Eur J Appl Physiol (1984) 53: 260–266

European Journal of
Applied
Physiology
and Occupational Physiology

Reproducibility of aerobic and anaerobic thresholds in 20–50 year old men

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Summary. The reproducibility of the aerobic (AerT) and the anaerobic (AnT) threshold was studied in 33 men aged 20–50 years. They completed two maximal exercise tests on a bicycle ergometer. The thresholds, as $\dot{V}_{O_2}$ ($l \cdot min^{-1}$), were determined visually by two investigators using both the blood lactate and the respiratory indices. The respiratory variables were measured with a computerized breath-by-breath method; samples of venous blood were drawn every 2nd min and analysed enzymatically for lactate. The reproducibility of the AerT ($r = 0.94$) and of the AnT ($r = 0.96$) were equally good. The AnT can be determined either from blood lactate concentrations (AnT_{La}) or from ventilatory and gas exchange response (AnT_r) during a 2-min incremental exercise test. They both also showed similar reproducibility: $r = 0.93$ for the AnT_{La} and $r = 0.95$ for the AnT_r. The work rate and the measured physiological variables at the AerT and AnT, except for the blood lactacte concentration, were very reproducible. Age did not affect the reproducibility of the thresholds. The poor reproducibility of blood lactate concentration of the AnT confirmed our previous opinion that the fixed blood lactate levels of 2 and 4 $mmol \cdot l^{-1}$ are poor indicators of AerT and AnT.

Key words: Aerobic threshold – Anaerobic threshold – Incremental exercise – Lactic acid – Ventilation

Introduction

The evaluation of endurance capacity with an aerobic (AerT) or anaerobic (AnT) threshold has become very popular in sports physiology. Only a few reports (e.g., Buchberger 1979) have applied this knowledge to the assessment of occupational work capacity or rehabilitation. Until recently, in most studies concerning AerT and AnT determination, the subjects have been young students, laboratory personnel or elite sportsmen about 20–30 years old (e.g., Davis et al. 1976; Kindermann et al. 1978, 1979; Rusko et al. 1980; Simon et al. 1981; Ready and Quinney 1982). On the basis of these studies, conclusions cannot be drawn about the applicability of AerT and AnT as criteria for the evaluation of working capacity and rehabilitation. In addition, the use of different determination procedures, different measurement variables and exercise protocols, and different concepts of anaerobic or aerobic thresholds have led to many contradictory results in the literature. Therefore, more systematic studies of an ordinary population, especially of working-aged people, are needed, as well as consistent determination procedures.

In several papers there have been reported results of the test-retest correlation of AerT (e.g., Davis et al. 1979; Nemoto and Miyashita 1980; Withers et al. 1981) and some of AnT (e.g., Nemoto and Miyashita 1980; Rusko et al. 1980), but no comprehensive investigation into reproducibility of these thresholds has been published. The aim of the present study is to analyse the reproducibility of AerT and AnT in 20–50 year old men, and to study if such factors as age and maximal aerobic power have influence on the reproducibility of these thresholds. As distinct from AerT, few data are presented about the reproducibility of AnT based on respiratory measurements and/or the blood lactate changes; therefore, both thresholds were determined and compared.

In this paper the concepts of AerT and AnT are comparable with the AerT and AnT defined by Kindermann et al. (1978, 1979) and Skinner and McLellan (1980). In order to avoid misunderstanding, the threshold concepts of the references used in

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the text are replaced with concepts according to these authors.

Material and methods

Subjects

Thirty-three voluntary and healthy men, aged 19–50 years, participated in the study. Most of them were acquainted with the physical stress involved in ergometer tests. Thirteen were enlisted in the Finnish Army and nine were recreational judo practitioners; the rest practised different kinds of sports for recreation. Their ages, heights, and body weights were (mean ± SD) 33.0 ± 7.8 years, 176.9 ± 4.9 cm, and 75.6 ± 7.5 kg, respectively.

