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Maximal heart rates and plasma lactate concentrations observed in middle-aged men and women during a maximal cycle ergometer test

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Summary. The purpose of this study was to investigate criteria for maximal effort in middle-aged men and women undertaking a maximal exercise test until they were exhausted if no measurements of oxygen uptake are made. A large group of 2164 men and 975 women, all active in sports and aged between 40 and 65 years, volunteered for a medical examination including a progressive exercise test to exhaustion on a cycle ergometer. In the 3rd min of recovery a venous blood sample was taken to determine the plasma lactate concentration ($[la^-]_{p,3min}$). Lactate concentration and maximal heart rate ($f_{c,max}$) were lower in the women than in the men ($P<0.001$). Multiple regression analyses were performed to assess the contribution of sex to $[la^-]_{p,3min}$, independent of age and $f_{c,max}$. It was found that $[la^-]_{p,3min}$ was about 2.5 $mmol \cdot l^{-1}$ lower in women than in men of the same age and $f_{c,max}$. In our population 88% of the men and 85% of the women met a combination of the following $f_{c,max}$ and $[la^-]_{p,3min}$ criteria: $f_{c,max}$ equal to or greater than 220 minus age $beats \cdot min^{-1}$ and/or $[la^-]_{p,3min}$ equal to or greater than 8 $mmol \cdot l^{-1}$ in the men and $f_{c,max}$ equal to or greater than 220 minus age $beats \cdot min^{-1}$ and/or $[la^-]_{p,3min}$ equal to or greater than 5.5 $mmol \cdot l^{-1}$ in the women.

Key words: Lactate – Heart rate – Exercise tests – Sex difference – Maximal exercise

Introduction

In maximal exercise testing it is always difficult to judge whether a subject has really performed up to his or her true maximum. There are several more or less objective criteria that may be used to judge the level of exhaustion in progressive exercise testing. It has been generally accepted that maximal effort is confirmed by a levelling-off of the oxygen consumption with increasing power output (Åstrand and Rodahl 1986). Other parameters which have been used are respiratory exchange ratios above 1.00, 1.05 or 1.10, a respiratory equivalent above 30 or combinations of these and other criteria (Froberg and Pedersen 1984; Kuipers et al. 1985; Löllgen and Ulmer 1985; Saris et al. 1985).

If no gas analysis equipment is available the maximal heart rate and the peak blood lactate concentration have often been used. Maximal heart rate ($f_{c,max}$) has often been assumed to be 220 minus age ($beats \cdot min^{-1}$) on average, with a standard deviation of 10 $beats \cdot min^{-1}$ at a given age, for men as well as women. As a minimal criterion of maximal effort, therefore, 200 minus age [220 minus (age + 2SD)] $beats \cdot min^{-1}$ for $f_{c,max}$ has been used (Åstrand and Rodahl 1986; Löllgen and Ulmer 1985). Åstrand and Rodahl (1986) have suggested using a peak lactate concentration of 8 $mmol \cdot l^{-1}$ or higher as a criterion for maximal effort. They did not mention the existence of a difference in peak lactate concentrations between men and women. However, Jacobs et al. (1983) have found significantly lower muscle lactate concentrations after maximal exercise in women than in men, suggesting that there may be sex differences in peak blood lactate concentration. Other authors have indeed found significantly different peak plasma lactate concentrations (Åstrand et al. 1973; Froberg and Pedersen 1984; Verstappen et al. 1989).

In this study the difference in plasma lactate concentration between men and women was quantified to set a criterion for maximal effort based on lactate concentration after maximal exercise in women similar to that used for men.

Methods

Subjects. All volunteers were aged 40 years or older and active in sports [participation rate of 4.0 (SD 3.4) $h \cdot week^{-1}$]. They performed a progessive maximal exercise test, as part of a sports-medical examination. Tests of subjects using cardiovascular medication were excluded from the analysis. Only subjects with complete data regarding maximal heart rate ($f_{c,max}$), plasma lactate

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Table 1. Characteristics and maximal exercise parameters of the subjects

