Determination of the anaerobic threshold by a noninvasive field test in runners

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CONCONI, FRANCESCO, MICHELE FERRARI, PIER GIORGIO ZIGLIO, PAOLA DROGHETTI, AND LUCIANO CODECA. *Determination of the anaerobic threshold by a noninvasive field test in runners.* J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 52(4): 869–873, 1982.—The relationship between running speed (RS) and heart rate (HR) was determined in 210 runners. On a 400-m track the athletes ran continuously from an initial velocity of 12–14 km/h to submaximal velocities varying according to the athlete's capability. The HRs were determined through ECG. In all athletes examined, a deflection from the expected linearity of the RS-HR relationship was observed at submaximal RS. The test-retest correlation for the velocities at which this deflection from linearity occurred (V_d) determined in 26 athletes was 0.99. The velocity at the anaerobic threshold (AT), established by means of blood lactate measurements, and V_d were coincident in 10 runners. The correlation between V_d and average running speed ($\bar{x}$RS) in competition was 0.93 in the 5,000 m ($\bar{x}V_d = 19.13 \pm 1.08$ km/h; $\bar{x}$RS = 20.25 ± 1.15 km/h), 0.95 in the marathon ($\bar{x}V_d = 18.85 \pm 1.15$ km/h; $\bar{x}$RS = 17.40 ± 1.14 km/h), and 0.99 in the 1-h race ($\bar{x}V_d = 18.70 \pm 0.98$ km/h; $\bar{x}$RS = 18.65 ± 0.92 km/h), thus showing that AT is critical in determining the running pace in aerobic competitive events.

maximum oxygen uptake; factors limiting performance in runners; electrocardiography; heart rate, running speed

MAXIMUM OXYGEN UPTAKE ($\dot{V}O_{2\,max}$) has been described as an important index for predicting performance in middle- and long-distance runners (1, 19, 23, 26); nevertheless success in distance running may rely more on factors determining a good or poor utilization of $\dot{V}O_{2\,max}$ than on $\dot{V}O_{2\,max}$ itself (4, 5, 7, 8, 18).

The anaerobic threshold (AT)[1] has been suggested as one of the factors that could limit performance in runners (10, 13) by causing metabolic acidosis and/or a faster depletion of muscle glycogen, with consequent reduced endurance (3, 15). Up to now, AT has been deduced by determining the relationship between blood lactate and running speed (RS) (11, 13, 21, 24) or by determining alterations in selected respiratory gas exchange variables (10, 11, 24).

In kayakers and sedentary subjects, Pendergast et al. (17) have shown that, above AT, the increase in $\dot{V}O_2$ is smaller than the increase in work intensity. Although similar observations have not been made in runners, above AT an increase in RS at least in part independent of $\dot{V}O_2$ and possibly of HR can be hypothesized. If, because of the anaerobic ATP production, the work intensity above AT increases more than HR, this phenomenon could be used to evaluate indirectly and noninvasively AT. To verify this hypothesis, we have developed a field test for the determination of the relationship between RS and HR in runners.

MATERIALS AND METHODS

Determination of relationship between RS and HR. The RS-HR relationship was determined in runners by measuring the HR while the athlete under study progressively increased his RS. The 210 athletes considered were male middle- and long-distance runners; their ages ranged from 15 to 65 yr. Of the athletes considered, 31 belonged to the national athletic team, 103 were of intermediate athletic level, and 76 were of amateur level. They were all well conditioned, and their training ranged from a minimum of 50 km/wk to a maximum of 215 km/wk for at least 3 consecutive years. The HR has been determined with the Heartcorder 232 System (San-Ei Instrument); the electrocardiogram (ECG) was recorded on a magnetic tape (CM5 lead configuration, electrodes Viatrode, International Medical).

A usual warm-up lasting 15–30 min preceded every measurement. During the experiment athletes ran continuously, covering a distance that varied from 8 to 12 laps of 400 m at a total running time 15–20 min. The initial velocity was 12–14 km/h. Athletes were asked to increase their RS slightly every 200 m; the ECG was recorded in the last 50 m of every fraction. The running times were determined manually by the operator, and the RSs were calculated accordingly.

All the athletes studied were able to follow the protocol and in particular to increase their RS only slightly (avg 0.5 km/h) and to keep it fairly constant from one acceleration to the next. The velocity of the last 200-m fraction ranged from 18 to 25 km/h, depending on the athletic level of the subject examined.

The RS-HR relationship obtained with the test was in part linear and in part curvilinear (see RESULTS). The linear portion has been drawn by regression analysis and by subjective judgment; both techniques gave superimposable results. The curvilinear part of the graph has been drawn by subjective judgment.

