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Maintenance of the threshold/maximum heart rate quotient in swimmers

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The anaerobic threshold (AT) was calculated in 23 swimmers by field methods: MADER (MM) and modified exponential MADER (EM) and laboratory methods: SKINNER (SM), ROBERGS (RM), CONCONI (CM), and ventilatory (VM). Two types of test were designed. The first in a swimming pool (test 1), performing four series of increasing intensity swims, and the second on a cycle ergometer increasing until exhaustion (test 2). In both tests the heart rate (HR) was recorded in beats per minute by telemetry. Despite the different HR at the AT: 180.0 ± 2.7 (MM), 179.1 ± 2.4 (EM), 166.0 ± 2.9 (SM), 157.0 ± 2.8 (RM), 167.6 ± 2.7 (VM) and 168.8 ± 2.2 (CM), and the different maximum HR (HRmax) in the two tests: 201.6 ± 2.0 in Test 1 and 188.5 ± 1.6 in Test 2; the percentage HR in the AT/HRmax proved to be similar for all the methods except RM (88.0 %-89.2 %). The mechanism of organic control in progressive exercise can therefore have, in this test, a "threshold" zone at a given percentage of the maximum capacity of adaptation, both when the exercise is carried out in a pool and also on a cycle ergometer.

Key words: Anaerobic threshold, Heart rate, Swimming, Effort test (field and laboratory).

Abbreviations

AT: anaerobic threshold.
CM, RM, SM, VM: Laboratory methods: CONCONI, ROBERGS, SKINNER, and ventilatory, respectively.
EM, and MM: field methods: modified exponential MADER, and MADER, respectively.
EV: Expired volume
HR: heart rate; maximum HR (HRmax)
LT: lactic threshold
PB: personal best
$PETCO_2$, and $PETO_2$: partial end tidal carbon dioxide pressure, and partial end tidal oxygen pressure, respectively.
VE/VCO_2, and VE/VO_2: ventilatory equivalent of carbon dioxide, and ventilatory equivalent of oxygen, respectively.
VO_2max: maximal oxygen uptake.
VT: ventilatory threshold.

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The present physiologic concept of training requires the application of both field and laboratory tests in order to determine the parameters indicative of the state of physical fitness and allow sports training to be programmed.

The AT has in fact acquired a great deal of importance in Exercise Physiology due to the better correlation it possesses with the sports performance in relation to VO_2max, formerly the most commonly used parameter, since the AT and VO_2max have shown to be modified by different mechanisms.

The AT can be calculated by metabolic methods, i.e. the LT, which determines the increase in blood lactic acid (19), or by indirect or ventilatory changes, i.e. the VT, which analyzes the respiratory compensation parameters of the metabolic acidosis arising from an accumulation of lactate (28).

The determination of the AT by means of the VM has undergone several changes over time. Initially DAVIS *et al.* (11) and WASSERMAN *et al.* (30) proposed the first parameters which, although valid, are not the most ideal. A more adequate parameter, the VE/VO_2, was later obtained by CAIOZZO *et al.* (4), while DAVIS (12) considered the increase in VE/VO_2 with no increase in the VE/VCO_2 to be a very specific parameter.

More recently, other authors (1, 28) have used the following parameters: second loss of linearity of VE with respect to the VO_2, reduction of the $PETCO_2$ after an increase in the PETO and an increase in VE/VCO_2 after an increase in VE/VO_2.

In order to obtain ever less invasive or damaging methods numerous tests, both laboratory and field, have been described to calculate the AT. However, there remains the problem of extrapolating the results of these to the corresponding sports activity, the ideal being that the tests are performed under sports-specific conditions. In swimming this is further complicated by the problem of finding a laboratory test which reproduces faithfully its practice. Numerous tests in swimming therefore are based on the relation between blood lactate concentration and swimming velocity measurements (18, 19, 27).

Due to the diversity of methods employed to calculate the AT a study was designed in swimming to compare by means of a common factor, the HR at AT determined for each method; the results obtained in the calculation of the AT by some of the most commonly used tests at present, both laboratory and field, in order to know the most reliable methods, the least expensive ones, and so that they proportion the earliest possible information.

