Noninvasive Use of Heart Rate or Stride Pattern as Compared to the Use of Blood Lactate for the Determination of Anaerobic Threshold

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INTRODUCTION

Noninvasive methods i.e. respiratory gas exchange, electromechanical properties of the muscles, integrated electromyograph and heart rate criteria have been used for the determination of the anaerobic threshold (AT). As it is the simplest one, the heart rate method (AT_{HR}) rapidly gained popularity among coaches. The concordance and the exceptionally high correlation ($r = 0.99$) between AT_{HR} and blood lactate threshold (AT_{LA}) repetitiously reported by the same laboratory pointed out the need for an external validation. The main purpose of this study was to compare the AT_{HR} with the AT_{LA}. Stride pattern alteration in relation to threshold response was also studied.

Twenty two elite male runners ($\bar{X} \pm SD = 26.3 \pm 5.2$ yr, 173 ± 6.0 cm, 65.3 ± 7.4 kg and 68.9 ± 3.7 ml/kg min/O_2max) performed two maximal multistage running field tests on a 183.9 m indoor track with inclined turns. The initial speed of 9 km/h was increased by 0.5 km/h every lap for the AT_{HR} test and by 1 km/h every 4 min (interspaced with a 45 s pause for fingertip blood sampling) for the AT_{LA} test. Stride frequency of different running speeds was measured throughout the AT_{HR} test. Threshold criteria were: the onset of heart rate plateau for the AT_{HR}, the

OBLA level at 4 mM and the sudden sustained increase in blood lactate concentration for the AT_{LA}, and any systematically occuring stride pattern alteration.

Correlation between AT_{HR} and AT_{LA} was very low ($r = 0.43$ and $r = 0.50$). Stride pattern did not reveal any detectable alteration at the threshold. The AT_{HR} running speed was inconsistent and significantly higher ($p < 0.01$) as compared to the AT_{LA} speed. In conclusion, our study failed to confirm the validity of the heart rate method or to detect any mechanical alteration in stride pattern at the threshold.

Although anaerobic threshold (AT) was first introduced for clinical applications (Wasserman and McIlroy, 1964; Wasserman et al., 1973), it is now widely used for training and evaluating athletes (Davis et al., 1979; Karlsson et al., 1984; Jacob et al., 1985). Many studies however, dispute the concept and the physiological meaning of the threshold response as well as the feasibility of its methodological approach (Jones and Ehrsan, 1982; Yeh et al., 1983; Brooks, 1985; Gladden et al., 1985; Hughson et al., 1987). This antagonism towards the AT has not prevented investigators from studying it further and attempting to improve the traditional methodology of invasive blood lactate (AT_{LA}), or noninvasive gas exchange (AT_{GE}), and even suggesting new methods. Hence, bicarbonate and pyruvate concentration in the blood (Beaver et al., 1986; Wasserman et al., 1985), integrated electromyograph (IEMG) (Moritani et al., 1981; Viitasalo et al., 1985) and heart rate criteria (Conconi et al., 1982) have been applied for the AT determination.

Among these methods, the heart rate method (AT_{HR}), i.e. the deflexion point in the running speed-heart linearity, is the simplest one. Also applicable in field conditions, the AT_{HR} rapidly gained popularity. The original study was carried out on runners (Conconi et al., 1982). Since that time, the same laboratory also has released data for cycling, rowing, swimming, cross-country skiing, roller- and ice-skating, walking and even horseracing (Conconi et al., 1984; Droghetti et al., 1985; Cellini et al., 1986; Borsetto and Conconi, 1986). Furthermore, Conconi and colleagues always reported coincidence between AT_{HR} with an almost perfect and unexpected correlation for biological material ($r=0.99$). The AT_{HR} method has been recently criticized, however, by external studies (Ribeiro et al., 1985; Coodman et al., 1986; Lacour et al., 1987). Regardless the reasonable criticism raised by these studies, none of these used the exact AT_{HR} procedure used by Conconi and colleagues.

The main purpose of this study is to investigate the validity of the heart rate anaerobic threshold as compared to the lactate threshold using the

same type of ptotocol that was used by Conconi et al. (1982). In addition, we took the opportunity to study any particular alteration in stride pattern at the threshold response. Such alterations may be expected in view of the accelerated anaerobic metabolism, the nonlinear inxrease in IEMG, and the link between the electromechanical properties of the working muscles and the anaerobic threshold (Moritani et al., 1981; Viitasalo et al., 1985; Moritani et al., 1987).