Experimental procedures

First, the subjects cycled to become familiar with the test procedure and with the equipment. One week after familiarization the subjects performed a continuous incremental exercise test according to the following procedure: After 3-min warm up at 50 W, the load was increased every 2nd min and the increments were equal throughout the test but were individually determined (15–33 W) on the basis of the subject's physical fitness. The planned duration of the test was 20 min (+ 3-min warm up). The tests were carried out until volitional exhaustion. After 1 week the test was repeated.

A bicycle ergometer (EM 369, Elema-Schönander) was used. The respiratory measurements were taken continuously with an on-line computerized breath-by-breath method (Salminen et al. 1982) and stored for later determination of AerT and AnT. The electrocardiogram was recorded continuously and observed on an oscilloscope. The blood pressure was measured at rest and every 4th min during the test. The rating of perceived exertion (RPE) according to Borg (1962, 1973) was recorded every 2nd min, as well as the intensity of tiredness in the legs. The samples of venous blood were withdrawn at rest and every 2nd min (near AnT every minute) during the tests by an indwelling teflon catheter (Venflon IV Cannula, Viggo AB) in the brachial vein for analyses of blood lactate (enzymatic method, Biochemica Boehringer). For control purposes the erythrocyte sedimentation rate (ESR), the hematocrit value (Hct), the blood hemoglobin level (Hb) and the serum protein (S-prot) concentration were measured before both exercise tests; standard measuring routines were used.

Determination of AerT and AnT

The blood lactate values and the mean values over the last 30 s of the ventilation ($\dot{V}_E$) and CO_2 production for every work load were plotted separately against the corresponding times, work rates, and oxygen uptakes ($\dot{V}_{O2}$). Figure 1 represents an example of data plotted against $\dot{V}_{O2}$. The investigator determined AerT and AnT visually, using all the above mentioned variables. AerT was determined as a point just below that level of energy metabolism ($\dot{V}_{O2}$) at which blood lactate concentration increased distinctly from its resting level around 2 mmol · l^{-1} and the first nonlinear increase in $\dot{V}_E$ and $\dot{V}_{CO2}$ compared with $\dot{V}_{O2}$ starts, corresponding to the 'anaerobic threshold' of Wasserman et al. (1973). AerT was determined mainly from the data of blood lactate because of its simplicity and its unambigious criterion for determination, and because nonlinear increases in the $\dot{V}_E$ and $\dot{V}_{CO2}$ curves were not detectable for every subject (Fig. 1). AnT was determined separately from blood lactate concentrations (as AnT_{La}) and from ventilatory and gas exchange response (as AnT_r). AnT_r was

