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Maximal oxygen uptake in 153 elderly Dutch people (69–87 years) who participated in the 1993 Nijmegen 4-day march

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Abstract There are no studies on oxygen uptake of groups of physically active subjects aged over 70. This study describes the maximal oxygen uptake ($\dot{V}O_{2max}$) of 153 elderly people who completed the Nijmegen annual 4-day march (at least 30 km · day^{-1}) in 1993. A total of 97 men with a mean age of 76.7 (SD 4.6) and 56 women with a mean age of 72.8 (SD 3.6) years participated in the study. The $\dot{V}O_{2max}$ was determined using incremental cycle ergometry; 91 men and 49 women completed a maximal exercise test. Criteria for maximal performance were respiratory exchange ratio equal to or greater than 1.00, vertilatory equivalent for oxygen equal to or greater than 30.00 and maximal heart rate equal to or greater than (beats · min^{-1}) 210 minus age (years). Mean maximal power output was 148.2 (SD 27.2) W and 120.4 (SD 20.5) W, mean $\dot{V}O_{2max}$ · body mass^{-1} was 26.8 (SD 4.9) ml · kg^{-1} · min^{-1} and 24.6 (SD 4.7) ml · kg^{-1} · min^{-1}, mean maximal heart rate was 152 (SD 18), and 157 (SD 14) beats · min^{-1} in men and women respectively. The mean $\dot{V}O_{2max}$ · body mass^{-1} was about 20% higher than reported in other studies on subjects over 70 years of age. Mean maximal heart rate was about 10 beats · min^{-1} higher than predicted from the equation 220 − age. The negative effect of chronic disease on $\dot{V}O_{2max}$ · body mass^{-1} was smaller than in a sedentary reference population. The mean decline in $\dot{V}O_{2max}$ · body mass^{-1} with age was 0.46 and 0.38 ml · kg^{-1} · min^{-1} per year in the men and women respectively, which is the same rate as found in younger subjects. It was concluded that regular exercise might substantially increase aerobic power in the physically active elderly, even when they have chronic disease, and that it is unlikely that there is an accelerated loss of aerobic power in physically active elderly people aged over 70 year.

Key words Exercise · Cycle ergometry · Successful aging Physical activity · Health

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Introduction

In the last decade the fitness of the aging population has become an important area of research. This interest has been stimulated by gerontologists (Posner et al. 1986), physiologists (Kemper and Binkhorst 1993) and cardiologists (Haskell 1985), because the elderly is the fastest growing segment of western populations (Campion 1994) and fitness is an important determinant of quality of life (Greig and Young 1992).

One indicator of fitness, the maximal oxygen uptake ($\dot{V}O_{2max}$), has been extensively studied in humans. However, only a few studies (Hollmann et al. 1978; Nieman et al. 1989), have included elderly people over the age of 70 years. There is general agreement that $\dot{V}O_{2max}$ declines with aging. The positive effects of physical training on fitness and health are well documented in selected groups, as are the negative effects of a sedentary lifestyle and diseases (Lakatta 1993).

The rate of decline of $\dot{V}O_{2max}$ with increasing age shows considerable variation, which might be explained by differences in physical activity and the prevalence of chronic diseases among the population under study, ergometry procedures, and study design. The rate of decline ranges from 0.2 to 0.8 ml · kg^{-1} · min^{-1} · year^{-1} in both sexes, while conflicting results of an accelerated loss have been shown after the age of years (Nieman et al. 1989).

Most studies on exercise and aging have excluded subjects with chronic diseases of (asymptomatic) coronary artery disease in order to separate the effects of aging per se (primary aging) from the effects of chronic disease (secondary aging). This has led to considerable selection of the population under study, especially of the elderly, because of the high prevalence olf hypertension and (asymptomatic) cardiovascular diseases in the elderly (Fleg 1986). The effect of this selection has been clearly described by Greig et al. (1994), who could include only 17% of the 585 volunteers over the age of 60 years who responded to a series of newspaper articles.

"Normal aging" is almost impossible to define, because many physiological variables show considerable variation within groups of elderly people. Rowe and Kahn (1987) have reported that in many studies describing an important average decline of a function with age, there are subjects who show no or hardly any decline of function compared with younger counterparts. Confronted with this problem they have introduced the concept of "successful aging" as opposed to "normal" and "pathological aging". It is important to study what "successful aging" is and what determines the "success" of the aging process. It has proved difficult to incorporate this attractive idea into the design of study.

We incorporated the concept in this study by selecting elderly people capable of considerable performance since they had completed the annual 4-day long-distance march in Nijmegen in 1993. The aim of this study was to determine the $\dot{V}O_{2max}$ of this group.

Methods

Subjects

Because the subjects had to be invited to participate in the study early in 1993, we selected them from the list of participants in the 1992 4-day march. This was possible because many elderly participants complete the 4-day march every year; over 50% had completed it more than ten times. In 1992, 539 men and 112 women born before 1924 (69–87 years) participated in the Nijmegen 4-day march. In our study we aimed at following 100 male and 100 female subjects, thus a quarter of these men and all the women were invited to participate. Relatively more men from the older cohorts (≥ 80 years) were invited to ensure an even age distribution. A total of 97 men [mean age 76.7 (SD 4.52) years] and 56 women [mean age 72.8 (SD 3.52) years] agreed, which was a positive response of 61% and 50% for men and women, respectively. The reasons given for non-participation in this study were health-related (elective surgery, trauma, etc.) in 26%, not health-related (family circumstances, holiday, etc.) in 39% and unknown in 35%. The subjects had to complete the 1993 march. This meant they had to walk 30 or 40 km each day on 4 consecutive days in July 1993. All the subjects gave their written informed consent and the study protocol was approved by the Ethics Committee of the Faculty.

Protocol

Between May and October 1993 all the subjects visited the Department of Physiology. Resting blood pressure, resting electrocardiogram (ECG) and anthropometric data were collected before breakfast. They performed an exercise test and were interviewed after a light breakfast or lunch. The exercise tests were performed in an ergometry laboratory. The room temperature was kept between 18.5 and 20.5°C and relative humidity varied between 66% and 90%. The total duration of a test session was on average 1 h, of which at least 30 min were spent instructing the subjects.