METHODOLOGY

Subjects. Twenty two elite male distance runners, scoring above 750 points on the Gardner and Purdy (1970) scale were informed of all the risks and stresses associated with the experiments and gave their written consent to participate in this study. The physical characteristics of the subjects are presented in Table 1.

Design and Protocols. Among the 22 runners only 19 provided complete pair data for the three maximal multistage running tests: two field tests on a 183.9 m indoor track with inclined turns for the AT_{LA} and the AT_{HR} and one treadmill test in the laboratory for the $\dot{V}O_{2max}$. Tests were performed in a random order with at least three days in between. Subjects warmed up using their usual procedure. Initial speed for the tests was set at 9 km/h, but measurement started at 11 km/h.

Based on the principle of the Léger and Boucher (1982) multistage aerobic track test, a prerecorded cassette was used to accurately (±2 m/lap) pace the runners for the AT_{LA} and the AT_{HR} tests. Each runner adjusted his speed by crossing four equidistant markers along the track at the same time he heard the recorded signal. The cassette was made by a computer program, and to insure speed accuracy, play back speed was calibratea uefore testing with a speed pitch control on the cassette deck.

For the AT_{LA} protocol, the speed was increased by 1 km/h every 4 min. The 4 min stages were interspersed by a 45 s pause for fingertip blood sampling.

For the AT_{HR}, the Conconi et al. (1982) protocol was used. The speed was continuously increased by 1 km/h per 1 ap up to 14 km/h and thereafter, by 0.5 km/h per lap.

For the VO_{2max}, after a familiarization period of running on the treadmill, a horizontal treadmill protocol was performed. The speed was continuously increased by 1 km/h every 2 min.

TABLE 1

Anthropometric and Physiological Values for the Maximal Oxygen Uptake the Conconi Heart rate Anaerobic Threshold and Blood Lactate Threshold Tests

VARIABLE	X	s	n[b]
ANTHROPOMETRY			
AGE, yr	26.3	5.2	22
WEIGHT, kg	65.3	7.4	22
HEIGHT, cm	173.0	6.0	22
FAT_a, %	9.0	2.1	22
VO_2max, ml/kg min	68.1	3.7	22
AT_{HR} TEST (Conconi)			
THRESHOLD VALUES			
SPEED, km/h	18.5	1.1	19
HEART RATE, bmp	176.2	10.8	19
MAXIMAL VALUES			
SPEED, km/h	21.8	1.1	19
HEART RATE, bpm	186.7	9.5	19
AT_{LA} TEST			
THRESHOLD VALUES			
SPEED, km/h	16.3	0.8	19
HEART RATE, bpm	175.8	9.3	19
MAXIMAL VALUES			
SPEED, km/h	18.8	1.0	19
HEART RATE, bpm	187.6	9.1	19

a Durnin % Wormesly, 1974

b A few data had to be deleted for pairwise analysis

Variables and methods. Heart rate was recorded every 5 s throughout the three tests using an AMF Quantum XL system. This system transmits the signal picked up through a small transmitter snapped onto the belt of the chest electrodes to a memory-equipped watch receiver that gives back heart rate as a function of time. Compared to ECG, the Quantum XL was found to be very accurate (Thivierge & Léger, 1986).

Stride frequency per minute (SF) was computed from the time (0.01 s precision) of ten consecutive contacts of the same foot during the AT_{HR}

test. Stride length (SL), expressed in meters, was defined as the distance of a complete cycle between two consecutive contacts of the same foot, and was calculated from SF and running speed.

For the blood lactate sample, the fingertip was cleaned with alcool, dried and pricked with an autolet mechanism which minimizes pain. Using a micropipette, a blood sample of 50 microlitres was drawn and immediately deproteinized with 0.6 M cold perchloric acid. This solution was centrifuged for 5 min at 1500 rpm and the supernatant was enzymatically analyzed for lactate (Behring Diagnostics).

For the $\dot{V}O_2$, expired air was collected in neoprene bags through a Collins low resistance valve during the last minute of each 2 min stage. The expired air volume ($\dot{V}E$) was measured with a Tissot spirometer, and the O_2 and CO_2 fractions were determined from a constant sample using the Beckman E-2 and the Beckman LB-2 gas analyzers.

