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Reference values for the physical work capacity on a bicycle ergometer for men – a comparison with a previous study on women

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Summary

The aim of the study was to collect new reference values for the clinical ramp exercise test on bicycle, because in our experience, the commonly used values were too low. A group of healthy men ($n = 81$, 20–80 years) was randomly selected from the local municipal register to achieve an even distribution in age. Data were compared with those obtained in a similar, previous study on women ($n = 87$). The subjects were encouraged to cycle until exhaustion (19 on the Borg scale) when maximal load, heart rate and systolic blood pressure were recorded. Maximal load (W_{max}) was related to age (years) and height (m) using a non-linear function: $W_{max} = (244{\cdot}6 \times \text{height} - 92{\cdot}1)/\{1 + \exp[0{\cdot}038 \times (\text{age} - 77{\cdot}3)]\}$. Maximal heart rate ($HR_{max}$) was described by a similar function: $HR_{max} = 203{\cdot}7/\{1 + \exp[0{\cdot}033 \times (\text{age} - 104{\cdot}3)]\}$. The maximal systolic blood pressure (BP_{max}) was described by a linear function based on age: $BP_{max} = 0{\cdot}505 \times \text{age} + 192$. Similar functions for the women are also given. It is suggested that 80–120% of the predicted maximal load can be taken as a reference interval for both men and women and similarly 90–110% of the maximal heart rate. In this study, 84% of the men reached a maximal load within the reference interval and 93% maximal heart rate within the reference interval. The reported values for maximal load were 104–132% of the reference values published by others.

Introduction

Exercise tests are of importance to quantify an individual's physical capacity in the presence (Jonson *et al.*, 1998) as well as in the absence of disease (Wisén & Wohlfart, 1999). Nowadays, the clinical exercise test is most commonly performed on a bicycle, as a ramp test with a continuous increase in load. In a preliminary study, we found that women reached a higher maximal load than predicted from the commonly used reference values. In order to obtain a correct clinical evaluation, it is important to have up-to-date reference values. Reference values are likely to vary over time because of changes in life style, amount of exercise and body weight, and may also vary between different geographical regions, partly because of cultural differences. Reference values must therefore be revised regularly and the aim of this study was to present new reference values. In a recent study, we reported reference values such as maximal workload, maximal heart rate and maximal systolic blood pressure for women (Farazdaghi & Wohlfart, 2001). This study is a direct continuation of that work and the corresponding reference values for men are presented and also compared with the previous data collected on women. A comparison is also made with reference values published by others.

Method

The protocol used in this study is almost identical to that of the previous study on 87 women (Farazdaghi & Wohlfart, 2001).

Subjects

An invitation to participate in the study was sent to 420 men in the municipality of Lund. The subjects were randomly selected from the municipal population register. Those born on a certain day of the month (starting from the 10th, followed by 11th, and so on) were chosen to obtain a group with a uniform distribution of ages. The subjects were required to be healthy (as stated in the invitation letter) and able to perform a maximal exercise test, with no history of cardiac or lung disease and not on regular medication. Ninety-four men accepted the invitation to participate in the study. A structured questionnaire was used to evaluate the health and the physical activity level of each subject.

Resting ECG was recorded and blood pressure was measured. Thirteen men were excluded because the ECG revealed conduction abnormality (m = 7), left ventricular hypertrophy (m = 2), or ST depressions before or during exercise (m = 4). Finally, 81 men were included in the study. The study was approved by the Ethics Committee of Lund University.