Medical history and habitual physical activity

These data were obtained from a questionnaire (Euronut SENECA investigators 1991); the interviewer was a trained medical student. The subjects were asked which, if any, chronic diseases they had and were classified in five categories (no chronic diseases, hypertension, other cardiovascular diseases, respiratory diseases, other chronic diseases). They were also asked whether they chronically used prescribed drugs and whether they were currently smokers. The habitual physical activity assessment was based on household activities, sports and other activities. The latter two were quantified by hours per week, month per year and an intensity code. This physical activity questionnaire has been validated in elderly Dutch people (Voorrips et al. 1991).

Anthropometric measurements

Body composition assessment included height in centimetres, total body mass in kilograms and skinfold measurements of the biceps and triceps muscles with a skinfold caliper (Holtain, Crosswell, UK). Body density was predicted using the regression equation to Visser et al. (1994), based on two skinfolds, which has been validated for elderly subjects. In the study of Visser et al. (1994) body density determination based on the sum of four skinfolds (supra-iliaca, sub-scapula, and biceps and triceps muscles) did not give better results than body density determination based on the sum of two skinfolds (biceps and triceps muscles). Body fat percentage (% BF) was calculated from density using the equation of Siri (1956).

Ergometry

Cycle ergometry was chosen instead of treadmill ergometry as the type of exercise for three reasons. Firstly almost all Dutch people are accustomed to cycling, secondly the external load can be determined accurately and thirdly with cycle ergometry the subject can be monitored better than with tread-mill ergometry. Before the exercise test a medical history, standard resting 12-lead ECG (Hewlett Packard 4745A, Amsterdam, The Netherlands) and blood pressure after 10 min of supine rest (mercury-sphygmomanometer, Erkameter, Bad Tölz, Germany) were recorded and, if indicated, a subject was examined by a physician to screen for exclusion criteria for maximal exercise. Exclusion and finishing criteria for maximal exercise as has been described by Posner et al. (1986) were used. These criteria are based on cardiovascular history, physical examination, resting ECG and blood pressure, and, in addition, symptoms, signs, blood pressure and ECG during exercise.

Ergometry was performed using a cycle ergometer (Lode L54/autolaod, Groningen, The Netherlands). The subjects were asked to maintain a pedalling rate of 60 rpm during a 6 min warm-up with a heart rate of 100–110 beats$\cdot$min^{-1}. The use of the mouthpiece was demonstrated and practised before the test and the mouthpiece were inserted after the warm-up. This was followed by a stepwise increasing intensity (10 W$\cdot$min^{-1}) until complete exhaustion. The time between warming-up and complete exhaustion varied from 5 to 10 min. The subjects were verbally encouraged to continued during the final stages. During the test, the subjects were monitored using an exercise ECG (modified V5 lead) and arterial oxygen saturation (S_aO_2), measured continuously using pulse oximetry (N200, Nellcor, Hayward, Calif., USA) on the forehead right above the left superior orbital margin. Respiratory gas analysis was conducted using an Oxycon IV (Mijnhard, Bunnik, The Netherlands). Base excess (BE) was analysed in a capillary earlobe sample after treatment with Finalgon (Boehringer Ingelheim, Alkmaar, The Netherlands), a cutaneous vasodilator cream. Samples were obtained before the test and 2 and 3 min into recovery (1312 Blood Gas Manager, Instrumentation Laboratory, Milan, Italy). The change in BE (ΔBE) was the largest difference between retest and post-test results. Physiological variables were calculated as the average of the highest two of the last three 30-s recordings during increasing intensity to avoid the influence of peak values on the results. Therefore, we have used the term $\dot{V}O_{2max}$ and not $\dot{V}O_{2peak}$.

Because we did not want to overexert our subjects, who were not selected on the basis of absence of diseases, we included, prior to testing, the following conservative criteria for maximal performance in our protocol; maximal heart rate (HR_{max}) equal to or greater than 220 − age − SD (years) beats · min^{-1} (SD = 10) (Åstrand and Rodahl 1977), respiratory exchange ratio (*R*) equal to or greater than 1.00 (Sidney and Shephard 1977) and ventilatory equivalent for oxygen equal to or greater 30.00. The levelling off of $\dot{V}O_2$ with increasing intensity was not used as a criterion since 50%–70% of subjects have been shown not to be able to meet this criterion (Sidney and Shephard 1977; Åstrand 1952). A performance was considered to be maximal if a subject met two out of three criteria, or if HR_{max} was equal to or greater than 210 − age (years) when respiratory data were missing.

Statistical methods

Differences between mean values were tested using the Student *t*-test and correlations between variables are given as Pearson's correlation coefficient. A value of *P* equal to or less than 0.05 was accepted the level of significance.

Results

Population

All the subjects included in this study completed the 1993 annual Nijmegen 4-day long-distance march. After initial consent 1 man and 1 woman refused further participation in the study because they considered the protocol to be too demanding. One man was excluded from the maximal test based on the criteria used for the ending of exercise (Posner et al. 1986). He showed premature ventricular complexes of increasing frequency on the exercise ECG during the warm-up. A total of 95 men and 55 women completed the exercise test. In the women there was a skewed age distribution; most of the women were aged between 70 and 75 years.

Medical history and habitual physical activity

The participants in this study enjoyed a high level of habitual physical activity. The men walked on average 4.8 (SD 3.1) h · week^{-1} throughout the year for recretion, the women walked 5.4 (SD 4.0) h · week^{-1}. Weekly time spent walking averaged over the previous year was not significantly correlated to age, either in the men ($r = 0.05$, P = NS) or in women ($r = 0.16$, P = NS). The mean physical activity questionnaire score was 20.7 (SD 12.2) in the men and 15.7 (SD 8.3) in the women and the physical activity questionnaire score was not significantly correlated to age, either in the men ($r = -0.05$, P = NS) or in the women ($r = -0.01$, P = NS). Walking constituted 31% of the total physical activity questinonnaire score for the men and 45% for the women.

Of the men, 45% had some form of chronic disease (Table 1): 16% had hypertension, 20% had coronary or cerebral vascular diseases and 3% had pulmonary diseases. For the women these figures were 44%, 15%, 4% and 9% respectively. Several subjects had more than one chronic disease. Prescribed drugs were used chronically by 48% of the men and 42% of the women; 20% of the men and 7% of the women were currently smokers, 79% of the men and 35% of the women were former smokers.

Anthropometry

Age and body composition are shown in Table 1. Except for a weak but significant correlation of height with age in the men ($r = -0.05$, $P = 0.019$) no other anthropometric values were statistically significant when correlated with age (data not shown).