The OBLA level (4 mM in blood lactate) and the rapid sustained lactate increase were used to define the threshold speed of the AT_{LA} test. For the AT_{HR} test, the criterion was the heart rate deflexion point. In addition, SF and SL were plotted against running speed in order to detect any possible alteration that may be related to the threshold response.

RESULTS

Mean and standard deviation values of anthropometric characteristics, VO_2max, and other investigated variables of the AT_{HR} and the AT_{LA} tests are presented in Table 1. The threshold response, yielded by the AT_{HR} test, was significantly higher (13.4%, $p < 0.01$) than that of the AT_{LA} test, demonstrating a lack of concordance between the two AT approaches. Maximal speed of running for the AT_{HR} test (21.8 km/h) was also higher (16%, $p < 0.01$) than the AT_{LA} test (18.8 km/h), but comparable to the threshold speed of the AT_{HR} test (18.5 km/h, Table 1).

Running speed at the OBLA was poorly correlated with the running speed corresponding to the deflexion point of the AT_{HR} test ($r = 0.43$ and SEE = 5.9% OBLA speed). Using the lactate inflexion point criterion, correlation was slightly improved ($r = 0.50$ and SEE = 4.5% AT_{LA} speed, Figure 1). The threshold speed, however, was better correlated to the maximal speed within each of the AT_{LA} and the AT_{HR} test (Figure 1). On the other hand, the $\dot{V}O_0max$ values yielded the lowest correlation with the threshold running speed in each test (AT_{LA}: $r = 0.16$ and AT_{HR}: $r = 0.19$).

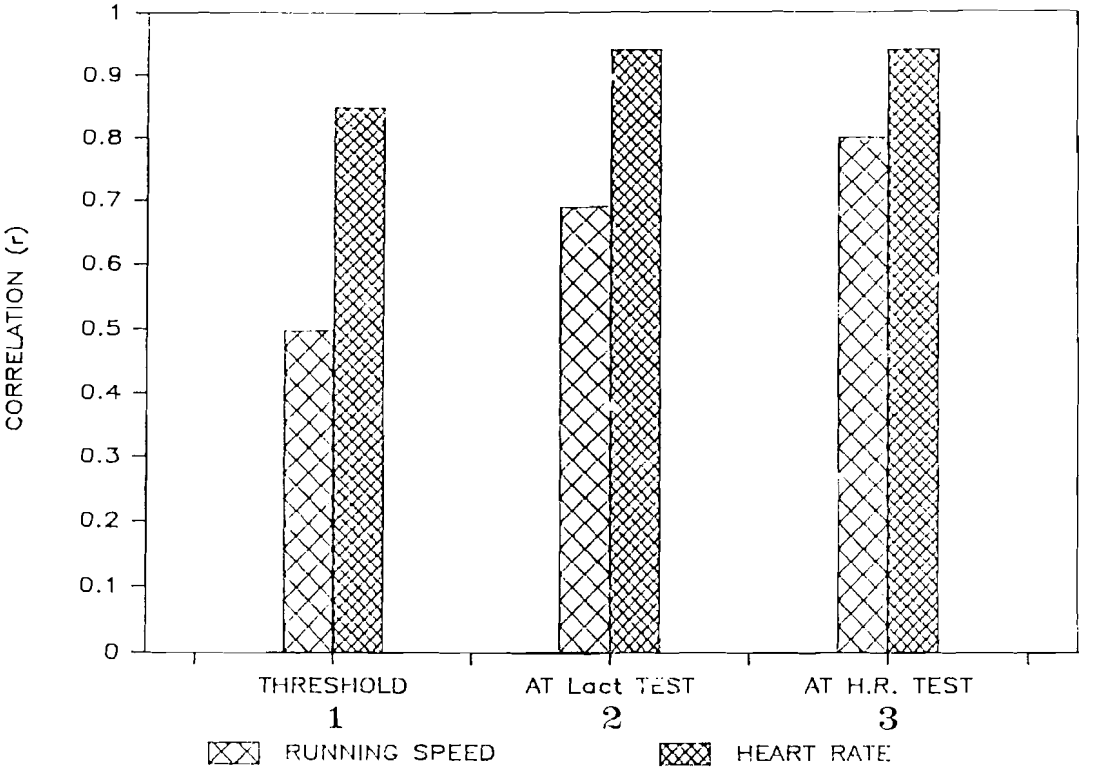

Fig. 1. Correlation coefficients of running speed and heart rate between 1) threshold values of the AT_{LA} and AT_{HR} tests, 2) threshold values and maximal values of the AT_{LA} test and 3) threshold values and maximal values of the AT_{HR} test.