Exercise test

One person monitored all the clinical exercise tests on the bicycle ergometer (on both women and men). The volunteers had been asked not to perform any strenuous exercise on the day before the test. They were asked not to eat a heavy meal up to 2 h before the test, or smoke up to 30 min before the test. After receiving both oral and written information, informed consent was obtained. A 12-lead electrocardiogram (ECG) was recorded before the test and it was required that the ECG was 'normal' or 'probably normal'. Systolic and diastolic blood pressure was measured in the right arm using a mercurymanometer. Body weight and height were measured, in light clothing without shoes before the cycling test (values are given in Table 1). An ECG was recorded continuously during the test. A Siemens Megacart electrocardiograph and an Ergomed 940 ergometer were used (Siemens-Elema AB Electrocardiography Division Solna, Sweden). The pedalling rate was close to 60 min^{-1}. The systolic blood pressure was measured every 2 min followed by Borg's rate of perceived exertion (RPE) scale (Borg, 1982). For the Borg scale, the subjects were asked to evaluate the general level of perceived exertion (respiratory/overall) and the values were entered on the Megacart. The last systolic blood pressure (reported as the maximum in this study) was measured during the last minute of cycling. The exercise test started at 50 W and the load was increased by 5 W every 20 s until exhaustion (the women in the earlier study started at 30 W and the load was increased by 5 W every 30 s). Care was taken to ensure maximal tests (to 19 on the Borg scale). The ECG recording continued 4 min after exercise with the test person resting on a bed. Finally, the blood pressure was again measured.

Statistics

The measurements were manually entered into a spreadsheet program (Microsoft Excel) for the statistical analysis and the mean ± SD was calculated. Curve fitting was performed within the program by minimization of the squared deviations between specified functions and observed values. The deviations from the specified functions were quantified as RMS (root mean square).

Results

Demographic data and measured values for the different decades of age are given in Table 1. Fifty-three of the men had reached 19 or more on the Borg scale by the end of exercise. Questions were asked about the daily physical activity of the men. 'Regular exercise at moderate intensity' was performed by 27 subjects and 'regular (at least twice per week) exercise at a low intensity' was performed by 25 subjects. The subjects in this study were predominantly physically active at low or moderate levels and a small fraction was completely inactive.

The maximal load attained was dependent on age, as shown in Fig. 1a. The load declined from about 310 W (20 years) to 160 W (80 years). It can be seen that the *rate* of decline increased progressively with each age decade. Mean values from the previous study on women ($n = 87$) are reproduced in Fig. 1a (dotted curve). It is clear that men performed at a level about 75–100 W higher than the women and also that the *rate* of work decline with age was greater for the men than for the women. The following non-linear functions describe the relation between the maximal load, and age and height (in m) for the men and the women.

Table 1 Characteristics of the men for different age groups. Values are given as the mean ± SD and range. Number of subjects (n), and number of smokers (in parentheses), $n = 81$ (11). Systolic blood pressure at rest (SBP_{rest}), diastolic blood pressure at rest (DBP_{rest}), maximal systolic blood pressure (SBP_{max}), maximal heart rate (HR_{max}), rating of perceived exertion at the end of the exercise test using the Borg scale (6–20, $Borg_{max}$) and maximal workload ($Load_{max}$).

Age groups	Age (years)	Weight (kg)	Height (m)	SBP_{rest} (mmHg)	DBP_{rest} (mmHg)	SBP_{max} (mmHg)	HR_{max} (min^{-1})	$Borg_{max}$	$Load_{max}$ (W)
20–29	26·3 ± 2·9	80 ± 7	1·80 ± 0·06	124 ± 10	73 ± 6	208 ± 15	191 ± 9	18·8 ± 0·6	303 + 43
n = 14 (3)	22·6 – 29·8	70 – 94	1·72 – 1·89	110 – 145	60 – 85	185 – 240	171 – 204	17 – 19	245 – 395
30 – 39	34·5 ± 25	80 ± 9	1·78 ± 0·07	120 ± 14	78 ± 6	205 ± 18	182 ± 10	18·7 ± 0·9	288 ± 40
n = 16 (1)	30·2 – 37·6	66 – 104	1·66 – 1·94	100 – 150	70 – 85	170 – 235	161 – 200	17 – 20	240 – 380
40 – 49	45·8 ± 2·9	77 ± 11	1·79 ± 0·08	123 ± 12	79 ± 8	215 ± 16	181 ± 12	18·4 ± 1·1	261 ± 48
n = 18 (3)	40·2 – 48·8	60 – 93	1·64 – 1·91	110 – 150	60 – 90	190 – 250	154 – 201	15 – 19	165 – 335
50 – 59	57·3 ± 3·1	82 ± 8	1·81 ± 0·05	132 ± 11	85 ± 8	220 ± 22	170 ± 12	18·2 ± 1·3	257 ± 40
n = 12 (1)	50·5 – 60·0	73 – 94	1·71 – 1·90	120 – 150	70 – 100	180 – 245	150 – 197	15 – 19	215 – 325
60 – 69	65·8 ± 2·8	78 ± 10	1·76 ± 0·05	144 ± 20	85 ± 7	223 ± 35	154 ± 13	16·5 ± 2·3	192 ± 37
n = 11 (3)	61·8 – 69·3	54 – 92	1·66 – 1·83	110 – 170	75 – 100	155 – 280	128 – 177	11 – 19	120 – 265
70 – 79	74·0 ± 2·5	83 ± 10	1·75 ± 0·08	146 ± 18	83 ± 6	232 ± 28	151 ± 9	17·9 ± 1·4	186 ± 24
n = 10 (0)	70·5 – 78·8	70 – 108	1·63 – 1·83	105 – 165	70 – 90	185 – 270	141 – 166	15 – 19	155 – 220