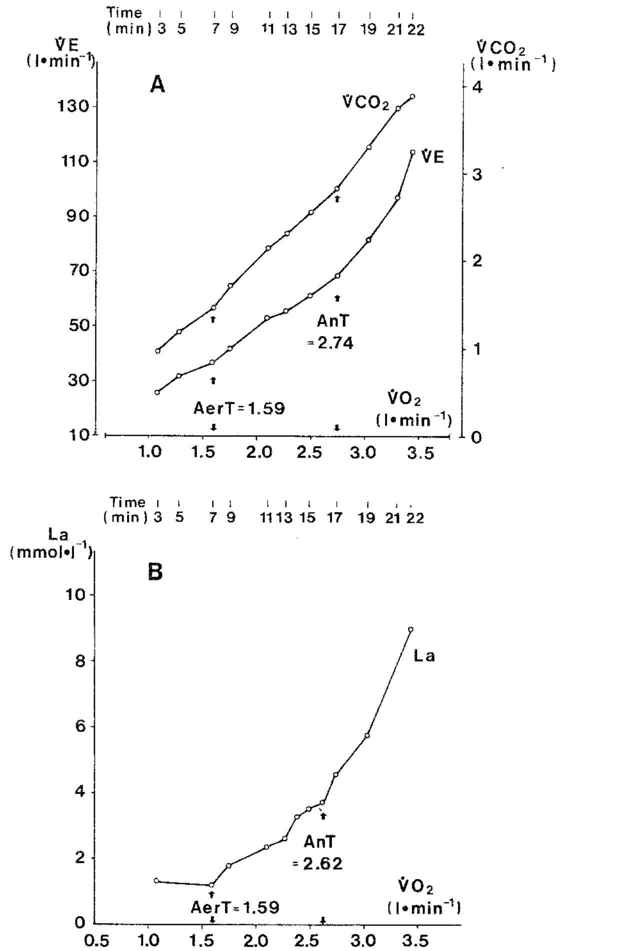

Fig. 1. Determination of aerobic (AerT) and anaerobic (AnT) thresholds: (A) the mean value over the last 30 s of respiratory data for every work load; (B) data of blood lactate

determined to be just below that point where the linearity in $\dot{V}_E/\dot{V}_{O2}$ and $\dot{V}_E$/work rate curves markedly disappears (Reiterer and Bachl 1977; Orr et al. 1982), usually for the second time (the first time at AerT); see Fig. 1a. AnT_{La} was determined as a starting point of accelerated lactate accumulation around 4 mmol · l^{-1}, however, depending on the individual level of blood lactate (Keul et al. 1979; Simon et al. 1981; Stegmann and Kindermann 1981); see Fig. 1b. After that the final AnT'determination (AnT) was made by combining the AnT_r and the AnT_{La}. In one subject, some blood samples for the lactate assay were missed during the second exercise test because of technical difficulties with the indwelling teflon catheter. For that subject only the AnT_r was estimated, and used as final AnT.

Two investigators first performed the AerT and AnT determinations independently. After that they discussed the differences which appeared, and agreed upon a compromise value for the final AerT and for the final AnT, and these were used for the analysis of reproducibility.

The AerT and AnT values were expressed as $\dot{V}_{O2}$ (l · min^{-1}) to avoid additional variance resulting from the weight changes of the subjects.

Statistical analysis

The reproducibility of AerT and AnT was evaluated by intraclass correlation coefficients and linear regression analysis (BMDP).

Similarity of the tests was implied by a regression intercept at zero and a slope of unity. The significance of differences between the means was tested by the paired *t*-test. The influence of an investigator and methods on AnT determinations and the influence of age and some other background variables on reproducibility were tested by a two-way analysis of variance applied for repeated measures (BMDP).

Reliability of AerT and AnT determinations

The reliability of the AerT and AnT determinations was evaluated by the determination accuracy between two investigators and by the redeterminations of AnT made by one investigator. The accuracy expressed with the intraclass correlation coefficients in the first and in the second tests was, for AerT 0.98 and 0.98, for AnT 0.95 and 0.95, for AnT_{La} 0.95 and 0.96, and for AnT_r 0.81 and 0.91. According to the analysis of variance the determinations of two investigators differed statistically in the first test with $P = 0.060$ and in the second test with $P = 0.028$. However, the largest difference of the means was only 0.05 $O_2\,l \cdot min^{-1}$ (1.8%), and that was for the AnT_r in both tests. The largest single difference between estimations was 0.60 $O_2\,l \cdot min^{-1}$ (20.3%) and that was for one AnT_r in the first test. The correlation coefficients for the determination-redetermination reliability (from the data of one investigator) varied between 0.94 and 0.96. The largest difference of the means was 0.01 $O_2\,l \cdot min^{-1}$ or below 0.5%, and that was for the AnT_r of the first test.

Results

At rest and at maximum, there were no differences between the first and the second test except with regard to maximal work rate, which was 6 W higher ($P < 0.01$) in the second test (Table 1 and Table 2).

