Eur J Appl Physiol (1985) 53: 299–303

European Journal of Applied Physiology and Occupational Physiology

Noninvasive determination of the anaerobic threshold in canoeing, cross-country skiing, cycling, roller, and iceskating, rowing, and walking

P. Droghetti, C. Borsetto, I. Casoni, M. Cellini, M. Ferrari, A. R. Paolini, P. G. Ziglio, and F. Conconi

Cattedra di Biochimica Applicata, Università degli Studi di Ferrara, 44100 Ferrara, Italy

Summary. The relationship between velocity (V) and heart rate (HR) was determined in four canoeists, 42 cross-country skiers, 73 cyclists, nine ice-skaters, 10 roller-skaters, 32 rowers, and 20 walkers. The athletes were asked to increase their work intensity progressively, from low to submaximal velocities; HRs were determined by ECG in roller-, ice-skating, and walking, or read on a cardiofrequency meter in canoeing, cross-country skiing, cycling, and rowing.

In all the athletes examined the linearity of the V-HR relationship was maintained up to a submaximal speed (deflection velocity, V_d), beyond which the increase in work intensity exceeded the increase in HR.

V_d and anaerobic threshold (AT), determined through blood lactate measurements, were coincident in 19 athletes (6 cross-country skiers, 3 cyclists, 2 roller-skaters, 3 rowers, and 5 walkers).

V_d was correlated with the average speeds maintained in walking (20 km, n = 13, r = 0.88), cross-country skiing (15 km, n = 20, r = 0.80; 30 km, n = 8, r = 0.82; 12 km, n = 7, r = 0.86; 11 km, n = 7, r = 0.86) and cycling (1,000 m flying-start, n = 68, r = 0.83), thus showing that AT is a limiting factor in these aerobic events.

Key words: Anaerobic threshold - Aerobic power - Factors limiting aerobic events - Work intensity-heart rate relationship

Introduction

The anaerobic threshold has been defined as the highest work intensity beyond which lactate begins accumulating in the blood (Davis et al. 1979). The metabolic acidosis occurring above AT has been indicated as one of the factors that could limit performance in runners (Costill et al. 1971; Davis et al. 1979; Liesen et al. 1977).

We have recently developed a field test for the noninvasive determination of AT in runners (Conconi et al. 1982); the same field test has now been adapted to canoeing, cross-country skiing, cycling, roller, and ice-skating, rowing, and walking.

Subjects and methods

Subjects

One hundred and seventy-two male and 18 female athletes volunteered to take part in this study; all were healthy and gave informed consent to the research. The subjects examined included:

Four canoeists, age 16–22, and 32 rowers, aged 18–31, 28 males and four females, all in good training condition.

Forty-two cross-country skiers, aged 17–31, nine females and 33 males, all belonging to the Italian National Team.

Seventy-three cyclists, well trained, of intermediate level, aged 14–47.

Nine ice-skaters, six males and three females, aged 17–26, belonging to the Italian National Team.

Ten roller-skaters, two females and eight males, aged 15–23, in good training condition.

Twenty walkers, aged 15–37; 14 of them belonged to the Italian National Team, the others were well trained but of intermediate athletic level.

Determination of the relationship between V and HR: general protocol

The V-HR relationship was determined by measuring HR while the athlete under study progressively increased his speed.

In all instances the relationship between V and HR of the athlete under study was determined while the subject performed his usual physical activity; each test was preceded by a warm-up lasting 15–30 min.

Offprint requests to: P. Droghetti, Istituto di Chimica Biologica, Via L. Borsari, 46, 44100 Ferrara, Italy

In walkers, roller, and ice-skaters, HR was determined with the Heartcorder 232 System (San-Ei Instrument); the ECG was recorded on a magnetic tape (CM5 lead configuration, Electrodes Viatrode, International Medical Corp.). In the other sport activities, HR was determined with a heart rate monitor, with digital display (Exersentry III, Respironics). The two instrumentations gave identical HR values when used simultaneously; identical results were also obtained when heart frequency and ECG were recorded through a telemetry system (e.g., Cardiotape system SFR-12, Fukuda Denshi Co, LTD).