Table 1 Age, anthropometric data, blood pressure at rest, hours of recreational walking per week over the last year, Physical Activity Questionnnaire score (Voorrips et al. 1991), Self-reported prevalence of chronic diseases, chronic diseases, chronic use of prescribed medication and smoking habits, in the participants in this study. $BP_{s,rest}$ systolic blood pressure at rest, $BP_{d,rest}$ diastolicblood pressure at rest

	Male subjects ($n = 96$)		Female subjects ($n = 55$)	
	mean	SD	mean	SD
Age (years)	76.67	4.55	72.82	3.55
Body mass (kg)	73.93	9.29	64.37	9.20
Body height (cm)	172.4	6.4	160.9	5.6
Body mass index (kg · m^{-2})	24.8	2.3	24.8	3.1
Body fat percentage (%)	30.1	1.7	41.8	1.6
$BP_{s,rest}$ (mmHg)	149	23	153	23
$BP_{d,rest}$ (mmHg)	84	12	86	10
Weekly time spent walking (h · week^{-1})	4.8	3.1	5.4	4.0
Pysical Activity Questionnaire score	20.7	12.2	15.7	8.3
All chronic disease (*n*)	43		24	
– Hypertension (*n*)	15		8	
– Cardiovascular disease (*n*)	20		2	
– Respiratory diseases (*n*)	3		5	
Chronic use of medication (*n*)	46		23	
Smoking (*n*)	19		4	

Table 2 Results of the maximal exercise tests on the participants in this study. W_{max} Maximal delivered power, $\dot{V}O_{2max} \cdot$ body mass^{-1} maximal oxygen uptake, per kilogram body mass, HR_{max} maximal heart rate, $\dot{V}_E \cdot \dot{V}O_2^{-1}$ maximal minute ventilation per maximal oxygen uptake R respiratory exchange ratio, ΔBE change in base excess (BE) (lowest BE 2–3 min after exercise minus BE at rest) x − 1, $\dot{V}_{Emax}$ maximal minute ventilation $\dot{V}_{Tmax}$ tidal volume at maximal exercise, $f_{b,max}$ breathing frequency at maximal exercise

	Men			Women		
	mean	SD (*n*)	range	mean	SD (*n*)	range
W_{max} (W)	148.2	27.2 (91)	80–210	120.4	20.5 (49)	70–160
$\dot{V}O_{2max} \cdot$ body mass^{-1} ($ml \cdot kg^{-1} \cdot min^{-1}$)	26.8	4.9 (86)	16.2–37.7	24.6	4.7 (46)	14.3–35.6
HR_{max} (beats $\cdot min^{-1}$)	152.4	18.3 (91)	78–193	157.1	14.2 (49)	132–183
$\dot{V}_E \cdot \dot{V}O_2^{-1}$	40.7	6.4 (86)	29.5–54.7	39.1	5.6 (46)	28.1–52.6
R	1.15	0.07 (86)	1.03–1.33	1.16	0.07 (46)	1.03–1.40
ΔBE ($mmol \cdot l^{-1}$)	7.9	2.3 (91)	3.4–14.0	7.2	2.0 (49)	2.4–11.9
$\dot{V}_{Emax}$ ($l \cdot min^{-1}$)	78.5	18.7 (86)	40.1–131.4	60.5	10.4 (46)	32.9–84.0
V_{Tmax} (l)	2.2	0.4 (86)	1.22–3.26	1.6	0.2 (46)	1.18–1.96
$f_{b,max}$ (min^{-1})	36.7	7.8 (86)	20–65	38.6	6.9 (46)	26–53

Performance

One male and 1 female subject were not willing to continue after the warm-up. A total of 3 men and 5 women did not meet at least two out of three criteria for maximal performance and their results were omitted from the analysis of maximal exercise. Finally, 91 men and 49 women delivered a maximal performance. Respiratory data were missing for 5 of these men and 3 of these women who were not able to breathe through a mouthpiece.

Maximal exercise

The results from the maximal exercise tests are summarized in Table 2. The ranges of the physiological variables at maximal exercise were considerable, the coefficients of variation for maximal power output (W_{max}) and $\dot{V}O_{2max}$ were around 18% in both the men and the women. The individual data on $\dot{V}O_{2max} \cdot$ body mass^{-1} are presented in Figs. 1 and 2 for the men and women, respectively. For comparison, regression lines based on this study and on the work by Hollmann et al. (1978) with elderly men and Nieman et al. (1989) with elderly women are shown.

Based on the results of this study, regression equations describing the relationship of W_{max} and other variables with age are shown in Table 3. The mean $\dot{V}O_{2max} \cdot$ body mass^{-1} declined with age by 0.46 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ in the men and 0.38 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ in the women. Adjusted for fat free mass (FFM) the mean rate of decline of $\dot{V}O_{2max}$ with age was 0.66 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ in the men and 0.72 $ml \cdot kg^{-1} \cdot min^{-1} \cdot year^{-1}$ in the women. There were no differences between the men and women with respect to HR_{max}. The rate of decline of HR_{max} with age was statistically significant in the men and not dependent on sex.

In both sexes maximal ventilation ($\dot{V}_{Emax}$) decreased with age due to a significant decrease with age of the tidal volume (V_T) at maximal exercise (V_{Tmax}). The R and ventilatory equivalent were not related to age, neither was ΔBE in the men. In the women ΔBE was related to age.