Table 1. The means and standard deviations of some variables at rest

	HR (beats · min^{-1}) ($n = 33$)	$RR_{Syst.}$ (mm Hg) ($n = 33$)	$RR_{Diast.}$ (mm Hg) ($n = 33$)	Hb ($g \cdot l^{-1}$) ($n = 33$)	Hct ($n = 33$)	S-prot ($g \cdot l^{-1}$) ($n = 32$)	La ($mmol \cdot l^{-1}$) ($n = 33$)
Test 1							
x̄	68.9	120.9	76.8	144.2	0.44	70.0	1.46
SD	10.9	13.4	10.4	9.6	0.03	4.9	0.35
Test 2							
x̄	66.8	122.0	78.9	144.0	0.44	70.3	1.45
SD	10.5	10.6	9.1	9.2	0.03	3.6	0.33

Table 2. The means and standard deviations of variables at the aerobic threshold (AerT), at the anaerobic threshold (AnT), and at maximal exercise (max)

		Work rate (watts) ($n = 33$)	$\dot{V}_{O_2}$ ($l \cdot min^{-1}$) ($n = 33$)	$\dot{V}_{O_2}$/kg ($ml \cdot min^{-1}$) ($n = 33$)	$\%\dot{V}_{O_2\,max}$ ($n = 33$)	$\dot{V}_E$ ($l \cdot min^{-1}$) ($n = 33$)	HR (beats · min^{-1}) ($n = 33$)	La ($mmol \cdot l^{-1}$) ($n = 32$)	RPE[a] ($n = 33$)
AerT									
Test 1	x̄	132	1.98	26.4	55	47	119	1.9	11.5
	SD	26	0.34	4.9	7	8	14	0.4	1.8
Test 2	x̄	134	2.00	26.6	55	48	118	1.9	11.4
	SD	28	0.36	5.1	7	9	15	0.4	2.0
	r	0.97	0.94	0.94	0.84	0.91	0.93	0.35	0.60
AnT									
Test 1	x̄	195	2.75	36.7	77	71	151	3.9	15.6
	SD	26	0.32	5.2	5	9	15	1.0	1.6
Test 2	x̄	198	2.75	36.7	76	72	149	3.7	15.2
	SD	26	0.35	5.6	4	8	15	0.9	1.2
	r	0.95	0.96	0.97	0.62	0.90	0.91	0.68	0.49
Max									
Test 1	x̄	269	3.58	47.6		117	177	11.7	
	SD	36	0.45	6.2		23	12	2.4	
Test 1	x̄	275*	3.63	48.2		120	178	12.0	
	SD	39	0.47	6.5		21	10	2.3	
	r	0.95	0.91	0.92		0.88	0.91	0.77	

[a] RPE = rating of perceived exertion

* Statistically significant difference between tests 1 and 2 with $P < 0.01$

AerT and AnT were similar in both tests, the correlation coefficients being 0.94 and 0.96 respectively (Fig. 2 and Table 2). For AnT there was a statistically significant deviation from the intercept zero and the slope of one ($P < 0.01$). The means of the other variables at AerT and at AnT were also very similar (Table 2). The increase of lactate from resting level to the AnT level was insignificantly smaller ($P = 0.06$) in the second test (2.2 $mmol \cdot l^{-1}$) than in the first test (2.4 $mmol \cdot l^{-1}$). The reproducibility of the blood lactate concentration at the AerT ($r = 0.35$) and at the AnT ($r = 0.68$) was significantly smaller (Fig. 3) than that of work rate or that of $\dot{V}_{O_2}$ ($P < 0.001$), that of ventilation ($P < 0.001$ and $P < 0.05$, respectively for AerT and AnT), and that of heart rate ($P < 0.001$ and $P < 0.01$). With maximal exercise, the reproducibility of blood lactate concentration was not as high as that of work rate ($P < 0.01$), or of $\dot{V}_{O_2}$ or heart rate ($P < 0.05$).