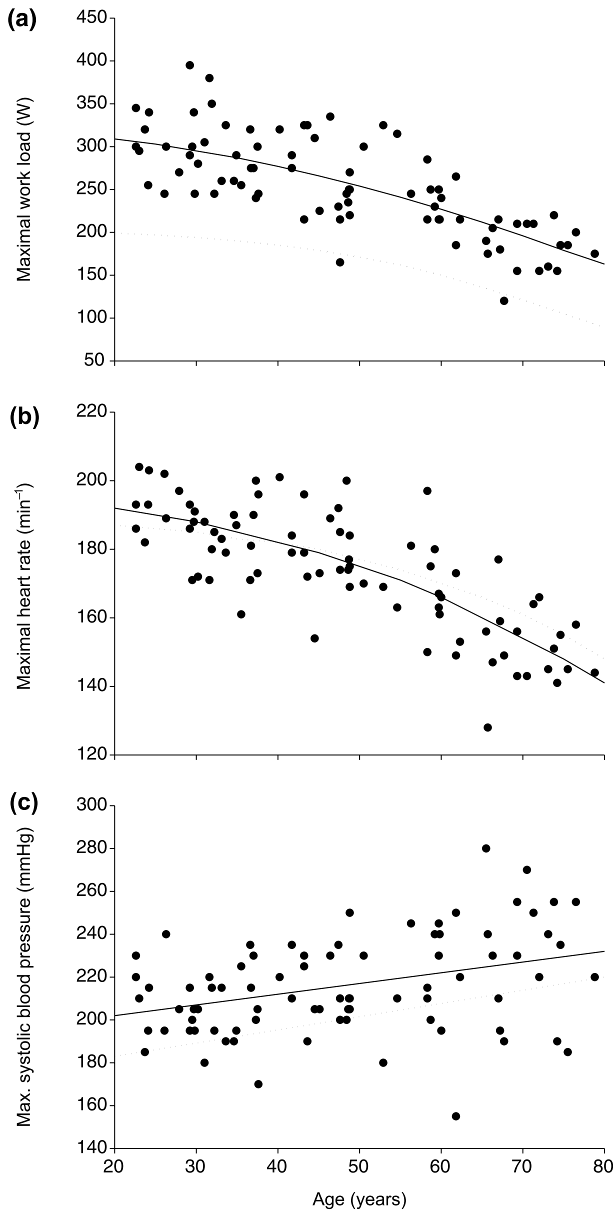

Figure 1 Measured values at the end of a ramp exercise test in a group of healthy men ($n = 81$). Functions, as described in the text, have been fitted to the original data (solid curves). For comparison mean values from the similar study on healthy women ($n = 87$) are also given (dotted curves).

$$W_{max} = \frac{244 \cdot 6 \times \text{height} - 92 \cdot 1}{1 + e^{0 \cdot 038 \times (\text{age} - 77 \cdot 3)}} \quad \text{(men)} \qquad (1)$$

$$W_{max} = \frac{137 \cdot 7 \times \text{height} - 23 \cdot 1}{1 + e^{0 \cdot 064 \times (\text{age} - 75 \cdot 9)}} \quad \text{(women)} \qquad (2)$$

The mean heights of the men and women (1.78 and 1.65 m, respectively) were used to calculate the curves shown in Fig. 1a. The mean deviation between the measured workload and the predicted workload was 36 W for the men and 24 W for the women. A comparison between the equations indicates that the dependence on height was greater for the men than for the women.