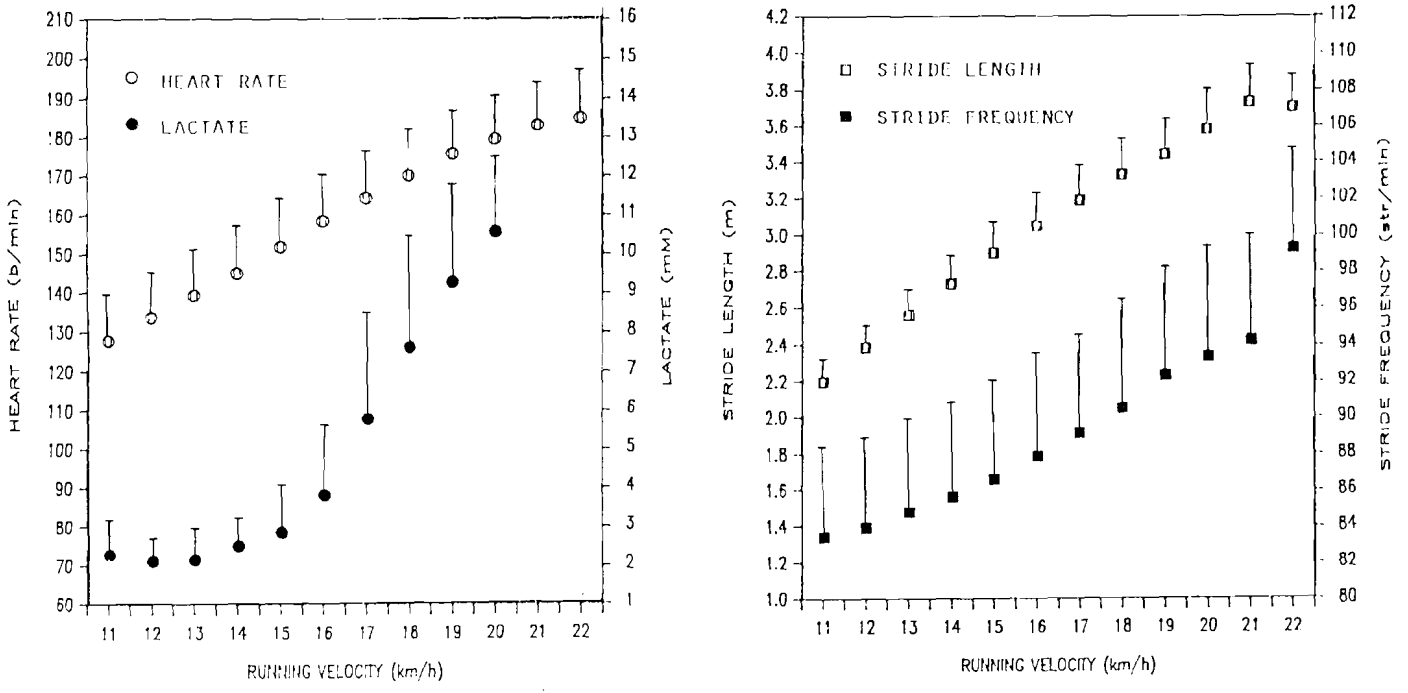

Fig. 2. Values ($\overline{X} \pm SD$) of heart rate (AT_{HR} test) and blood lactate (AT_{LA} test) as a function of running speed (right panel), and stride length and stride frequency (AT_{HR} test) as a function of running speed (left panel). The number of subjects was progressively reduced in the last three stages.

The disaccordance between AT_{HR} and AT_{LA} is obvious from the average heart rate and lactate data plotted against running speed (Figure 2). Figure 2 also shows mean and standard deviation values of SL and SF obtained during the AT_{HR} test. Average values of SL and SF do not display any particular trend at AT_{HR} or any other speed, except the last one which is readily explained by the lower number of subjects (n=8) who attained such a speed.

Comparing the heart rate responses at the threshold instead of the running speed yielded higher correlation (r: 0.85 vs 0.50 and SEE: 2.8% vs 4.5%, Figure 1). However, as was the case for the running speed variable, the heart rate response at the threshold was better correlated to the maximal heart rate in each test (Figure 1). In contrast with the running speed, the heart rate response, both at the threshold and at the maximal level, yielded similar values in each test (Figure 3 and Table 1).