In walkers, roller, and ice-skaters, HR was calculated by averaging the heart beats from the ECG record for approcimately 10 s in the last part of each stage; in the other sport activities HR was read by the athlete and reported to the operator at the end of every stage. Speed was increased after stages varying in length for the various sports considered (see below); the athletes were asked to keep their V constant during each stage. The speed variations within each stage were negligible as demonstrated occasionally for the different sports examined in tests during which each stage was subdivided into several identical parts by the use of photoelectric cells.

The time to cover each stage was measured manually and the speed was calculated accordingly.

Determination of the relationship between V and HR: details for the various sport activities

Canoeists and rowers: The test was performed over a distance of 2,400 m in a rectilinear channel, with the stream. The water velocity through the distance employed was $36 \text{ m} \cdot \text{h}^{-1}$. The athletes increased their speed after stages of 200 m.

Cross-country skiers: In the absence of snow the test was performed over a distance of 1,680 m, on an asphalt up hill road, with a constant slope of 5.5%, using the roller-skis normally employed for training. The speed was increased after stages of 140 m. In the presence of snow the test was performed on a flat course (frozen lake). The track used had two linear parts 200 m in length. Speed and HR were measured at the end of the linear parts. In the connecting curvilinear tracts the athletes were asked to keep the work intensity constant (the speed was not measured). The test lasted 10–14 laps. All athletes used the diagonal stride technique. Skis and waxes varied according to the snow conditions.

Cyclists: The test was performed on a velodrome with a concrete cycle-track of 335 m. Speed was increased very lap; the test lasted for 12–16 stages of 335 m. Each athlete used his own racing bicycle; the gear choosen varied from subject to subject and was kept constant through the test.

Ice-skaters: The test was performed on a 400-m artificially frozen track. Speed was increased after every lap. The test lasted 10–12 stages of 400 m.

Roller-skaters: The test was performed on a 325-m asphalt skating-track. Speed was increased after every stage of 325 m. The test lasted 10–12 laps.

Walkers: The test was performed on a 400-m track, and lasted eight to 10 laps. Speed was increased after every stage of 200 m.

Blood lactate concentration at different work intensities

These determinations have been carried out in six cross-country skiers (on roller-skis), three cyclists, two roller-skaters, three rowers, and five walkers.

The athlete was at the first submitted to the determination of the V-HR relationship. On the basis of the results obtained, six different velocities were chosen, three below and three above the so called deflection velocity (V_d: see below). Each speed was reached gradually and maintained for 1,000 m in walkers, cross-country skiers, and rowers; 2,000 m in roller-skaters and 3,000 m in cyclists. Venous blood samples were collected (in tubes containing sodium EDTA fluoride) both before and 5 min after the end of each fraction. For each sample, 1 ml of blood was taken from the cubital vein, after cleaning the skin with cotton-wool moistened with disinfectant. The skin was dried with dry cotton-wool before venopuncture. Each test was separated by an interval of 15 min of light work. The determination of blood lactate was performed according to the procedure of Noll (1974), using the Monotest lactake kit manufactured by Boehringer.

Correlation between V_d and average speed in competitions

Cross-country skiing: Twenty-one cross-country skiers have been submitted to the V_d determination the day before four races, either official (15 km, $n = 20$; 30 km, $n = 8$) or simulated (12 km, $n = 17$; 11 km, $n = 7$). The average velocity during the race was calculated from the official timing.

Cycling: Sixty-eight cyclists have been submitted to the V_d determination 30 min before they performed an all-out test of 1,000 m with flying-start.The average velocity during the test was deduced from manual timing. One cyclist performed during the period april-october 1982 11 simulated races of 16 km, following the same course: the day before his V_d was determined.The average velocity during the race was deduced from manual timing.

Walking: Thirteen walkers have been submitted to the V_d determination 2 days before a national competition of 20 km.

Statistical analysis

Correlations were evaluated by linear regression analysis.