A normal range for maximal workload is often taken as 80–120% of the predicted value (Nordesjö & Landelius, 1975). In this study, 68 (84%) men reached this level. A lower maximal workload was reached by six men (62–78%) and a higher load by seven men (120–127%). The standard deviation for both men and women was 14%.

Maximal heart rate is related to age in Fig. 1b. It can be seen that the maximal heart rate did not decline with age in a linear fashion. Rather, a curve described the relationship. The mean deviation between measured values and the curve shown was 11 beats min^{-1}. It is clear that the rate of reduction in heart rate with age increased with age for the men. The reduction with age for the women, however, (dotted curve in Fig. 1b) was shallower than for the men. At the age of 20 the women had a maximal heart rate that was 5 beats min^{-1} lower than the men, but at the age of 80 the heart rate for women was 7 beats min^{-1} higher than for the men. The following equations describe the relation between maximal heart rate and age for the men and the women.

$$HR_{max} = \frac{203 \cdot 7}{1 + e^{0 \cdot 033 \times (\text{age} - 104 \cdot 3)}} \quad \text{(men)} \qquad (3)$$

$$HR_{max} = \frac{190 \cdot 2}{1 + e^{0 \cdot 045 \times (\text{age} - 107 \cdot 5)}} \quad \text{(women)} \qquad (4)$$

In the previous study on women 90–110% of predicted maximal heart rate was suggested as a reference interval. Seventy-five men attained the predicted heart rate. Three had a lower heart rate (80–87%) and three exhibited a higher heart rate (112–118%). For the whole group of men the mean predicted heart rate was 100 ± 6.5% and the corresponding values for the women were 100 ± 5.5%.

The systolic blood pressure at the end of the exercise test was about 200 mmHg for 20 years old and about 230 mmHg for 80 years old, as shown in Fig. 1c. In general, the men had a higher systolic blood pressure at the end of work than the women (about 20 mmHg higher at the age of 20 years and 10 mmHg higher at the age of 80 years. The maximal blood pressure increased with age (by about 0.5–0.6 mmHg $year^{-1}$) as indicated by the regression lines for men and women given below.

$$BP_{max} = 0 \cdot 505 \times \text{age} + 192 \quad \text{(men)} \qquad (5)$$

$$BP_{max} = 0 \cdot 619 \times \text{age} + 171 \quad \text{(women)} \qquad (6)$$

The mean systolic blood pressure (±SD) at the end of the exercise test for the different decades of age are given in Table 1. It can be seen that the SD was between 15 and 35 mmHg and that the SD tended to increase with age.

Discussion

The subjects

The test subjects were randomly selected from the local municipal population register. However, it is most probable that the most sedentary individuals did not accept the invitation to perform the exercise test. But some individuals, probably less well trained, used the opportunity to perform a medical health test. As stated above 13 subjects were excluded from the study because of pathological resting ECG or an exercise test indicating coronary insufficiency.

When testing a subject who is either sedentary or very fit, comparing the measured maximal workload with the mean reference value given in this study (100% of the predicted value) may not be the best approach. The degree of physical fitness of the subject should perhaps be included in the evaluation of the test result. Physically fit individuals are likely to attain more than 120% of the predicted value while sedentary individuals are likely to achieve somewhat below 80%.

The same groups of men and women have been used to test and validate a novel one-page RPC (rating of perceived capacity) scale (Wisén *et al.*, 2002). The subjects were asked to rate their physical capacity before performing the exercise test. The RPC (recorded in units of METs, metabolic equivalents) was corrected for age, weight and a systematic bias to obtain a predicted exercise capacity. The difference between the recorded maximal load and the corrected RPC was 38 W. This value is similar to the value of 36 W given above, i.e. the mean absolute difference between recorded and predicted maximal load based on age and height.