Materials and Methods

Study Group.– A study was carried out with 23 healthy swimmers (12 male and 11 female) belonging to the same club and all highly trained (14 hours per week with 5-8 years training). Their ages ranged from 14 to 17 years and their basic anthropometric measurements were determined according to the different methods (13, 25, 32). The homogeneity of the sample was verified with the Kolmogorov-Smirnov Test (26). All the subjects were fully informed of the work to be done and their permission was obtained. Nevertheless, they were able to abandon the study at any moment at will. Prior to initiating the study a protocolized history was taken and the subjects were given a general physical examination, with resting ECG and measurements of the HR and arterial blood pressure, in order to rule out the existence of any organic pathology. The female swimmers, performed the test

between the eighth and tenth days of the menstrual cycle.

Design of the Stress Tests.– The subjects undertook two types of stress tests, Test 1: Cycle ergometry test at a constant pedalling speed of 60 rpm, marked by audio-visual metronome and controlled with a programmable digital system.

After a two minute warmup the test was begun at a charge of 30 W, with progressive increases of 20 W/min until exhaustion, that is either exceeding the theoretical maximum heart rate, and/or inability to maintain the pedalling speed for more than 10 seconds during one of the step increases, and/or at the subject's own request. Controls were established, during the test, for arterial blood pressure, blood lactic acid concentration every three minutes, central HR by ECG and telemetry, and continuous ECG monitoring in V5.

The breath by breath ventilatory response and the gas exchange were also measured using an integrated computerized system (CPX- S2000) previously described by GAESSER *et al.* (14-16), and validated by POOLE and GAESSER (23). A mixture of gases at a known concentration was used for the calibration of the expired gases. Mean minute values, based on the measurements obtained during the last 30 seconds, were used to determine ventilatory parameters. VO_2max was taken to be the highest VO_2 value during the incremental test.

Test 2: A field test carried out in a 25 meter, thermoregulated, covered swimming pool. It consisted of swimming four series of 200 meters at 65 % (A), 80 % (B), 85 % (C), and 95 % (D) of their personal best (PB), with 30 minute rest periods between series. The HR was controlled by telemetry (17) every five seconds during the test.

Blood lactic acid concentration was determined by enzyme method, ANALOX micro-stat P-LM4 (2, 7), with arterialized capillary blood samples obtained from the soft part of the fingers (3). In test 1 samples were taken at the beginning of the test, every three minutes throughout the test, at the end, and at minutes 1, 2, 3, 4, 5, 10 and 15 of recovery, and in test 2 at minutes 1, 2, 3, 4, and 5 of recovery time, in order to only represent the maximal level (20).

Both tests were carried out following International Commission Sciences Sport and Physical Education (ICSSPE) norms, fasting, at the same time of day and year, regulating both ambient and water temperatures, and controlling the relative humidity and atmospheric pressure. The ambient details under which the field and laboratory tests were performed were respectively: Ambient temperature (25 ± 0.6 and 25 ± 0.4 °C), relative humidity (65 ± 1.8 and 60 ± 1.4 %), atmospheric pressure (760 ± 2.8 and 760 ± 1.7 mmHg), and swimming pool water temperature (25 ± 1.2 °C).

Methods used to calculate the anaerobic threshold.– Laboratory test: a) Ventilatory method (VM). The HR was measured corresponding to the exercise intensity producing both the second loss of linearity of the VE and the VCO_2 with respect to the VO_2, and the decrease in $PETCO_2$ after the increase in $PETO_2$ together with the increase in the VE/VCO_2 after the increase in VE/VO_2: ventilatory threshold 2 or VT_2 of SKINNER-MCLELLAN (28). The abrupt increase in RER next to the unit was also taken into account (30). This parameter was assessed on an independent basis by two skilled technicians who were familiar with the indicators of VT_2. In each instance, the same break-point was identified by the two technicians.

b) CONCONI's method (CM) (8, 9). The HR corresponding to the point of deflection or rupture of the HR with respect to the exercise intensity was determined visually independently by two experienced observers, with disagreements resolved in conference.

c) SKINNER's method (SM) (20, 21, 28). The HR was measured coinciding with the exercise intensity corresponding to the point at which 4 mmol/l is reached on the graphical representation of the lactic acid values obtained every three minutes during the cycle ergometry test.

d) ROBERGS' method (RM) (24). The HR was obtained corresponding to the exercise intensity at which, graphically, the exponential function between the time during the laboratory test and the respective lactic acid values, determined every three minutes, reached 4 mmol/l.