	Men $n=2164$		Women $n=975$	
	mean	SD	mean	SD
Age (year)	47.0	6.4	47.9	6.8**
Body mass (kg)	77.3	8.8	63.6	7.6***
Height (m)	1.76	0.06	1.64	0.06***
Body fat (%)	23.5	5.1	33.2	4.9***
W_{max} (W)	250.9	48.0	157.8	29.3***
$W_{max} \cdot kg^{-1}$ ($W \cdot kg^{-1}$)	3.3	0.7	2.5	0.5***
$f_{c,max}$ ($beats \cdot min^{-1}$)	173.0	13.6	168.4	13.5***
$[la^-]_{p,3min}$ ($mmol \cdot l^{-1}$)	10.5	3.2	7.7	3.7***

** $P<0.01$ (Mann-Whitney *U*-test); *** $P<0.001$ (*t*-test)
W_{max}, maximal power output; $f_{c,max}$, maximal heart rate; $[la^-]_{p,3min}$, plasma lactate concentration at 3rd min of recovery

concentration in the third minute of recovery ($[la^-]_{p,3min}$) and maximal power output (W_{max}) were analysed. Data on 3139 volunteers (2164 men and 975 women) were obtained over a period of 4 years.

Characteristics of the population studied including measurements of height, body mass, and percentage of body fat, estimated from the sum of four skinfolds determined according to the method of Durnin and Womersley (1974), are given in Table 1.

Exercise test. The subjects were seated upright on a electrically braked cycle ergometer (Lode) with 3-lead (II, V1 and V5) electrocardiogram (ECG)-electrodes in place. The test was performed with a pedal frequency between 60 and 80 rpm, starting at a power output of 100 W for the men and 50 W for the women for 5 min. Thereafter, power output was increased by $50\ W \cdot 2.5\ min^{-1}$ until a heart rate between 140 and 150 $beats \cdot min^{-1}$ was reached. Then the increment was $25\ W \cdot 2.5\ min^{-1}$ until exhaustion. The W_{max} was the highest power output that could be maintained for 2.5 min. If the final increment of power output could not be maintained for 2.5 min, W_{max} was calculated with a correction for the completed time of that increment (5 W per 30 s). The test lasted between 12.5 and 15 min for the men and between 11 and 13.5 min for the women. Heart rate was determined from the ECG over the last 30 s of each exercise intensity, and the highest value recorded was considered to be $f_{c,max}$. In the 3rd min of recovery, a blood sample was drawn from a cubital vein for measurement of $[la^-]_{p,3min}$ (640 lactate analyzer, Roche) (Geyssaut et al. 1985).

Data analysis. Means and standard deviations of variables were calculated separately for the men and for the women. Differences between the men and the women were tested by two-sample Student's *t*-tests, except for differences in age, which were tested by Mann-Whitney *u*-tests because the distribution was not normal. Correlation coefficients between sex, age, $f_{c,max}$ and $[la^-]_{p,3min}$ were determined. Multiple linear regression analyses were used to evaluate the influence of the independent variables of sex, age and $f_{c,max}$ on $[la^-]_{p,3min}$.

Results

A small, but significant, difference in age (0.9 year, $P<0.01$) between the sexes was found (Table 1). Moreover, the women reached significantly lower $f_{c,max}$ than the men [168.4 (SD 13.5) versus 173.0 (SD 13.6) $beats \cdot min^{-1}$, $P<0.001$]. The $[la^-]_{p,3min}$ was $2.8\ mmol \cdot l^{-1}$ ($P<0.001$) lower in the women compared to the men. Only 40% of the women reached a $[la^-]_{p,3min}$ value of $8\ mmol \cdot l^{-1}$ or higher, compared to 79% of the men. To correct for a lower effort level of the women, as suggested by the lower $f_{c,max}$, multiple linear regression analysis was performed with $[la^-]_{p,3min}$ as dependent and age (year), sex (1 man; 0 women) and $f_{c,max}$ ($beats \cdot min^{-1}$) as independent variables ($n=3139$): $[la^-]_{p,3min}$ ($mmol \cdot l^{-1}$) $= 0.067 \times f_{c,max} + 2.5 \times sex - 0.055 \times age - 0.91$ ($r=0.48$, $P<0.001$). All individual coefficients in the multiple regression equation contributed significantly ($P<0.001$). This analysis shows a sex difference for $[la^-]_{p,3min}$ of $2.5\ mmol \cdot l^{-1}$ independent of age and $f_{c,max}$. Figure 1 shows the percentages of the population studied meeting different criteria of maximal effort based on $[la^-]_{p,3min}$ and $f_{c,max}$. Characteristics of the subpopulations based on these criteria are presented in Table 2.