DISCUSSION

The validity of the heart rate threshold

The significant difference and the low correlation coefficient of our study (t test $p < 0.01$ and $r = 0.50$, or OBLA $r = 0.43$) failed to support the concordance and the high validity ($r = 0.99$) between the AT_{HR} and the AT_{LA} claimed by Conconi et al. (1982). Our results could be partially explained by the difficulty to properly detect the deflexion point from the scatterplots of heart rate data. This problem was also raised by Ribeiro et al. (1985) who questioned the physiological meaning of the AT_{HR} measurement. Furthermore, Goodman et al. (1986) found AT_{HR} systematically higher than AT_{GE}, while Lacour et al. (1987) concluded that the Conconi heart rate method does not provide any valid information on the anaerobic threshold.

Apart from the threshold running speed, maximal running speed was also significantly different ($p < 0.01$) between the two AT protocols, but the threshold speed of the AT_{HR} and the maximal speed of the AT_{LA} test were similar (Table 1). The sharp contrast between our results and those of Conconi et al. (1981) may be explained by the methodological approaches used. In both studies, experiments were carried out with elite runners in field conditions using a similar AT_{HR} protocol. For the AT_{LA} however, we adopted the 4 min stage incremental protocol with 45 s interruption for blood sampling, as often is seen in the literature

(Hagberg, 1984; Tanaka et al., 1984; Kumagai et al., 1982). In their AT_{LA} test, however, Conconi et al. (1982) selected the 1200 run stage at three speeds below and three speeds above the predetermined AT_{HR} speed, and each stage was interspaced with long recovery period (5 min passive recovery for blood sampling, plus 15 min active recovery with jogging). Such a protocol affected the lactate kinetics; indeed, blood sampling in elite runners is recommended within the first minute of recovery (McKenzie et al., 1985). In addition, the complete lactate recovery and the preselected speed along with the unusual detection of the threshold with a crossing point of two linear components corresponding to three speeds below and three speeds above the preselected AT_{HR} speed, always set the AT_{LA} very close to AT_{HR} response. Such a mathematical bias ensures high correlation and coincidence that could not be reproduced with an «independent» and conventional AT_{LA} protocol.

Metrological considerations

Since the use of AT_{HR} instead of AT_{LA} cannot be justified from our data ($AT_{HR} = AT_{LA}$ and $r = 0.50$), we tried to examine whether AT_{HR} could be better related to another performance index. This was undertaken with the consideration that AT is independent of other fitness attributes such as endurance, $\dot{V}O_2max$, or maximal anaerobic power. In this regard the speed at AT_{HR} was adequately correlated with maximal speed of AT_{LA} ($r = 0.67$) or AT_{HR} test ($r = 0.80$). This correlation was not confirmed with $\dot{V}O_2max$ and AT_{LA} ($r = 0.16$) nor AT_{HR} ($r = 0.19$), probably because of large inter-individual differences in mechanical efficiency and high homogeneity in $\dot{V}O_2max$ of the subjects.

The high correlation between the threshold and the maximal speeds was somewhat expected since a higher $\dot{V}O_2max$, or a higher maximal speed, is obviously associated with a threshold point that is always situated further on the right side of the curve. To avoid this undesirable bias, the threshold response was expressed as a percentage of maximal value (AT_{HR}: $85.2 \pm 3.0\%$ and AT_{LA}: $86.5 \pm 3.4\%$). However, the correlation was not improved: while removing one bias, another was probably introduced by compressing the relative range of data (i.e. $CV = 100\ SD/X$ for AT_{HR} and AT_{LA}: $CV = 5.9\%$ and 5.1% for speed expressed in km/h and $CV = 3.5\%$ and 3.9% for speed expressed in % maximal value). Thus, our set of data cannot provide sufficient explanation for the significance accorded to the threshold response.

It is interesting to note that the correlation between the threshold

speed (expressed in % maximal aerobic speed) and the maximal speed of the AT_{LA} test was negative ($r = -0.43$). With cross-sectional data and a less homogeneous group, this might indicate that individuals with high VO_2max tend to have less endurance and vice-versa. In fact, under different testing conditions, individuals with low VO_2max use a higher proportion of their aerobic power as compared to those with high $\dot{V}O_2max$ (Tsarouchas et al., 1982). With training however, both $\dot{V}O_2max$ and endurance a well as the threshold response expressed in percent of maximal values should improve (MacDougall, 1982; Léger and Lavoie, 1985).