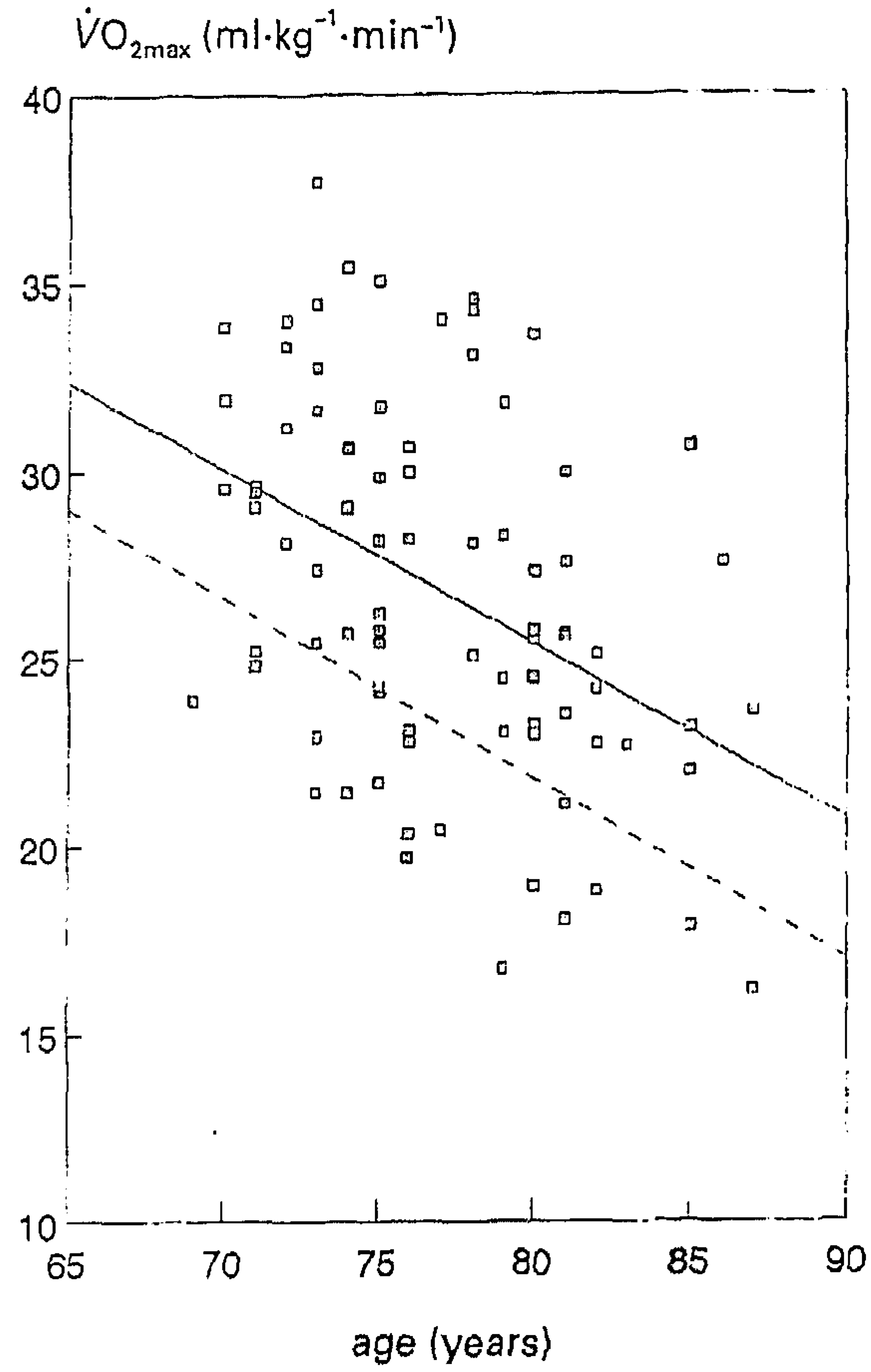

Fig. 1 Individual values of maximal oxygen uptake ($\dot{V}O_{2max}$)$\cdot$ body mass^{-1} (in millilitres per kilogram per minute) according to age in the male subjects ($n = 87$). *Squares* represent individual data. *Solid* and *broken lines* represent regression lines based on this study ($y = 62.7 - 0.46x$) and the study of Hollmann et al. (1978) ($y = 54.8 - 0.41x$), respectively

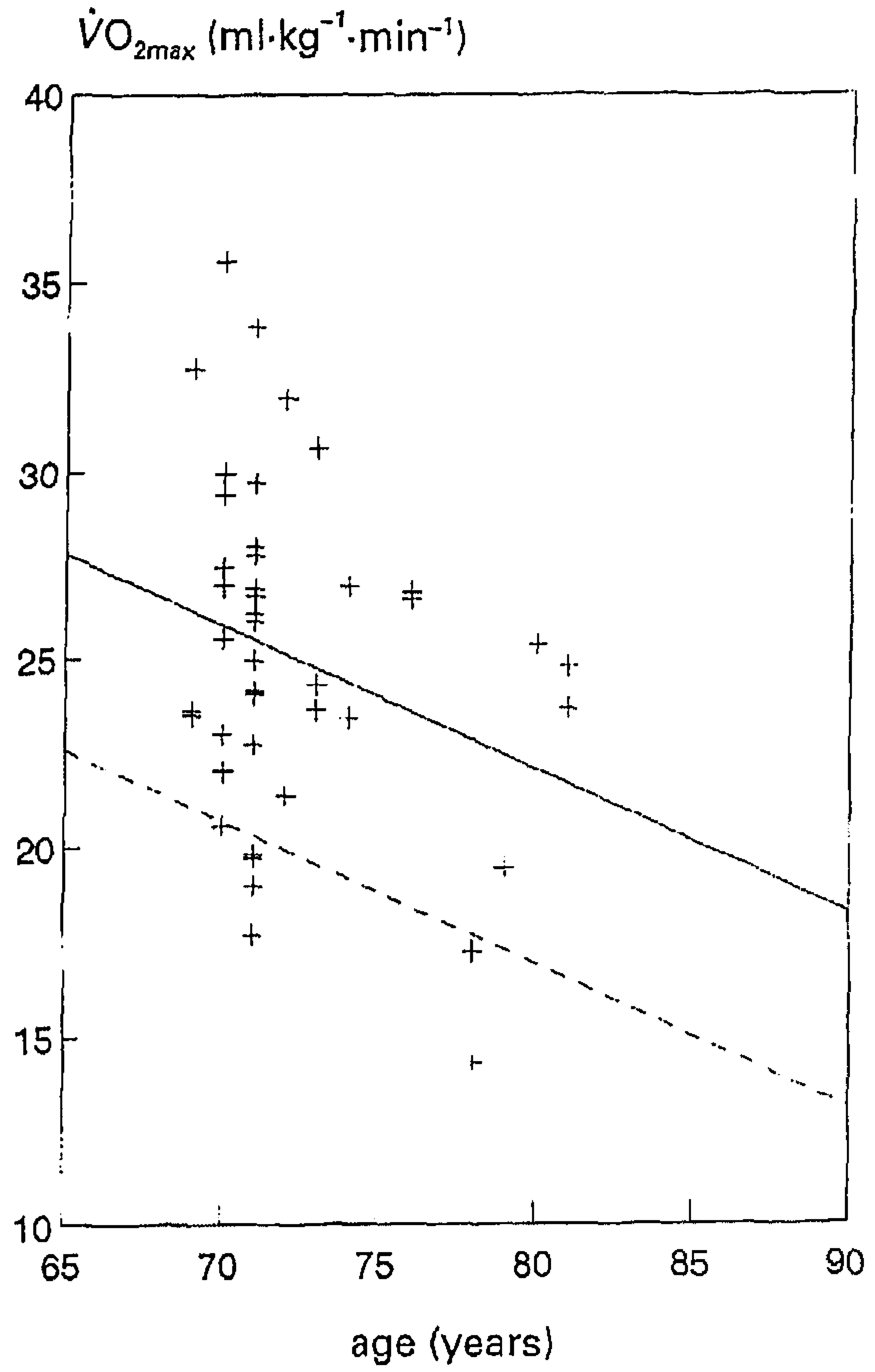

Fig. 2 Individual values of maximal oxygen uptake ($\dot{V}O_{2max}$)·body mass^{-1} (in millilitres per kilogram per minute) according to age in the female subjects (n = 87). *Crosses* represent individual data. *Solid* and *broken lines* represent regression lines based on this study ($y = 52.6 - 0.38x$) and the study of Nieman et al. (1989) ($y = 64.7 - 0.58x$), respectively