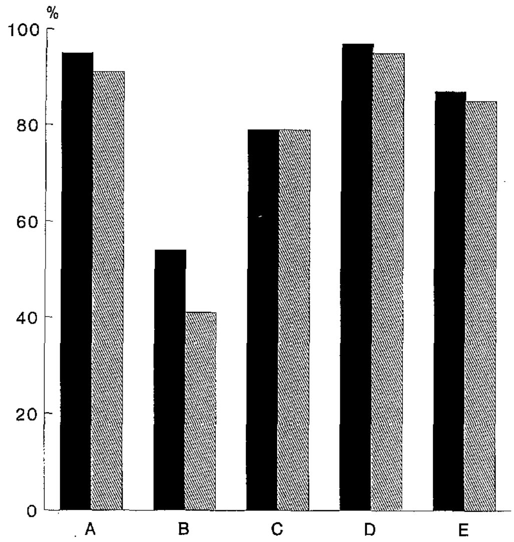

Fig. 1. Percentages of population meeting different criteria of maximal effort based on $f_{c,max}$ and $[la^-]_{p,3min}$; A, $f_{c,max} \geq 200$ minus age $beats \cdot min^{-1}$; B, $f_{c,max} \geq 220$ minus age $beats \cdot min^{-1}$; C, $[la^-]_{p,3min} \geq 8\ mmol \cdot l^{-1}$ (men), $[la^-]_{p,3min} \geq 5.5\ mmol \cdot l^{-1}$ (women); D, $f_{c,max} \geq 200$ minus age $beats \cdot min^{-1}$ and/or $[la^-]_{p,3min} \geq 8$ (men) or ≥ 5.5 (women) $mmol \cdot l^{-1}$; E, $f_{c,max} \geq 220$ minus age $beats \cdot min^{-1}$ and/or $[la^-]_{p,3min} \geq 8$ (men) or ≥ 5.5 (women) $mmol \cdot l^{-1}$; definitions as in Tables 1 and 2. ■ Men; ▒ women

In Table 3 the correlation coefficients between age, $f_{c,max}$ and $[la^-]_{p,3min}$ are presented for the men who achieved a $f_{c,max}$ equal to or greater than 220 minus age $beats \cdot min^{-1}$ and/or $[la^-]_{p,3min}$ equal to or greater than $8\ mmol \cdot l^{-1}$ and for the women who achieved a $f_{c,max}$ equal to or greater than 220 minus age $beats \cdot min^{-1}$ and/or $[la^-]_{p,3min}$ equal to or greater than $5.5\ mmol \cdot l^{-1}$. The correlation coefficients between age and $[la^-]_{p,3min}$ and between $[la^-]_{p,3min}$ and $f_{c,max}$ are low but statistically significant.

Discussion

If no gas analyses are performed in exercise testing, $f_{c,max}$ and lactate have often been used as objective criteria of maximal effort. In this study the influence of sex

Table 2. Characteristics and maximal exercise parameters of groups (A–E) based on different criteria levels

	Sex	A M $n=2056$ F $n=887$		B M $n=1190$ F $n=401$		C M $n=1710$ F $n=770$		D M $n=2099$ F $n=926$		E M $n=1904$ F $n=829$	
		mean	SD	mean	SD	mean	SD	mean	SD	mean	SD
Age (year)	M	47.0	6.4	47.6	6.4	46.4	5.8	46.9	6.3	46.7	6.1
	F	47.9	6.8	48.4	7.2	47.1	6.1	47.7	6.7	47.4	6.5
Body mass (kg)	M	77.2	8.7	77.0	8.3	77.0	8.5	77.2	8.7	77.1	8.5
	F	63.5	7.6	62.8	7.4	63.4	7.7	63.4	7.5	63.4	7.6
Height (m)	M	1.76	0.06	1.76	0.06	1.76	0.06	1.76	0.06	1.76	0.06
	F	1.63	0.06	1.63	0.06	1.64	0.06	1.63	0.06	1.64	0.06
Body fat (%)	M	23.5	5.1	23.7	4.9	23.4	5.0	23.5	5.1	23.4	5.0
	F	33.2	4.9	33.0	4.8	33.0	5.0	33.2	4.9	33.0	5.0
W_{max} (W)	M	252	47	255	47	257	45	252	47	255	46
	F	159	29	160	29	163	28	159	29	162	28
$W_{max}\cdot kg^{-1}$ ($W\cdot kg^{-1}$)	M	3.3	0.6	3.3	0.6	3.4	0.6	3.3	0.6	3.3	0.6
	F	2.5	0.5	2.6	0.5	2.6	0.5	2.5	0.5	2.6	0.5
$f_{c,max}$ ($beats\cdot min^{-1}$)	M	175	12	181	9	175	12	174	13	175	12
	F	171	11	179	7	171	12	170	12	171	12
$[la^-]_{p,3min}$ ($mmol\cdot l^{-1}$)	M	10.7	3.1	11.0	3.0	11.6	2.5	10.7	3.1	11.2	2.8
	F	7.9	3.7	8.3	2.7	8.6	3.6	7.9	3.7	8.4	3.6