Biomechanical observation in stride pattern

Notwithstanding the absence of AT response in stride pattern (Figure 2) some runners ($n = 4$) accelerated their SF at the threshold speed of the AT_{HR} test, while some ($n = 3$) above that speed. Of course, AT is an individualized concept and should be treated separately for each runner. Nevertheless, mean as well as standard deviation values presented in figure 2 reflect individual data and affect the shape of the curve. For instance, the existence of an AT point would be associated not only with an inflexion point on the average curve, but also with a sudden change, or to be more accurate, an increase in the variance of this curve. The presence of an inflexion point without change in variance would simply mean that all the individuals have the same AT, which is contrary to the AT concept itself. Among the investigated variables, only lactate appears to meet both conditions, while heart rate, as well as SF and SL have not a neat distinct inflexion point or have similar variance over the whole range of running speeds.

The slight plateau in SF at the speed of 20 and 21 km/h, together with the abrupt increase at 22 km/h appearing in figure 2, reflects individual variability. Above 20 to 21 km/h some runners ($n = 5$) increase only SL, while SF was even decreased at the last maximal speeds ($n = 3$). Further it is interesting to notice that the best runners ($n = 8$), those who completed the speed of 22 km/h, possessd higher SF. Therefore, the variance in stride pattern corresponds to inter- individual variability (Tokmakidis et al., 1987) rather than to alterations due to AT. A better technique for the detection of stride pattern, or the use of a high speed camera would possibly eliminate methodological errors and reveal more information.

Training implication of heart rate threshold

When applying the results of a threshold test to a design training regimen, one must be aware of the testing procedures that reveal the threshold response. For instance, a 15% higher threshold response was found on the cycloergometer during speed increments without load as opposed to load increments at constant cycling speed of 60 rpm (Tsopanakis et al., 1982). The uncommon constant distance stage incremental protocols, in which duration in decreased while speed is increased, used by Conconi et al. (1982), as opposed to the traditional constant duration stage protocols can explain the higher maximal speed attained in our AT_{HR} as compared to our AT_{LA} test. Such an obvious effect in running speed seriously compromises any training application. Furthermore, the predicted VO_2 requirement (Léger and Mercier, 1984) corresponding to the AT_{HR} test maximal speed (76.3 ml/kg min) is much higher than the $\dot{V}O_2max$ of these subjects (68.6 ml/kg min) and reflects non-steady state conditions, whereas for the maximal speed of the AT_{LA} test, the predicted $\dot{V}O_2$ requirement (65.9 ml/kg min) is very close to the measured $\dot{V}O_2max$. In fact, the threshold speed of AT_{HR} test corresponds to the VO_2max speed. Thus, training at AT_{HR} speed corresponds to a load greater than the AT_{LA} speed and similar to the maximal aerobic speed.

Although the AT_{HR} response is based on heart rate measurements, Conconi et al. (1982) never reported heart rate data obtained during their AT_{LA} test. Our data of heart rate responses at the threshold speed were similar for both the AT_{HR} and the AT_{LA} tests ($x \simeq 176$ bpm, 94% HRmax, Figure 3), and were highly correlated ($r = 0.85$, Figure 1). Ribeiro et al. (1985) also reported similar heart rate values at the breakpoint (95% HRmax). So, at first sight, the use of heart rate instead of running speed as a training stimulus appears to reconcile the AT_{LA} and AT_{HR} test. However, one must know that the large intra-individual variability in heart rate response prevents any accurate application with the elite athlete. Also, heart rate is a good training load indicator in steady state conditions below 85% $\dot{V}O_2max$ only. Above 85% $\dot{V}O_2max$, the heart rate levels off and reaches 100% HRmax (Maritz et al., 1961; Rowell et al., 1964; Davies, 1968). Thus, for running loads above 85% $\dot{V}O_2max$, the heart rate cannot increase any more and cannot accurately indicate the training intensity. Moreover, the very high heart rate (94% HRmax) as well as the predicted $\dot{V}O_2$ requirement (> 85% $\dot{V}O_2max$) at the AT_{HR} indicate that heart rate is useless for training applications at the threshold.