AerT occurred at 55% (range 41–70%) and AnT occurred at 76–77% (range 67–87%) of $\dot{V}_{O_2\,max}$ in both tests (Table 2). The %-AerT was more reproducible ($r = 0.84$) than the %-AnT ($r = 0.62$; $P < 0.05$). When the subjects were divided into two groups of equal size according to their $\dot{V}_{O_2\,max}$ as $ml \cdot kg^{-1} \cdot min^{-1}$ (the mean of two tests), it was found, that the 'fit group' ($\dot{V}_{O_2\,max}$ = 52.8 $ml \cdot kg^{-1} \cdot min^{-1}$; age = 30.2 years) achieved the

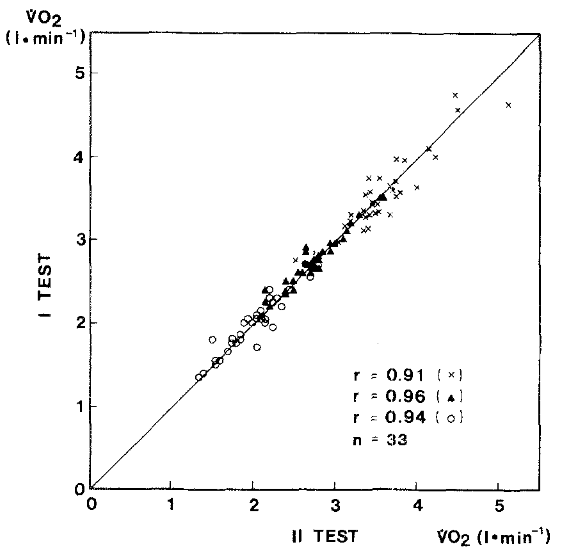

Fig. 2. Reproducibility of aerobic threshold (○), anaerobic threshold (▲) and $\dot{V}_{O_2\,max}$ (×): ○, y = 0.91 · X + 0.17; ▲, y = 0.88 · X + 0.33; ×, y = 0.87 · X + 0.43, n = 33

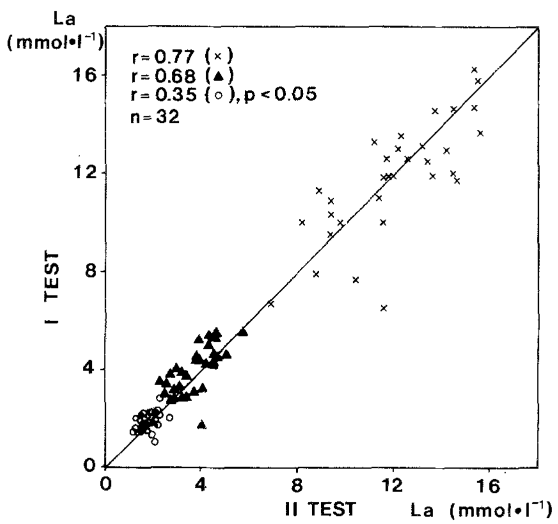

Fig. 3. Reproducibility of blood lactate concentration at aerobic threshold (○), at anaerobic threshold (▲), and at maximal exercise (×), n = 32

Table 3. The aerobic threshold (AerT), anaerobic threshold (AnT), and $\dot{V}_{O_2\,max}$ in the young and old age groups

	< 35 year old (n = 19)				≥ 35 year old (n = 13)			
	$\dot{V}_{O_2}$ ($l \cdot min^{-1}$)		La ($mmol \cdot l^{-1}$)		$\dot{V}_{O_2}$ ($l \cdot min^{-1}$)		La ($mmol \cdot l^{-1}$)	
	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
AerT								
x̄	2.02	2.02	1.9	1.9	1.92	1.97	1.9	1.8
SD	0.36	0.38	0.4	0.4	0.35	0.35	0.3	0.3
r	0.942		0.262		0.944		0.523	
AnT								
x̄	2.82	2.83	4.0	4.0	2.63	2.60	3.7	3.2
SD	0.30	0.31	1.1	0.8	0.32	0.37	1.0	0.8
r	0.968		0.634		0.945		0.709	
$\dot{V}_{O_2\,max}$								
x̄	3.64	3.68	12.0	12.6	3.46	3.50	11.4	11.2
SD	0.46	0.39	2.7	2.3	0.44	0.57	1.9	2.2
r	0.892		0.728		0.928		0.854	