A: maximal heart rate, $f_{c,max} \geq 200$ minus age $beats\cdot min^{-1}$; B: $f_{c,max} \geq 220$ minus age $beats\cdot min^{-1}$; C: $[la^-]_{p,3min} \geq 8$ $mmol\cdot l^{-1}$ (M), $[la^-]_{p,3min} \geq 5.5$ $mmol\cdot l^{-1}$ (F); D: $f_{c,max} \geq 200$ minus age $beats\cdot min^{-1}$ and/or $[la^-]_{p,3min} \geq 8$ (M) or ≥ 5.5 (F) $mmol\cdot l^{-1}$; E: $f_{c,max} \geq 220$ minus age $beats\cdot min^{-1}$ and/or $[la^-]_{p,3min} \geq 8$ (M) or ≥ 5.5 (F) $mmol\cdot l^{-1}$; other definitions as in Table 1

Table 3. Correlation coefficients between $f_{c,max}$, $[la^-]_{p,3min}$ and age in men and women who met the criterion of $f_{c,max} \geq 220$ minus age $beats\cdot min^{-1}$ and/or $[la^-]_{p,3min} \geq 8$ (men) or ≥ 5.5 (women) $mmol\cdot l^{-1}$ (group E, Table 2)

	Male	Female
$f_{c,max}$ versus age	−0.30***	−0.37***
$[la^-]_{p,3min}$ versus age	−0.21***	−0.11***
$f_{c,max}$ versus $[la^-]_{p,3min}$	0.13***	0.10**
(adjusted for age)	0.08***	0.06*

* $P<0.05$, ** $P<0.01$, *** $P<0.001$; other definitions see Tables 1 and 2

on plasma lactate concentrations after progressive maximal exercise testing was investigated. There were significant differences between the men and the women for $[la^-]_{p,3min}$ [10.5 (SD 3.2), 7.7 (SD 3.7) $mmol\cdot l^{-1}$, respectively] but also for $f_{c,max}$ [173.0 (SD 13.6), 168.4 (SD 13.5) $beats\cdot min^{-1}$, respectively] in our population. According to Hossack and Bruce (1982) no difference in $f_{c,max}$ between men and women in this age group should have been expected. This would suggest that the level of effort was lower in the women than in the men in our study. It is possible that this factor was responsible for the sex difference in $[la^-]_{p,3min}$ in combination with the difference in age between the women and men. To adjust for these factors multiple regression analyses were performed. These analyses showed that a significant sex difference of 2.5 $mmol\cdot l^{-1}$ still remained for $[la^-]_{p,3min}$, independent of age and $f_{c,max}$. It is important to stress that in both the men and the women similar methods were used, so sex differences cannot be the result of differences in methods used in the men and the women. Thus we concluded that a sex difference in $[la^-]_{p,3min}$ was indeed present and should be taken into account in maximal exercise testing.