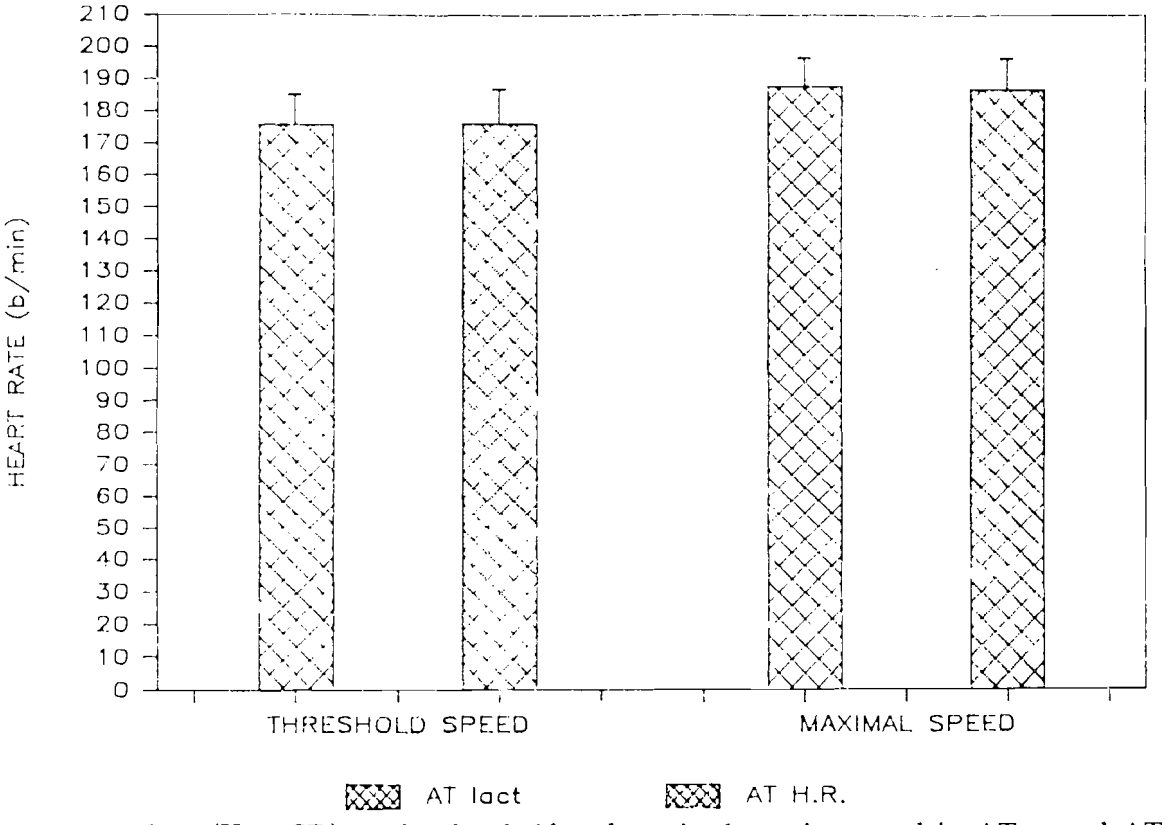

Fig. 3. Heart rate values (X ± SD) at the threshold and maximal running speed in AT_{HR} and AT_{LA} tests.

In our study, heart rate values at the threshold ($\simeq$ 94% HRmax) were close to maximal ones for both AT tests. This indicates that at the threshold intensity (> 85% $\dot{V}O_2$max) subjects were approaching a heart rate plateau, and so, the heart rate responses at the threshold, as is physiologically expected for the maximal ones, were similar (Figure 3). The fact that the heart rate values were similar for both the AT_{HR} and AT_{LA} tests does not necessarily confirm the validity of the Conconi method, as was oversightly suggested by an unqualified study on three cyclists (Guerdon, 1987). Moreover, considering the results of our study, and the success that Conconi obtained with his method on world class athletes (Ennis, 1985; Ferstle, 1986; Guerdon, 1987), one may wonder if it is the method itself or individual talent and endowment that was responsible for the gold medals and world records. However, even if there was a small but significant contribution, the Conconi AT_{HR} method would deserve attention.

CONCLUSION

The Conconi heart rate anacrobic threshold does not coincide with, and is poorly correlated to, the lactate threshold.

The physiological and electromechanical alteration at the threshold cannot be detected in the stride pattern during progressively increasing running speeds.

Setting training load at heart rate threshold as an optimal training stimulus is a possibility that cannot be ruled out from our data. Such a hypothesis remains to be proven experimentally.

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