Field Test (fig. 1B): a) Two swim MADER method (MM) (19). The swimming velocity at which 4 mmol/l was reached graphicallywas determined, by prolonging the line joining the lactic acid values for two of the 200 m series, one being maximum and the other submaximum. b) Mader method modified by an exponential function (EM). The swimming intensity was determined at which, graphically, the exponential function obtained between the swimming intensities of the four series and their respective lactic acid values reached the 4 mmol/l line.

These last two methods, therefore, express the swimming intensity AT, which is necessary to relate this parameter to the HR obtained by telemetry as follows: In the four swimming series, performed at different intensities, the corresponding logarithmic function between the HR values and the swimming time during the test was obtained. These logarithmic functions have in their second half a stabilization phase of the HR with respect to the time during the test. From the HR interval of this phase of the functions mean HR values were obtained corresponding to each one of the four series or swimming intensities (fig. 1A). By

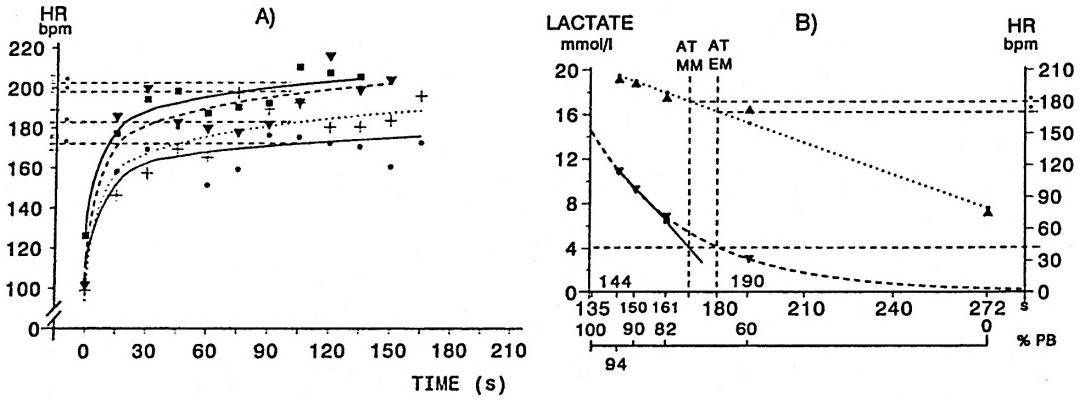

Fig. 1. *Obtention of the HR in different conditions.*
A) Mean HR (*) corresponding to the intensity of the four swimming series, based on the logarithmic functions between the heart rate and the time in each of the series. Series A (65% PB): •—, Series B (85 % PB): +..., Series C (90 % PB): ▼---, and Series D (95 % PB): ■—. B) HR at the anaerobic threshold (*) calculated by the Mader method (▪—), exponential Mader method (▼---), extrapolating the swimming intensities obtained to lineal regression (▲···) established between the swimming intensities and their corresponding mean heart rate values. %PB: Percentage of Personal Best.

relating the mean HR values obtained this way for each of the four series with their corresponding swimming intensity, expressed either as total time for each one or as a percentage which each time represents with respect to the personal best (%PB), a lineal regression is established (fig. 1B). Finally, once the swimming intensities corresponding to the AT were known, by both the MM and the EM methods, they could be referred to their corresponding AT HR by means of the lineal regression previously obtained.

Statistical Analysis.– The results were analysed by ANOVA 1 and regression analysis to determine possible statistical significance and correlation between the different ways of obtaining the HR, as well as the coefficients of variation.

Results

Anthropometry.– The anthropometric measurements of the group were: age 16 ± 0.3 years, height 168.8 ± 1.9 cm, weight 61.0 ± 2.0 kg, and fat weight 11.1 ± 0.4 %.

Field Test: Table I shows the mean heart rates for each one of the four swimming series, as well as their corresponding swimming intensities, expressed both as total time spent in each, and as a percentage that this time represents with respect to their personal best (%PB). The concentrations of blood lactic acid corresponding to the four swimming intensities are also shown. Table II shows the HR coinciding with the AT, obtained by MM and EM.

Laboratory Test: Fig. 1 shows the methodological procedure used in one subject to calculate the HR corresponding to the AT for the various field methods. Table II represents the heart rates at the moment of AT obtained by these methods for the whole group of swimmers forming the study.