Table 3 Regression equations relating performance variables to age (Pearson's correlation coefficient r and p values). W_{max} Maximal delivered power, $\dot{V}O_{2max}$ maximal oxygen uptake, $\dot{V}O_{2max}$·body mass^{-1} maximal oxygen uptake per kilogram body mass, $\dot{V}O_{2max}$·FFM^{-1} maximal oxygen uptake per kilogram fat free mass, R respiratory exchange ratio, HR_{max} maximal heart rate, $f_{b,max}$ frequency of breathing at maximal exercise, V_{Tmax} maximal tidal volume, $\dot{V}_{Emax}$ maximal minute ventilation, $\dot{V}_E \cdot \dot{V}O_2^{-1}$ maximal minute ventilation per maximal oxygen uptake, ΔBE change in base excess (BE) (lowest BE 2–3 min after exercise minus BE at rest) $x - 1$

Men	$n = 91$	r	P
W_{max} (W)	$= 422.2 - 3.57 \cdot$age	−0.58	0.0001
$\dot{V}O_{2max}$[a] (l·min^{-1})	$= 5.04 - 0.039 \cdot$age	−0.41	0.0001
$\dot{V}O_{2max}$·body mass^{-1}[a] (ml·kg^{-1}·min^{-1})	$= 62.7 - 0.46 \cdot$age	−0.40	0.0001
$\dot{V}O_{2max}$·FFM^{-1}[a] (ml·kg^{-1}·min^{-1})	$= 89.1 - 0.66 \cdot$age	−0.41	0.0001
R[a]	$= 1.33 - 0.002 \cdot$age	−0.14	ns
HR_{max} (beats·min^{-1})	$= 225 - 0.94 \cdot$age	−0.20	0.03
$f_{b,max}$[a] (min^{-1})	$= 43.2 - 0.08 \cdot$age	−0.10	ns
V_{Tmax}[a] (l)	$= 5.1 - 0.04 \cdot$age	−0.36	0.0005
$\dot{V}_{Emax}$[a] (l·min^{-1})	$= 198.5 - 1.6 \cdot$age	−0.35	0.0006
$\dot{V}_E \cdot \dot{V}O_{2max}^{-1}$[a]	$= 32.1 + 0.1 \cdot$age	0.20	ns
ΔBE (mmol·l^{-1})	$= 8.9 + 0.01 \cdot$age	0.10	ns

Women	$n = 49$	r	P
W_{max} (W)	$= 306.1 - 2.53 \cdot$age	−0.43	0.001
$\dot{V}O_{2max}$[a] (l·min^{-1})	$= 3.46 - 0.026 \cdot$age	−0.35	0.01
$\dot{V}O_{2max}$·body mass^{-1}[a] (ml·kg^{-1}·min^{-1})	$= 52.6 - 0.38 \cdot$age	−0.22	ns
$\dot{V}O_{2max}$·FFM^{-1}[a] (ml·kg^{-1}·min^{-1})	$= 94.8 - 0.72 \cdot$age	−0.28	0.03
R[a]	$= 1.61 - 0.006 \cdot$age	−0.30	ns
HR_{max} (beats·min^{-1})	$= 223 - 1.03 \cdot$age	−0.22	ns
$f_{b,max}$[a] (min^{-1})	$= 5.6 + 0.45 \cdot$age	0.22	ns
V_{Tmax}[a] (l)	$= 4.3 - 0.04 \cdot$age	−0.60	0.0001
$\dot{V}_{Emax}$[a] (l·min^{-1})	$= 114.5 - 0.8 \cdot$age	−0.17	ns
$\dot{V}_E \cdot \dot{V}O_{2max}^{-1}$[a]	$= 22.1 + 0.2 \cdot$age	0.10	ns
ΔBE (mmol·l^{-1})	$= 30.0 - 0.3 \cdot$age	−0.50	0.0005

[a] n = 86 in men, n = 46 in women

Arterial oxygen saturation

The S_aO_2 decreased marginally at maximal exercise. The mean S_aO_2 at rest was 99.1 (SD 1.2)% and at maximal exercise was 98.0 (SD 2.3)% ($P < 0.001$) in the men. Corresponding mean values in the women were 99.2 (SD 1.1)% and 98.8 (SD 1.3)% (P = NS). A mean decrease of the S_aO_2 of 4%–7% was observed in 10 of the men and none of the women.

Chronic diseases

The relationship between, on the one hand, chronic diseases (self-reported prevalence of hypertension and/or coronary artery disease and/or cerebrovascular disease and/or pulmonary disease) and, on the other hand W_{max}, $\dot{V}O_{2max}$ and $\dot{V}O_{2max}$·body mass^{-1} is given in Table 4. There were no differences in $\dot{V}O_{2max}$, and W_{max} and $\dot{V}O_{2max}$·body mass^{-1} were lower in the groups with the chronic diseases. Except for W_{max} in the women these differences were significant. The women with chronic diseases had a significantly higher body mass (on average 6 kg). There were no differences with respect to age between the groups with and without chronic diseases.