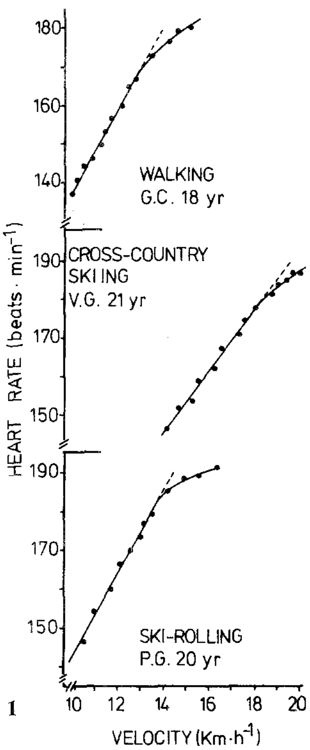
Results

Relationship between V and HR in canoeists, cross-country skiers, cyclist, roller and ice-skaters, rowers and walkers.

Figures 1, 2, and 3 show the relationship between V and HR demonstrated in the seven sport activities considered. In every instance V and HR are linearly related up to a speed (called deflection velocity, V_d) beyond which there is a definite decrease in slope.

As demonstrated in runners (Conconi et al.1982) the same V-HR relationship is obtained when the athlete follows different protocols, keeping the speed constant for longer fractions.

Of the 190 athletes considered, 101 were tested from three to 32 times. The results obtained show that the V-HR relationship and V_d in the various



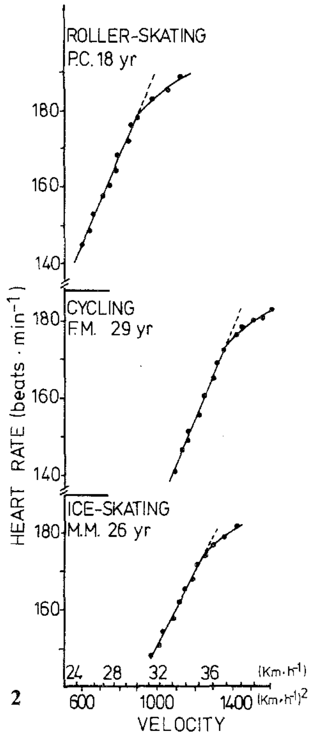


Fig. 1. Relationship between velocity and heart rate in walking, cross-country skiing, and ski-rolling

Fig. 2. Relationship between velocity and heart rate in roller-skating, cycling, and ice-skating. The scale of the abscissa takes into consideration the fact that the work intensity for overcoming the air resistance increases with the second power of the velocity (Di Prampero et al. 1971 and 1976 and Di Prampero 1983)

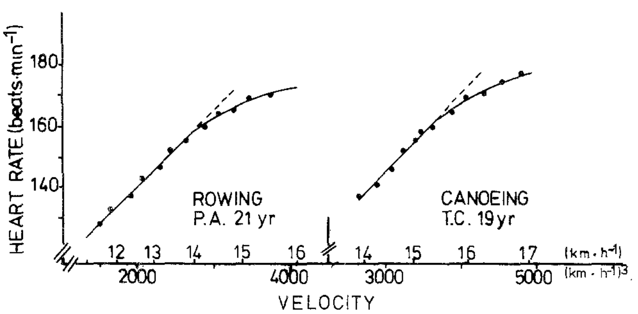


Fig. 3. Relationship between velocity and heart rate in rowing and canoeing. The scale of abscissa takes into consideration the fact that the work intensity for overcoming the water resistance increases with the third power of the velocity (Åstrand and Rodhal 1977, Di Prampero et al. 1971)

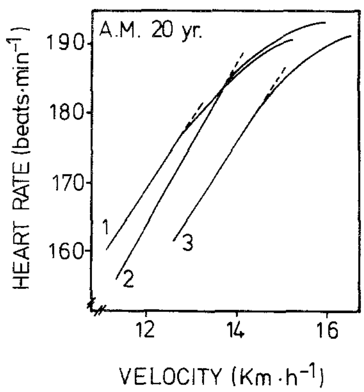


Fig. 4. Modification of the velocity-heart rate relationship with time, following training in a 1 cross-country skier (examined on roller-skis). The three tests have been done on May '81 (1), July '81 (2), and February '82 (3)

sport activities considered are typical of each individual and are modified predictably by training, detraining, or by disease. An example of such variations is given for a skier (Fig. 4).