Comparison between Methods: Table II shows the mean and standard error values for the HR at the AT, calculated by the various field and laboratory methods. Statistical study of these data showed significant differences between the methods. The greatest degrees of significance were found between the laboratory (SM, RM, VM, and CM) and field (MM and EM) methods. Expressing the percentages of the HR at the AT obtained by the various methods with respect to the corresponding maximum HR (HRmax). In all cases, except RM, these HR at AT are in the same percentage zone with respect to the HRmax (88 % - 89.2 %), and only between RM and the other methods is there a significant statistical difference, with $p<0.001$. The coefficients of variation of the HR at AT were calculated as a dispersion index, with the following results: 7.3 (MM), 6.5 (EM), 8.5 (SM), 8.4 (RM), 7.6 (VM), and 5.9 (CM).

Regression analysis of the HR at AT, made between the different study methods, shows a high coefficient of correlation between the field methods MM and EM ($r = 0.9$, $p < 0.001$), and also between the laboratory metabolic methods SM and RM ($r = 0.8$, $p < 0.001$). On the other hand, although with a lower statistical significance ($p < 0.01$), there was a correlation of the VM with the two metabolic methods MM ($r = 0.6$) and SM ($r = 0.6$) and also with CM ($r = 0.6$). Finally, there was also a correlation ($p < 0.05$) of the VM with the metabolic methods modified by an exponential function EM ($r = 0.4$) and RM ($r = 0.4$) and of the CM with the MM ($r = 0.5$). No significant correlation was found between the field (MM and EM) and laboratory (SM and RM) metabolic methods, nor between the CM and EM, SM, or RM.

Table I. *Maximum lactate and heart rate (HR) values (mean ± ES) for each of the four swimming series intensities.*
Intensities expressed either as final time in seconds (s), or as a percent (%) that this time represents against their personal best (PB).

	Series A	Series B	Series C	Series D
Mean HR (bpm)	162.2 ± 3.5	179.2 ± 3.1	192.2 ± 2.6	201.7 ± 2.0
Lactate (mmol/l)	2.5 ± 0.3	4.4 ± 0.3	6.2 ± 0.4	8.4 ± 0.0
Final time (s)	205.0 ± 8.3	184.5 ± 4.8	174.1 ± 4.8	166.7 ± 4.5
PB (%)	66.9 ± 2.0	80.7 ± 1.1	87.4 ± 1.0	92.2 ± 1.0

Table II. *Heart rate values at the anaerobic threshold and maximum, and as their percentage.*
The mean ± SE heart rate values at the anaerobic threshold (Threshold HR) and maximum (HRmax) in beats per minute, and the percentage of the threshold HR with respect to the corresponding HRmax (Threshold HR/HRmax) as a percentage (% HRmax), for the different study methods. MM:Mader method, EM: Mader "exponential" method, SM: Skinner's method, RM: Robergs' method, VM: Ventilatory method, CM:Conconi's method. Statistical study (HR at the AT): +p < 0.05, ++p < 0.01, *p < 0.005 and **p < 0.001.

Method	Threshold HR	% HRmax	HRmax	SM	RM	VM	CM
MM	180.0 ± 2.7	89.2 ± 0.8	201.6 ± 2.0	**	**	++	++
EM	179.1 ± 2.4	88.8 ± 0.6	201.6 ± 2.0	**	**	++	++
SM	166.0 ± 2.9	88.0 ± 1.2	188.5 ± 1.6		+		
RM	157.0 ± 2.8	83.2 ± 1.2	188.5 ± 1.6			++	++
VM	167.6 ± 2.7	88.7 ± 0.9	188.5 ± 1.6				
CM	168.8 ± 2.2	89.2 ± 1.0	188.5 ± 1.6				

Discussion

The basic mean anthropometric characteristics of the study group are similar to those obtained by CARTER (6) for young swimmers of the same age, participants in different Olympic Games.

Recently, telemetric methods have become more common for the continuous monitoring of the HR during exercise (10, 17, 29). This has made it possible to express the AT of swimmers at the HR instead of the classic parameter of swimming speed, and to carry out a regression analysis as in this study, thereby allowing different methods using the same HR parameter to be compared later.