Discussion

This study reports $\dot{V}O_{2max}$ as established using cycle ergometry in a large group of physically active elderly men and women over the age of 70 years. The $\dot{V}O_{2max}$ has been said to be "the bet physiological yardstick for exercise capacity" (Weeda 1989). It is related to endurance for aerobic exercise. The reason for this study is the lack of data on $\dot{V}O_{2max}$ measured in large groups of

Table 4 W_{max}, $\dot{V}O_{2max}$ and $\dot{V}O_{2max} \cdot$ body mass^{-1} in subjects with and without chronic diseases with a negative effect on exercise performance (hypertension and/or cardiovascular diseases and/or respiratory diseases). For definitions see Table 2

Men (n = 91)	No chronic diseases (n = 62)		Chronic diseases (n = 29)		P
	mean	SD	mean	SD	
W_{max} (W)	152.6	26.8	139.0	25.8	< 0.03
$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	2.02	0.40	1.89	0.38	NS
$\dot{V}O_{2max} \cdot$ body mass^{-1} ($ml \cdot kg^{-1} \cdot min^{-1}$)	27.6	4.5	25.0	5.0	< 0.02

Women (n = 49)	No chronic diseases (n = 37)		Chronic diseases (n = 12)		P
	mean	SD	mean	SD	
W_{max} (W)	122.4	19.0	114.2	23.6	NS
$\dot{V}O_{2max}$ ($l \cdot min^{-1}$)	1.56	0.21	1.51	0.31	NS
$\dot{V}O_{2max} \cdot$ body mass^{-1} ($ml \cdot kg^{-1} \cdot min^{-1}$)	25.4	4.4	22.0	5.0	< 0.04

active elderly. Habitual physical activity has been negatively correlated with age, which confounds both cross-sectional and longitudinal studies on $\dot{V}O_{2max}$ and aging (Blair et al. 1992; Lakatta 1993).

Medical history and habitual physical activity

The mean physical activity questionnaire score [20.7 (SD 12.2) in the men, 15.7 (SD 8.3) in the women], determined for a considerable part by walking (men 31%, women 45%), was substantially higher than that observed in apparantly healthy free-living elderly subjects [11.0 (SD 4.6) Voorrips et al. 1991]. Neither the physical activity questionnaire score nor the weekly time spent walking, both indicating that the subjects were habitually physically active, were negatively correlated with age in this study.

With respect to the prevalence of chronic diseases there are no major differences between our results (men 45%, women 44%) and a study of sedentary free-living elderly Dutch people (men 50%, women 59%) of comparable age who participated in the follow-up of the SENECA study. That study can be considered as a reference since it studied Dutch subjects and used the same questionnaire. Chronic use of medication was less common in our study (men 48% compared to 69%, women 42% compared to 79%) than in the study among the sedentary free-living subjects. Habitual physical activity seems to be the most distinguishing characteristic between our population and sedentary reference populations. We presume that the results are valid for the active elderly population aged over 70, although the data concerning the invited subjects who did not participate in this study showed that a considerable percentage (30%) did not participate because of health problems.

Anthropometry

The average height of the subjects in our study is no different from that of a Dutch population of free-living sedentary elderly people, the mean body mass index is substantially lower than among sedentary elderly [men 26.1 (SD 3.0), women 27.6 (SD 4.2)]. Body fat is lower than in the population described by Visser et al. (1994); men 31.2 (SD 5.6)%, women 43.3 (SD 6.1)%. The SD of body fat in the population described by Visser et al. (1994) was much higher than in this study. This indicates a lower prevalence of high body fat in the present study which might be due to a higher level of physical activity. In training studies with the elderly, body fat has been found to decrease after training, possibly due to a higher energy expenditure and/or fat mobilization and oxidation (Poehlman et al. 1994).

Maximal exercise

With our ergometry protocol maximal exercise tests could be performed safely in active elderly people. Complications occurred in only 7 subjects (3 supraventricular arrhythmia, 1 ventricular tachycardia, 2 angina pectoris, and 1 vasovagal syncope), and were mild and of short duration. All the subjects tolerated the test well and recovered quickly. The cause of the problems with the mouthpiece in some subjects was not always clear; sometimes it was due to poor dental condition or prosthesis. This problem has also been observed by others (Greig et al. 1994).

The questions whether a subject really reached his/her $\dot{V}O_{2max}$ and how this should be determined are not easy to answer. We used three criteria: attainment of the age-predicted HR_{max} predicted with a commonly used equation, R and ventilatory equivalent. The use of HR_{max} is limited in the elderly because of a high prevalence of (asymptomatic) cardiovascular disease. All the men in Fig. 3 with a HR_{max} below 140 beats · min^{-1} had hypertension and/or cardiovascular diseases. The male subject with a HR_{max} of 78 beats · min^{-1} was known to use β-blockers after he had suffered a myocardial infarction. He also had a sinus bradycardia at rest (38 beats · min^{-1}). Another factor limiting the use of HR_{max} was the considerable variation of HR_{max} in the elderly (Table 2), the coefficient of variation was 12% in the men and 9% in the women. The mean HR_{max} attained in this study was about 10 beats · min^{-1} higher than that predicted using the equation 220 − age (years) (Åstrand 1952). This has also been described by others (Binkhorst et al. 1966; Jones and Campbell 1982; Timmers 1969) and suggests that the decrease in HR_{max} with aging is less than the equation, based on younger subjects, predicts. The mean R at maximal exercise in this study indicated that R equal to or greater than 1.10