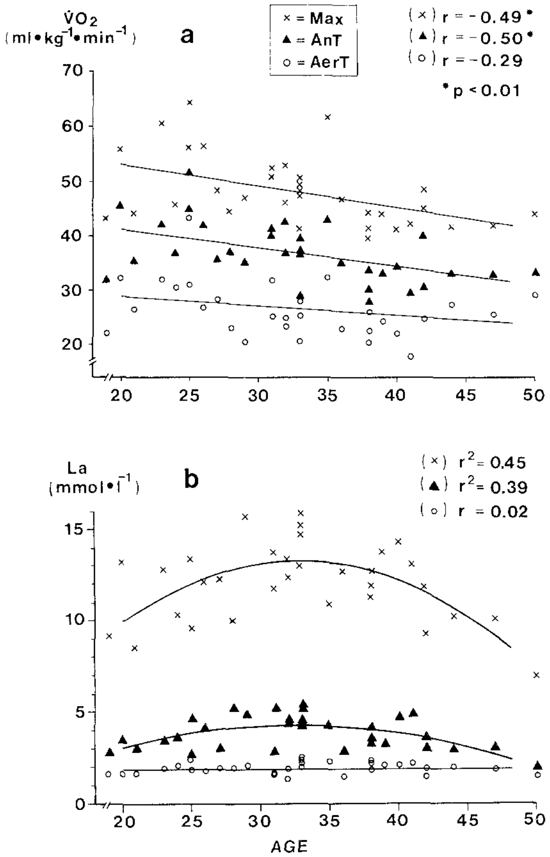

Fig. 4. Aerobic threshold (○), anaerobic threshold (▲), and maximal exercise (×) expressed as $\dot{V}_{O_2}$ **a** and blood lactate concentration **b** related to age; $n = 33$. **a:** (○), y = −0.18 · X + 32.6; (▲), y = −0.34 · X + 48.1; (×), y = −0.41 · X + 61.5. **b:** (○), y = −0.00 · X + 1.88; (▲), y = −0.008 · X^2 + 0.49 · X −3.74; (×), y = −0.020 · X^2 + 1.33 · X −8.53

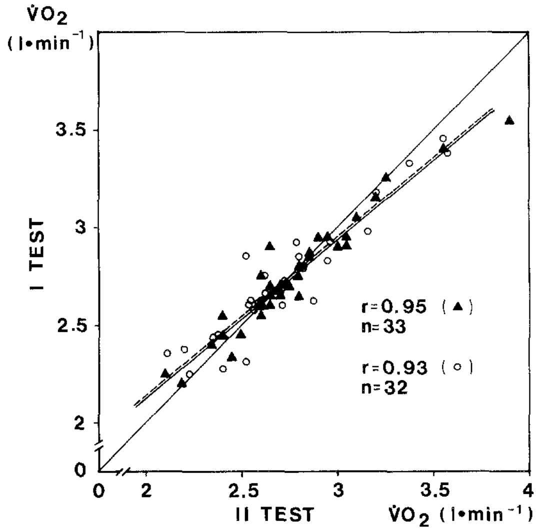

Fig. 5. Reproducibility of respiratory anaerobic threshold (▲) and blood lactate anaerobic threshold (○): ▲———▲ y = 0.80 · X + 0.52, n = 33; ○– – –○ y = 0.80 · X + 0.53, n = 32

same %-AnT (77%) in both tests but the 'less fit group' ($\dot{V}_{O_2\,max}$ = 42.9 ml · kg^{-1} · min^{-1}; age = 35.9 years) had a lower %-AnT (75%) in the second test than the 77% achieved in the first test ($P < 0.05$). However, in both groups, AerT, AnT, and $\dot{V}_{O_2\,max}$ as absolute values were equally reproducible.