Analysis of the HR values coinciding with the AT, calculated by the various methods used in both tests, show a greater threshold values of HR in the MM and EM methods, used in the pool, with statistically significant differences ($p < 0.05$), than those values obtained with the laboratory methods SM, RM, VM, and CM. These higher values, obtained with the same telemetric system for the monitoring of the HR in all cases, coincide with CALDWELL and PEKKARINEN (5), who found lower values of AT in cycle ergometer tests than during free swimming in a pool. This may be due to the use of a greater muscle mass in this test than in a laboratory test, and also the fact that a more specifically trained active muscle mass is employed (31). Other authors (17) found no differences in the threshold HR between such laboratory methods as CM in cycle ergometry and SM, whilst O'TOOLE *et al.* (22) obtained higher values for LT than for VT.

The use of a target maximal heart rate to prescribe exercise cardiorespiratory conditioning is an accepted practice (1). In this study, in all cases except in RM, the HR values at AT are grouped around 88-89.2 % of the HRmax in both tests, with the statistical differences between the %HRmax disappearing. This means that, in this study group, all these methods found the AT in the same percentage zone as the HRmax.

The validity of a laboratory method for calculating the AT could therefore be proposed, and once the percentage which this AT represents with respect to the HRmax in the same test is established, it could be extrapolated with respect to the same %HRmax found in the field test, with less physical and economic expense.

We calculated the coefficient of variation of the HR at AT obtained by the various methods as a dispersion index, and noted that there was a great concentration of the results in all cases, the best being those calculated for VM and MM, and the most disperse the modified ones using the exponential function EM and RM and CM.

Regression analysis of the HR at AT between the various study methods showed a high coefficient of variation between MM and EM, carried out in the pool, and with a lower statistical significance, between the field methods and SM, which are metabolic. No significant correlation was found between these (metabolic methods) and the VM or CM, possibly due to the fact that, at least in our study, the AT calculated by the metabolic laboratory methods SM and RM is detected earlier than by VM. This means that the metabolic changes at the AT precede the ventilatory modifications.

Therefore, obtaining the AT at the same %HRmax in the different maximum tests studied implies that, independently of the muscle masses used, and whether specifically trained or not, the organic control mechanism in exercise, when large muscle groups are activated, presents a zone of greater energy demand on behalf of the active muscle cells at any given percentage of their maximum capacity of adaptation with the time of effort.

It remains to be seen whether these results will still hold throughout the whole of a specific training programme or using other methods to calculate the threshold which collect different maximum adaptations, due to the use of different muscle masses or the specificity of the trained musculature (with morphofunctional differences), or the body position, or the ambient conditions.

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V. J. FERNÁNDEZ-PASTOR, F. PÉREZ, J. C. GARCÍA, A. M. DIEGO, F. GUIRADO and N. NOGUER. *Mantenimiento del cociente de F.C. umbral/frecuencia cardíaca máxima en nadadores.* J. Physiol. Biochem. (Rev. esp. Fisiol.), 53 (3), 327-334, 1997.

Se calcula el umbral anaeróbico (UA) en 23 nadadores por métodos de campo: MADER (MM) y MADER modificado por una función exponencial (ME) y, por métodos de laboratorio: SKINNER (MS), ROBERGS (MR), CONCONI (MC) y método ventilatorio (MV). Se diseñan dos tipos de tests. El primero se hace en piscina cubierta termorregulada, realizando 4 series incrementando la velocidad de nado; el segundo, se diseña en el laboratorio mediante un test incremental hasta el agotamiento. En ambos tests se registra la frecuencia cardíaca (FC) en lat/min por telemetría. Los resultados de FC en el UA son: 180 ± 3 (MM), 179 ± 2 (ME), 166 ± 3 (MS), 157 ± 3 (MR), 168 ± 3 (MV) y 169 ± 2 (MC). Los de FCmax en ambos tests son 202 ± 2 en el test 1 y 189 ± 2, en el test 2. El porcentaje de FC en el UA en relación a la FCmax es similar en todos los métodos (88.0-89.2 %)

excepto en el método de ROBERGS. Por lo que se deduce que, en el mecanismo de adaptación al ejercicio progresivo existe una "zona umbral" a un mismo porcentaje dado de la máxima capacidad de adaptación al ejercicio, tanto si el esfuerzo físico se realiza en cicloergómetro como si se efectúa en piscina.

Palabras clave: Umbral anaeróbico, Frecuencia cardíaca, Natación, Tests de esfuerzo (campo y laboratorio).

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