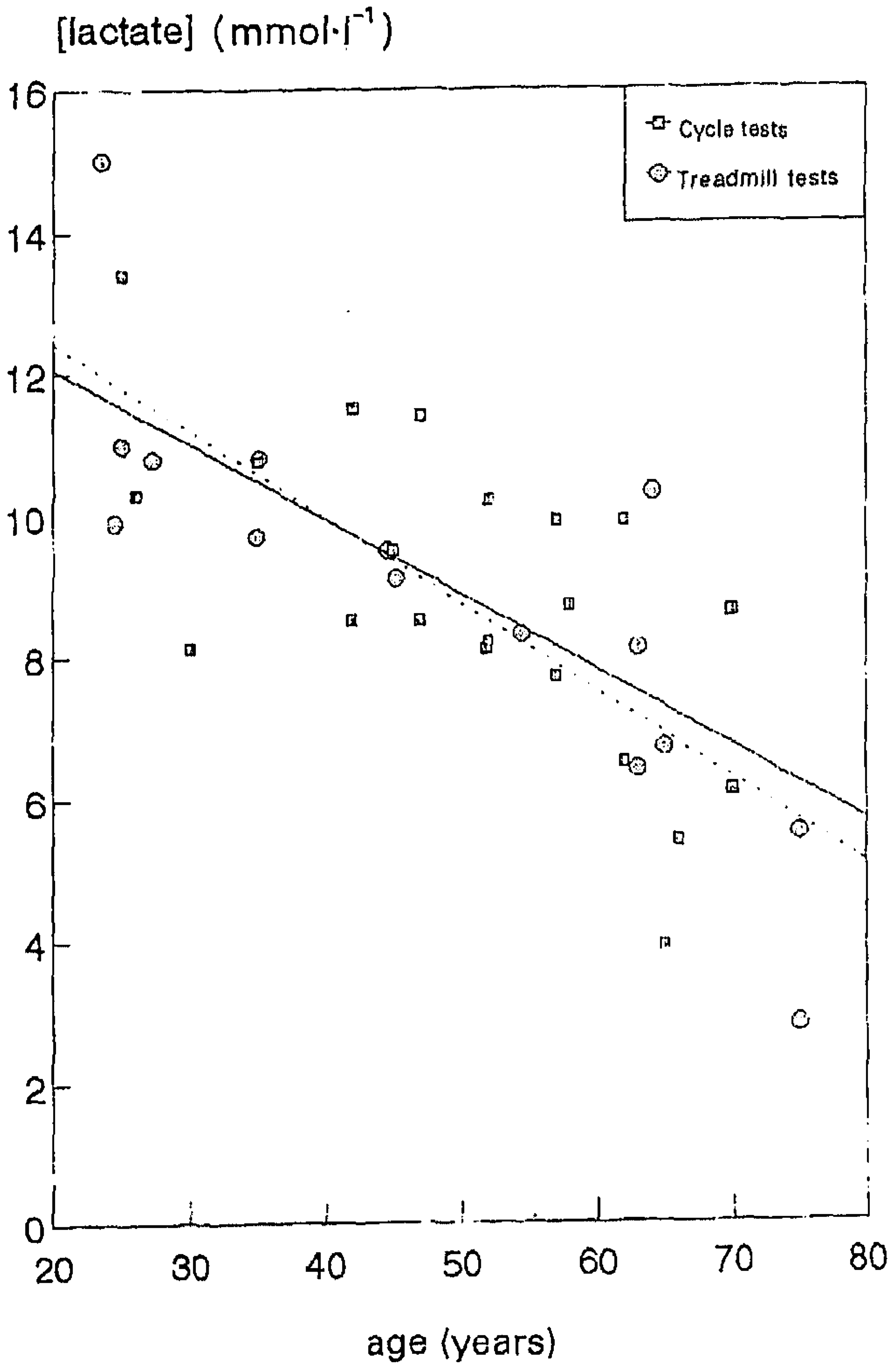

Fig. 3 Lactate concentration after maximal exercise on treadmill or cycle ergometer against age (references see discussion). *Solid line* represents linear regression in cycle ergometry, *dotted line* linear regression in treadmill ergometry

would have been a more appropriate criterion. We used R equal to or greater than 1.00 (Sidney and Shephard 1977) because we did not want the protocol to be too demanding, since we had not excluded subjects with chronic diseases. The results on ventilatory equivalent are the same as observed in younger populations.

Another criterion for maximal exercise which has often been used is a lactate concentration equal to or greater than 8.8 mmol · l^{-1} (Sidney and Shephard 1977) in arterial blood after maximal exercise. Data on a lactate concentration between 2 to 5 min after maximal exercise (Åstrand et al. 1973; Bovens et al. 1993; Massé-Biron et al. 1992; Robinson, 1939; Seals et al. 1984; Sidney and Shephard 1977; Stachenfeld et al. 1992; Tzankoff and Norris 1979) are shown in Fig. 3 as a function of age. Irrespective of the type of exercise, this concentration is negatively correlated with age ($r = -0.71$, $P < 0.001$). This might be due to a diminished lactate production in a smaller muscle mass, a decreased muscle lactate dehyrogenase activity (Powers et al. 1992), a decreased muscle glycogen store (Cartee 1994), a decreased W_{max} (Massé-Biron et al. 1992), the relatively large atrophy of type IIb fibres with aging (Grimby and Saltin 1983), or a delayed release of lactate of the blood (Cartee 1994). In our study ΔBE was used as the estimate of lactate production (Forster et al. 1972) and mean values 7.9 and 7.2 mmol · l^{-1} in the men and women respectively were found, which is in accordance with the results shown in Fig. 3.

The maximal performance of the subjects, given in Table 2 and Figs. 1 and 2, showed a wide range. The average $\dot{V}O_{2max}$ · body $mass^{-1}$ of this population was higher than that found by others in men (Hollmann et al. 1978) and women (Niemen et al. 1989) even though their subjects were selected on the basis of the absence of disease. These studies were used as reference studies because they included subjects aged over 70 years and used cycle ergometry. The higher $\dot{V}O_{2max}$ · body $mass^{-1}$ of our subjects was most probably due to their physically active lifestyle.

The relationships between age and variables directly related to maximal exercise are described in Table 3. To evaluate the influence of age on maximal exercise performance in this population, our results were compared to the results of predictions based on younger populations. As much as possible large series were used for reference. When we used the regression equation reported by Rodeheffer et al. (1984) ($W_{max} = 157.29 - 0.54 \cdot age$), who had studied subjects between 20 to 80 years, to predict W_{max} for our subjects, the values were lower (30 W in the men, and 7 W in the women) than the values we obtained with our own regression equation. So, in spite of the fact that one would expect to obtain higher values of W_{max} with the equation of Rodeheffer et al. (1984) since they excluded subjects with chronic diseases, we obtained higher values with our equation. This might have been caused by an attenuating effect of physical activity on the rate of decrease of W_{max} with aging.

When we used the regression equation reported by Dehn and Bruce (1972; 700 men aged 10–80 years, $\dot{V}O_{2max} \cdot$ body mass^{-1} = 56.6 − 0.398 · age) or the regression equation reported by Niemen et al. (1989; 1114 women aged 15–80 years, $\dot{V}O_{2max} \cdot$ body mass^{-1} = 47.31 − 0.38 · age) to predicted $\dot{V}O_{2max} \cdot$ body mass^{-1} for our subjects, mean values of 25.9 ml · kg^{-1} · min^{-1} and 19.8 ml · kg^{-1} · min^{-1} were obtained for men and women respectively. Thus, in our subjects, $\dot{V}O_{2max} \cdot$ body mass^{-1} was higher than predicted with equations based on cross-sectional data from studies including subjects aged between 10 and 80 years in spite of the fact that many of the studies used by Dehn and Bruce (1972) and Nieman et al. (1989) used treadmill ergometry. This suggests that regular aerobic exercise increases $\dot{V}O_{2max}$ in the elderly. The same is suggested when $\dot{V}O_{2max}$ is predicted based on age, body mass and height in men. The following equation was obtained in men in the present study: $\dot{V}O_{2max}$ (l · min^{-1}) = 2.15 + 0.016 · body mass (kg) + 0.007 · height (cm) − 0.03 · age (years); $\dot{V}O_{2max}$ predicted with this equation is 2.23 l · min^{-1}. In contrast, predicted with similar equations reported for Dutch men, 1.87 l · min^{-1} (Binkhorst et al. 1966) and 1.60 l · min^{-1} (Weeda 1989) for $\dot{V}O_{2max}$ were obtained for our subjects. The beneficial effects of physical activity on exercise performance, which have been demonstrated in numerous training studies but not in epidemiological studies in the elderly could explain the high aerobic power and $\dot{V}O_2$ in this study. However, at this point, we cannot exclude the possibility that our subjects had maintained a high exercise performance throughout their lives.