Comparison with other studies

The mean values for the work capacity of men in this study are higher (by 73–80 W) than the mean values given by Nordenfelt *et al.* (1985). An explanation could be that nowadays, in the clinic, patients are encouraged to keep on cycling to a level closer to their maximum than was typical earlier (we aimed at 19 on the Borg scale). In line with this, we also observed higher maximal heart rates (3–18 beats min^{-1}). Also, Nordenfelt *et al.* (1985) increased the load more slowly but in greater steps (10 W min^{-1}) than the 5 W every 20 s in this study. In general, women and men in this study both reached 132% of the maximal load given by Nordenfelt *et al.* (1985). We have also made comparisons with reference materials published by others. In comparison with Åstrand (1960) the women reached 92% of the predicted values and the men 104%. For this comparison, the load recorded in this study had to be converted to maximal oxygen uptake and expressed in units of ml min^{-1} kg^{-1}. The following formula (from our own unpublished data based on cycling with measurements of oxygen uptake) was used.

$$VO2_{max} = 4{\cdot}3 + 10{\cdot}93 \times \frac{W_{max}}{\text{weight}} \qquad (7)$$

As Åstrand (1960) only presented values up to the age of 69 years for men and 65 years for women, our linear regression analysis had to be extrapolated to 80 years for the comparison to be made. In comparison with values given by the American Heart Association (Fletcher *et al.*, 1990) our women and men both achieved 104% and in comparison with the normal values given by Wasserman *et al.* (1994) the women reached 134% and the men 121%. This means that our reference values in general are somewhat higher than the values published by others. Our study may also reflect the fact that nowadays more people regularly perform physical exercise than before. Many of the test subjects lived in the city of Lund, which is hilly and where cycling is common.

Heart rate

The maximal heart rate declined with age for both the men and the women. Between 20 and 80 years the mean decline for the men was 51 min^{-1} [eqn (3)]. The decline with age was greater for the older ages (11 min^{-1} between 60 and 70 years) than for the younger ages (6 min^{-1} between 30 and 40 years). The decline in heart rate with age is thus clearly not linear. We therefore decided to use a non-linear function to describe the relationship. A range of 90–110% of the predicted value may be suitable as a reference interval, as in this study, 93% of the men fell within this range.

Blood pressure

We have presented mean values for blood pressure in relation to age (as regression lines) for men and women in this study. We consider it controversial to suggest upper and lower limits of a reference interval. We did not include subjects treated for hypertension in the study but did, on the other hand, not exclude subjects with high blood pressure before the exercise test. At the end of the exercise two test men clearly showed high blood pressures (270 and 280 mmHg). These high values must have shifted the regression line to some extent towards higher blood pressure.

Reproducibility

When an exercise test is performed with the same test person a second time, the test values will probably differ. In the second test, the maximal load, maximal heart and maximal systolic blood pressure are often greater. This can be explained by the test person being more accustomed to the test situation leading to a better performance. In a previous study, we examined the reproducibility of the exercise test (Wergel-Kolmert *et al.*, 2002). The reproducibility expressed as 2 SD of the differences between the two tests was 23 W for maximal load and 10 min^{-1} for the maximal heart rate.

Differences between men and women

As expected, the men in general reached higher maximal loads than the women. Common explanations for this are the greater height and weight of men compared with women and also a greater muscle mass. The maximal load decreased with age in both men and women, but the decline was more pronounced in the group of men. Also, maximal heart rate declined with age, slightly more for the men than for the women. It thus seems that the effects of age on maximal load and maximal heart rate were less pronounced in women, at least up to the age of 50 years. The mean increase in maximal blood pressure with age, on the other hand, was more pronounced for the women. Especially after the age of 50 years, some women exhibited high maximal systolic blood pressures (250–270 mmHg). The slope of the regression line between blood pressure and age was 0.6 mmHg year^{-1} for the women and 0.5 mmHg year^{-1} for the men.

The reference values presented in this study are higher than those generally used in Sweden. The reason for this is probably that we encouraged the test persons to perform a close-to-maximal exercise test. Such a test must be more informative than an exercise test that is terminated at an earlier stage.

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