Reproducibility of repeated observations

When the V-HR relationship is determined within a few days, and the experimental conditions are kept constant, superimposable results are obtained; in addition, the V_ds of two such tests are practically indistinguishable (see Table 1).

V_d and blood lactate concentration

The coincidence between V_d and onset of lactate accumulation in the blood, previously established in runners (Conconi et al. 1982), has been tested in six

Table 1. V_d values determined in the same athlete within a few days

Sport activities	Subjects	1st V_d ($km \cdot h^{-1}$)	2nd V_d ($km \cdot h^{-1}$)
Cycling	1	39.500	39.500
	2	36.870	36.870
Rollerskating	3	28 900	29 200
	4	26.000	25 800
	5	29 200	29 000
Rowing	6	14.580	14.580
	7	15.670	15.620
Walking	8	11.500	11.600
	9	12.900	13.100
	10	12.400	12.400
	11	13.700	13.800
	12	12.000	12.200
	13	14.300	14.100
	14	14.100	13.600
	15	14.900	14.800
	16	12.600	12.400

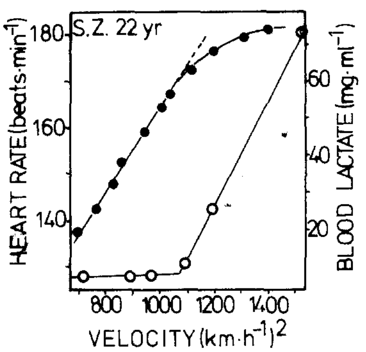


Fig. 5. Velocity-heart rate relationship (●——●) and blood lactate concentrations (○——○) at various speeds in a cyclist

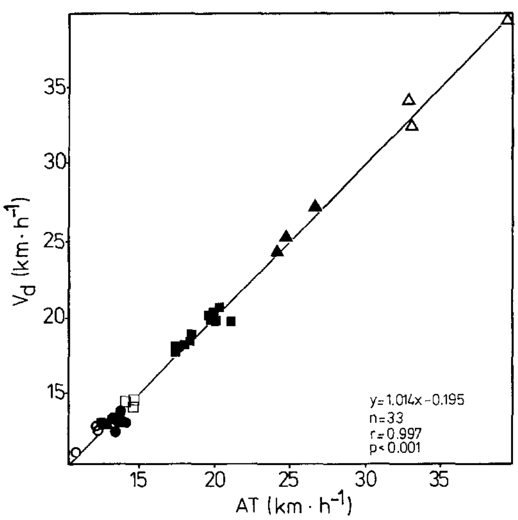


Fig. 6. Correlation betwen anaerobic threshold (AT) and deflection velocity (V_d) in cross-country skiing (●), cycling (△), roller-skating (▲), rowing (□), walking (○), and running (■)

Table 2. Correlation coefficients between V_d and average speed in competitions

Sport activities	Events	Number of cases	r	$P <$
Cross-country skiing	15 km	20	0.80	0.001
	30 km	8	0.82	0.01
	12 km	7	0.86	0.01
	11 km	7	0.86	0.01
Cycling	1,000 m flying-start	68	0.83	0.001
Walking	20 km	13	0.88	0.001

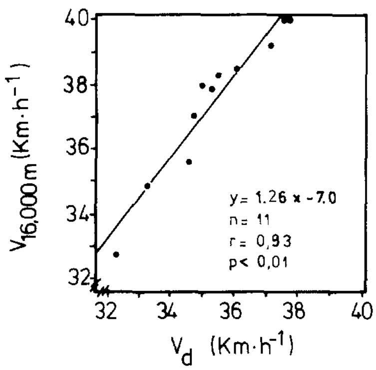


Fig. 7. Correlation between deflection velocity (V_d) and average speed in a 16-km cycling simulated race

cross-country skiers (on roller-skis), three cyclists, two roller-skaters, three rowers, and five walkers.