The decrease of $\dot{V}O_{2max}$ with aging has several causes; the decrease of HR_{max} has been reported to be the main cause of a decreaseing $\dot{V}O_{2max}$ in endurance athletes (Heath et al. 1981); in a recent review (Folkow and Svanborg 1993) both HR_{max} and maximal stroke volume have been reported to contribute equally (50%) to the decrease of $\dot{V}O_{2max}$ with age. In general (Lakatta 1993) the aging process, the decrease of physical activity, the increasing prevalence of chronic diseases and the loss of muscle mass have all been factors contributing to a decreasing $\dot{V}O_{2max}$. The relative importance of, and correlations among, these factors of those people aged over 70 years are largely unknown. From this study it is obvious that, as at younger ages, the decrease of muscle mass was not the only cause for a decreasing $\dot{V}O_{2max}$ over the age of 70 years since $\dot{V}O_{2max}$ still decreased after adjustment to FFM in both sexes.

The observed rate of decrease of $\dot{V}O_{2max}$ with aging (men: 0.46 ml · kg^{-1} · min^{-1} · year^{-1}, women 0.38 ml · kg^{-1} · min^{-1} · year^{-1}) is an argument against an accelerated loss of aerobic power in the elderly, at least in the active elderly, as has been reported by Foster et al. (1986). They have reported a decrease of 0.88 ml · kg^{-1} · min^{-1} · year^{-1} in a group of elderly women from a retirement centre (aged 73–86 years). This rate of decrease might have been high due to the fact that subjects from a retirement centre lead a sedentary life.

In our subjects the sex difference in $\dot{V}O_{2max}$ declined after adjustment to FFM. This is probably explained by the difference in %BF between the men and women; women have a lower muscle mass per kilogram body mass. This also illustrates that correcting $\dot{V}O_{2max}$ for muscle mass is a disadvantage for subjects with a high $\dot{V}O_{2max}$ and a high muscle mass per kilogram body mass, usually the well-trained subjects.

The $\dot{V}_{Emax}$ decreases with age, in both sexes caused by a significant decrease in V_{Tmax}. In contrast, in another study (Binkhorst et al. 1966), a decrease of $\dot{V}_{Emax}$ with aging in men between 20 and 60 years due to a significant decrease of frequency of breathing at maximal exercise $f_{b,max}$ has been reported. The V_{Tmax} and $f_{b,max}$ might act differently at different ages since a decline of $\dot{V}_{Emax}$ due to a declining $f_{b,max}$ before the age of 50 years and due to a declining V_{Tmax} after the age of 50 years has been reported in a study including 1424 healthy men (Inbar et al. 1994). The $\dot{V}_E$ however did not appear to limit the $\dot{V}O_{2max}$ since the mean R reached by our subjects was well over 1.00.

Arterial oxygen saturation

The mean S_aO_2 during maximal exercise (98%) was comparable to the mean S_aO_2 at rest (99%). The slight but significant decrease might have been caused by the acidosis-induced shift of the a haemoglobin oxygen saturation curve to the right. The relative large decrease observed in 10 men might have been due to measurement errors, or might be interpreted as exercise induced hypoxaemia as has been reported for master endurance athletes (Préfaut et al. 1994). In general our results indicated adequate ventilation-perfusion matching, no decrease of S_aO_2 at maximal exercise with aging in the active elderly, and seemed to indicate that pulmonary $\dot{V}O_2$ did not limit $\dot{V}O_{2max}$. That neither ventilation nor pulmonary $\dot{V}O_2$ seemed to limit $\dot{V}O_{2max}$ was further supported by the fact that in our data there was no correlation between R and ΔS_aO_2 at maximal exercise.

Chronic diseases

Regarding the influence of selected chronic diseases on $\dot{V}O_{2max} \cdot$ body mass^{-1} there were significant differences in $\dot{V}O_{2max} \cdot$ body mass^{-1} between subjects with and without chronic diseases in both sexes. In the women these results could not be interpreted since there was a significant difference in body mass. The differences in $\dot{V}O_{2max} \cdot$ body mass^{-1} (men 2.6 ml · kg^{-1} · min^{-1}, women 3.4 ml · kg^{-1} · min^{-1}: Table 4) were smaller than described by Bruce et al (1973). They compared the $\dot{V}O_{2max}$ · body mass^{-1} of healthy sedentary men aged 45 years and over with male subjects of the same age with hypertension and/or cardiovascular diseases of varying severity. He found mean differences between healthy men and men with chronic diseases from 6.1 to 14.0 ml · kg^{-1} · min^{-1} in subgroups with different chronic diseases. The small difference we observed among subjects with and without chronic diseases might have been caused by an attenuation of the negative effects of chronic diseases on $\dot{V}O_{2max}$ due to physical activity. However, we cannot exclude other explanations such as age, classification of chronic diseases or severity of chronic diseases.

Conclusion

From this study, on 153 physicaly highly active male and female subjects aged 69–87 years, it can be concluded that $\dot{V}O_{2max}$ can be determined safely in elderly subjects with our ergometry protocol. Elderly participants in the Nijmegen annual 4-day march had an aerobic power 20% higher than sedentary age-matched reference populations. The decline in aerobic power in this population with aging is similar to the decline found in the adult years. The observed HR_{max} was 10 beats · min^{-1} higher than predicted with the equation 220 − age (years). The negative effect of chronic diseases on $\dot{V}O_{2max}$ in this study was much smaller than in a sedentary population of middle-aged men. Regular aerobic exercise seems to have had substantial beneficial effects on aerobic power in men and women in their eighth and ninth decades, even when they had chronic cardiovascular or pulmonary diseases.

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