In the literature studies showing a difference in plasma lactate concentrations between men and women can be found (Åstrand et al. 1973; Froberg and Pedersen 1984; Verstappen et al. 1989). Froberg and Pedersen (1984) have found a difference in maximal blood lactate concentration between men ($n=7$) and women ($n=6$) of 2 $mmol\cdot l^{-1}$ [12.3 (SD 1.9), 10.3 (SD 1.7) $mmol\cdot l^{-1}$, respectively], but it was not statistically significant. Verstappen et al. (1989) have found a significant sex difference (25 men and 11 women) in $[la^-]_{p,3min}$ of 2.3 $mmol\cdot l^{-1}$. Sidney and Shephard (1977) have found blood lactate concentrations of 11.1 $mmol\cdot l^{-1}$ in 19 sedentary men [age, 63.7 (SD 2.7) years] and 9.1 $mmol\cdot l^{-1}$ in 20 women [age, 63.4 (SD 3.6) years] showing a plateau of the oxygen consumption in a progessive treadmill test. The authors have suggested that the lower blood lactate concentration of the women may be indicative of a smaller ratio of the muscle mass to the total blood volume, a factor which has also been shown to contribute to the decline of maximal lactate concentration values with increasing age (Sidney and Shephard 1977). On the other hand, it cannot be ignored that differences in the production of lactate also contribute to a sex difference. Jacobs et al. (1983) have mentioned significant differences in muscle lactate concentration between men and women after performing a Wingate anaerobic test. It is suggested that female skeletal muscle has a lower glycogenolytic potential per unit of mass, reflected in lower phosphorylase and phosphofructokinase activities (Komi and Karlsson 1978; Nygaard 1981). It has been shown that lactate within the active muscle is not in equilibrium with that of the extracellular space and, consequently, of blood (Gollnick et al. 1986). Nevertheless, a lower lactate production rate in women is consistent with the lower $[la^-]_{p,3\,min}$ concentration.

From the correlation coefficients in Table 3, it would appear that the correlation of $[la^-]_{p,3\,min}$ with age is not very marked. Binkhorst et al. (1966) have found higher correlations in men. However, because of methodological differences, such as the selection of the population to be studied, it is difficult to compare these studies. One factor that may explain the low correlation in this study was the relatively small age distribution in our population. In establishing criteria for maximal effort in this population we decided not to include age, without suggesting that it may not be appropriate in other situations.

Besides $[la^-]_{p,3\,min}$, heart rate has also often been used as a criterion of maximal effort. Heart rate is a good indicator for the stress of the cardiovascular system, whereas peak blood lactate concentration reflects more the local stress of exercising muscles. Table 3 shows that the correlation between these variables was low (also when adjusted for age), which indicates that they were largely independent physiological parameters. Thus a combined criterion for maximal effort using both $f_{c,max}$ and $[la^-]_{p,3\,min}$ seems valid.

Several studies have determined regression equations of $f_{c,max}$ versus age (Binkhorst et al. 1966; Hossack and Bruce 1982). Åstrand and Rodahl (1986) have stated that it is quite meaningless to be too sophisticated in the choice of the target heart rate during maximal exercise testing. They have suggested a simple formula, assuming the average $f_{c,max}$ to be 220 minus the subject's age. The standard deviation of $f_{c,max}$ is 10 beats$\cdot$min^{-1}. Thus, on theoretical grounds, about half of a population would be expected to achieve a $f_{c,max}$ equal to or greater than 220 minus age and about 95% a $f_{c,max}$ equal to or greater than 200 minus age. In our population about 55% of the men and 41% of the women met this criterion of $f_{c,max}$ equal to or greater than 220 minus age and 95% and 91%, respectively, met the $f_{c,max}$ equal to or greater than 200 minus age criterion (Fig. 1). A considerable percentage of the male and female population reached a combination of the $f_{c,max}$ criterion of 220 minus age and/or $[la^-]_{p,3\,min}$ (88% and 85%, respectively). On the other hand, the results of the combination of the $f_{c,max}$ criterion of 200 minus age and/or $[la^-]_{p,3\,min}$ (D, Table 2) were similar to those of the $f_{c,max}$ criterion of 200 minus age alone (A, Table 2), indicating that this $f_{c,max}$ criterion dominated the $[la^-]_{p,3\,min}$ criterion. Making a choice between the criteria for maximal effort based on $f_{c,max}$ and $[la^-]_{p,3\,min}$ is arbitrary. The $f_{c,max}$ equal to or greater than 220 minus age beats$\cdot$min^{-1} and/or $[la^-]_{p,3\,min}$ equal to or greater than 8 mmol$\cdot$l^{-1} in men or $f_{c,max}$ equal to or greater than 220 minus age beats$\cdot$min^{-1} and/or $[la^-]_{p,3\,min}$ equal to or greater than 5.5 mmol$\cdot$l^{-1} in women seemed to be a more conservative combination.

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