller B.C., Y.G.Casas, C.A.Desouza, D.R.Seals (2001) Maximal aerobic capacity across age in healthy Hispanic and Caucasian women. *J.Appl.Physiol*. 91:1048-1054

24. Stenberg J., P.O.Åstrand, B.Ekblom, J.Royce, B.Saltin (1967) Hemodynamic response to work with different muscle groups, sitting and suspine. *J.Appl.Physiol*. 22:61-70

25. Tanaka H., C.A.DeSouza, P.P.Jones, E.T.Stevenson, K.P.Davy, D.R.Seals (1997) Greater rate of decline in maximal aerobic capacity with age in physically active vs. sedentary healthy women. *J.Appl Physiol*. 83:1947-1953

26. Tanaka H., K.D.Monahan, D.RSeals (2001) Age-predicted maximal heart rate revisited. *J.Am.Coll.Cardiol.* 37:153-156

27. Trappe S.W., D.L.Costill, M.D.Vukovich, J.Jones, T.Melham (1996) Aging among elite distance runners: a 22-yr longitudinal study. *J.Appl.Physiol*. 80:285-290

28. Uth N., H.Sorensen, K.Overgaard, P.K.Pedersen (2004) Estimation of VO_{2max} from the ratio between HR_{max} and HR_{rest}–the heart ratio method. *Eur.J.Appl.Physiol*. 91:111-115

29. Vodak P.A., W.M.Savin, W.L.Haskell, P.D.Wood (1980) Physiological profile of middle-aged male and female tennis players. *Med.Sci.Sports Exerc*. 12:159-163

30. Wells C.L. (1985) Women, Sport, and Performance. Human Kinetics, Champaign IL, pp. 36-41

31. Whaley M.H., LK.A.Kaminsky, G.B.Dwyer, L.H.Getchel, J.A.Norton (1992) Predictors of over-and underachievement of age-predicted maximal heart rate. *Med.Sci. Sports Exerc.* 24:1173-1179

32. Wilson T.M., H.Tanaka (2000) Meta-analysis of the age-associated decline in maximal aerobic capacity in men: relation to training status. *Am.J.Physiol.* 278:H829-H834

33. Wychowański M., I.Wojcieszak, J.Wojczuk (1982) Ergometr kajakarski EK-1. *Sport Wyczyn.* 6:23-36 (in Polish, abstract in English)

Accepted for publication 29.08.2006