$\dot{V}_{O_2\,max}$ and AnT as $\dot{V}_{O_2}$ (ml · kg^{-1} · min^{-1}) were dependent on age with a linear relationship, $r = 0.49$ and $r = 0.50$ ($P < 0.01$) while AerT was not age-dependent (Fig. 4a). There was no correlation between age and %-AerT ($r = 0.13$), nor with %-AnT ($r = -0.12$). The blood lactate concentrations at maximum and at AnT were dependent on age with a quadratic relationship (Fig. 4b): The squared multiple correlation coefficient (r^2) was 0.45 for maximum and 0.39 for AnT. The reproducibility of AerT and AnT were equal among subjects below or over 35 years of age (Table 3).

AnT_{La} correlated well with AnT_r in both tests: $r = 0.92$ in the first test and $r = 0.93$ in the second test. The reproducibility of AnT_{La} and AnT_r were found to be very similar: the intraclass correlation coefficients were 0.93 and 0.95 respectively, and both regression slopes were 0.80. The slopes deviated statistically significantly ($P < 0.01$) from unity and the intercepts from the expected value zero (Fig. 5).

The threshold of 4 mmol ·l^{-1} blood lactate was compared with AnT_{La}. It was 0.03 (SD ± 0.18) O_2 l · min^{-1} higher in the first test (NS) and 0.07 (SD ± 0.20) O_2 l · min^{-1} higher in the second test ($P < 0.05$) than the AnT_{La}. The respective correlation coefficients were 0.86 and 0.84. The difference was more pronounced in subjects over 35 years ($n = 13$): 0.07 (SD ± 0.16) and 0.16 (SD ± 0.18) O_2 l · min^{-1} respectively for the first (NS) and the second ($P < 0.01$) tests. That can be seen indirectly in Fig. 4b. The largest single difference was 0.43 and 0.42 O_2 l · min^{-1} respectively for the first and second tests. The reproducibility of the threshold of 4 mmol · l^{-1} blood lactate was indicated with $r = 0.86$.

Discussion

The reproducibility of both the AerT and the AnT thresholds was good. It was the same as reported for the respiratory AerT in the study of Davis et al. (1979) or for the AnT in the study of Rusko et al. (1980). However, the regression slopes deviated from unity: Because of very high homogenity of the subjects, small differences in the results of some subjects may have considerably influenced the slopes of the regression lines between the tests.

Work rate, ventilation and heart rate had very good reproducibility at all three metabolic levels. The blood lactate concentration at AerT, at the AnT and at $\dot{V}_{O_2\,max}$ had relatively poor reproducibility, if compared with some other measured variables. This is due to intraindividual variation in blood lactate concentration, not only at AerT and AnT but also at rest and after maximal exercise, depending on factors regulating carbohydrate and fat metabolism, such as diet (Kelman et al. 1975; Maughan et al. 1978; Jansson 1980), glycogen content of the exercising muscles (Gollnick et al. 1981; Heigenhauser et al. 1983), free fatty acids in blood (Ivy et al. 1981), and activity levels before the test. Moreover, Finch et al. (1976, 1979) found in studies on rats that iron deficiency in tissues increased lactate production in exercising muscles. Ohira et al. (1981) found a negative correlation ($r = -0.41$; $P < 0.05$) between serum iron and post-exercise lactate levels in human subjects. This factor affects comparisons of results which have a long measurement interval (e.g., training period). Disturbances in water and acid-base balances also influence blood lactate concentration both in submaximal and maximal exercise (Saltin 1964a, 1964b; Sutton et al. 1981), but they are controllable with relative ease. Because of these factors, and the others reviewed in our previous paper (Aunola and Rusko 1982), the fixed blood lactate concentrations of 2 and 4 mmol $\cdot$ l^{-1} cannot be reliable indicators of individual AerT and AnT values.

Reproducibility of %-AerT or %-AnT is dependent on variation in two variables, so that it cannot be very good. Our results showed that the reproducibility of the %-AnT was a little better in the 'fit group' than in the 'less fit group'. But as absolute values, the thresholds were reproducible independent of subjects' maximal aerobic power. Because our subjects were more fit (see Table 2) than the average for people of the same age, conclusions must be drawn with great caution.