The amount of lactate present in the blood 5 min after fractions of various distance (see Subjects and methods), covered at various given constant speeds, was determined. Figure 5 shows the results obtained in a cyclist: V_d and AT are practically coincident. This is emphasized by the results of Fig. 6, showing a highly significant correlation ($r = 0.99$) between the two variables: in this figure are also included the values of 13 runners, previously studied.

V_d and average velocities in various sport events

The relationship between V_d and the average speed maintained during cross-country skiing and walking races and in an all-out test of 1,000 m cycling with a flying-start is shown in Table 2.

Correlation coefficients ranging from 0.80 to 0.88 have been obtained.

Figure 7 shows the relationship between the variations of V_d and of average cycling speed in a 16-km simulated race, demonstrated in a single athlete, in different training conditions; the correlation coefficient in this instance is 0.93.

Discussion

The field test developed in runners (Conconi et al. 1982) has been adapted to canoeing, cross-country skiing, cycling, roller, and ice-skating, rowing and walking. In these sports, as in running:

1 – a linear relationship between V and HR, typical for every athlete and sport considered has been found;

2 – the linear relationship is lost at high work intensities;

3 – coincidence between V_d and onset of blood lactate accumulation, and therefore AT, has been demonstrated in cycling, cross-country skiing, roller skating, rowing, and walking. The field test therefore permits the indirect noninvasive determination of the velocity (or of the heart rate) at which lactate begins accumulating in the blood;

4 – the highly significant correlation found between V_d and average speed in cross-country skiing, cycling, and walking competitions, apart from indicating that AT is an important factor in limiting the utilization of $\dot{V}_{O_{2max}}$, demonstrates that V_d is a simple physiological signal useful for predicting performance in aerobic events;

5 – the test allows the identification, athlete by athlete, of the training intensity (or of the heart rate) above which the anaerobic mechanisms of ATP production are utilized; it is therefore useful for adapting training intensities to the conditions of individual athletes.

Acknowledgements. We are indebted with the Italian Federation of Winter Sports (Milan), the Italian Olympic Committee and the Scuola dello Sport (Rome) for their technical and financial support.

We wish also to thank the trainers and the athletes for their cooperation and Miss. Velia Margutti and Mrs. Elisabetta Mariotti for typing the manuscript.

References

Åstrand PO, Rodhal K (1977) Textbook of work physiology. (2nd ed) Mc Graw, New York

Conconi F, Ferrari M, Ziglio PG, Droghetti P, Codecà L (1982) Determination of the anaerobic threshold by a noninvasive field test in runners. J Appl Physiol: Respirat Environ Exercise Physiol 52: 869–873

Costill DL, Branam G, Eddy D, Sparks K (1971) Determination of marathon running success. Int Z Angew Physiol Einschl Arbeitsphysiol 29: 249–254

Davis JA, Frank MH, Whipp BJ, Wasserman K (1979) Anaerobic threshold alterations caused by endurance training in middle-aged men. J Appl Physiol: Respirat Environ Exercise Physiol 46: 1039–1046

Di Prampero PE, Cortili G, Celentano F, Cerretelli P (1971) Physiological aspects of rowing. J Appl Phyisiol 31: 853–857

Di Prampero PE, Cortili G, Mognoni P, Saibene F (1976) Energy cost of speed skating and efficiency of work against air resistance. J Appl Physiol 40: 584–591

Di Prampero PE (1983) Le coût énergétique de la locomotion humaine sur terre et dans l'eau. Schweiz Z Sportmed 31: 87–94

Liesen H, Du Faux B, Hollmann W (1977) Modifications of serum glycoproteins the days following a prolonged physical exercise and the influence of physical training. Eur J Appl Physiol 37: 243–254

Noll F (1974) Methoden der enzymatischen Analyse. In: Verlag Chemie (3rd ed), vol II, Bergmeyer, Weinheim HV, p 1521.

Accepted March 25, 1984