According to Rusko et al. (1980), the age of the subjects (young women athletes) correlated positively with %-AnT ($r = 0.54$, $P < 0.05$). In adults, even in middle-aged subjects, AerT (Williams et al. 1967; Davis et al. 1979; Sady et al. 1980) and AnT (Ready and Quinney 1982) can also be increased by training by a far greater percentage than can $\dot{V}_{O_2\,max}$. In the present study, there was no significant correlation between age and AerT, %-AerT or %-AnT. This may be due to the rather large variability of the individual training level among the subjects. According to the linear regression line, $\dot{V}_{O_2\,max}$ decreased at a rate of 0.4 ml $\cdot$ kg^{-1} $\cdot$ min^{-1} per year, nearly the same rate as reported in other studies. AnT decreased at a rate of 0.3 ml $\cdot$ kg^{-1} $\cdot$ min^{-1} for each year. Expressed as percentages, both AnT and $\dot{V}_{O_2\,max}$ decreased by 0.8% for each year from the age of 20 years. Age did not affect the reproducibility of thresholds. AerT and AnT were equally reproducible in the young and old age groups; and the blood lactate level at both thresholds were equally but not well reproducible in both age groups.

The accuracy and reliability of determination methods must be taken into consideration when AnT_{La} and AnT_r are compared. As demonstrated in our previous study (Aunola and Rusko 1982), the exercise protocol influenced the accuracy of AnT_{La} and AnT_r: the last appeared to be most accurate in the 2-min incremental exercise test. In the present study, there was only one large deviation in the first test between the AnT_r determinations made by two investigators, and the intraclass correlation coefficient in the first test was the same ($r = 0.81$) as in our previous study (Aunola and Rusko 1982), corresponding well with the coefficient ($r = 0.79$) for AnT_r reported by Nemoto and Miyashita (1980). In the second test, the correlation coefficient was 0.91, which was close to the respective coefficients for our AnT_{La} determinations and for the threshold determinations reported by Rusko et al. (1980). Over all, the AnT_r values can be considered reliable and accurate enough if this kind of test protocol (with rather small load increments) is used. The fact that AerT could not be determined from ventilatory and gas exchange responses in all subjects might be due to too short an accustoming period to stabilize respiration at the beginning of the exercise test.

AnT_r and AnT_{La} showed correlation coefficients (0.92 and 0.93) as high as previously reported between respiratory and blood lactate AerT values: e.g., $r = 0.95$ by Davis et al. (1976), and 0.94 by Reinhard et al. (1979). The reproducibility of both AnT_r and AnT_{La} (as $\dot{V}_{O_2}$) was good. The correlation coefficient for AnT_r (0.95) in the present study was higher than the level of 0.79 reported by Nemoto and Miyashita (1980). The poor reproducibility of the corresponding blood lactate concentrations can be considered due to the great intraindividual variation discussed earlier. Consequently, the test-retest correlation coefficient of the threshold of 4 mmol $\cdot$ l^{-1} blood lactate ($r = 0.86$) was lower than the coefficient of AnT_{La}. This, together with the high correlation between AnT_r and AnT_{La} in both tests, and the low test-retest correlation coefficients of blood lactate ($r = 0.77$ at AnT_r and $r = 0.52$ at AnT_{La}) as opposed to the test-retest coefficients for AnT_r ($r = 0.95$) or AnT_{La} ($r = 0.93$), question the validity of a blood lactate criterion fixed at 4 mmol $\cdot$ l^{-1} for AnT. This is in accordance with the results of Stegmann and Kindermann (1982).

Acknowledgements. The authors acknowledge with gratitude the assistance of those members of the staff of The Rehabilitation Research Centre who participated in this work. We also want to thank the subjects for their cooperative attitude, and the Finnish Army for granting enlisted men permission to participate.

This work was supported in part by grant No. 9189/78/79 from the Ministry of Education, Finland.

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Accepted September 19, 1984