[1] AT is defined as the highest $\dot{V}O_2$ beyond which lactate begins accumulating in the blood causing a metabolic acidosis (10).

The velocity at which the linearity of the RS-HR relationship is lost has been called deflection velocity (V_d). In the original protocol, devised for the determination of the RS-HR relationship in runners, the athletes were tested during a 10-km continuous run. The increase in velocity was performed after every 1,000-m fraction. After 40 such tests it was demonstrated that identical results could be obtained following an easier protocol, where the speed was increased after fractions of 400 m for which the speed was kept constant. The test lasted for 6–7 km. Two hundred such tests were performed in 63 runners. In both protocols the HR was calculated from the ECG recorded in the last 50 m of the various fractions, and the speed was derived from the time required to run the last 200 m.

Finally, the observation was made that the time required for the HR to adapt to every new speed was 10–20 s (when the increase in velocity did not exceed 0.5 km/h), and the protocol presented here was subsequently developed. The curvilinear part of the RS-HR relationship is better defined when using the protocol in which the speed is varied every 200 m, because of the higher number of observations that one can collect above V_d following this procedure.

For comparison of the three protocols, Fig. 2 is representative. The data were collected from a national-level middle-distance athlete (best time in the 5,000-m event, 14 min:12 s) who ran 11, 6.4, and 4 km. The three tests were separated by 3-day intervals.

Determination of blood lactate concentration at various speeds. This study was carried out in 10 runners. The athletes were at first submitted to the determination of the RS-HR relationship. On the basis of the results obtained, different velocities were chosen, three below and three above the deflection velocity (see RESULTS). Each running speed was reached gradually to avoid the initial lactacid oxygen deficit and maintained for 1,200 m.

Venous blood samples were collected in tubes containing ethylenediamine tetraacetic acid-sodium fluoride before the experiment and 5 min after the end of each fraction. Each test was separated by an interval of 15 min of jogging. The determination of blood lactate was performed according to the procedure of Noll [16 (p. 1521)] using the Monotest lactate kit manufactured by Boehringer. In all cases, the four determinations corresponding to the resting value and to the velocities below V_d and the three points above V_d have been connected by two straight lines. The velocity at the intersection of the two lines has been defined as AT.

RESULTS

Relationship between RS and HR. A typical relationship between RS and HR is shown in Fig. 1. RS and HR are linearly related up to 20.1 km/h. At higher speeds (above V_d), there is a definite decrease in slope. The same RS-HR relationship is obtained when the athlete follows different protocols, as in the experiment reported in Fig. 2 in which a middle-distance runner keeps his speed constant for 1,000-m fractions (Fig. 2*A*), for 400-m fractions (Fig. 2*B*), and for 200-m fractions (Fig. 2*C*). V_d has been demonstrated in 40 tests in which the speed was increased after every 1,000-m fraction in 10 km of a continuous run, in 200 tests in which the velocity was augmented after every lap in 6–7 km of a continuous run, and in all 1,300 tests or more we have carried out on the 210 runners examined to date following the present pro-

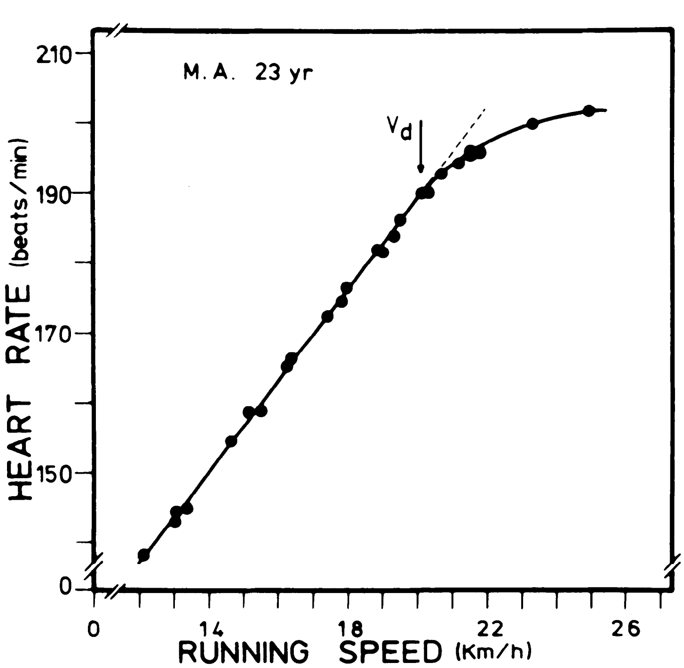

FIG. 1. Relationship between running speed and heart rate in a long-distance runner (best time for 10,000 m, 29 min:04 s).

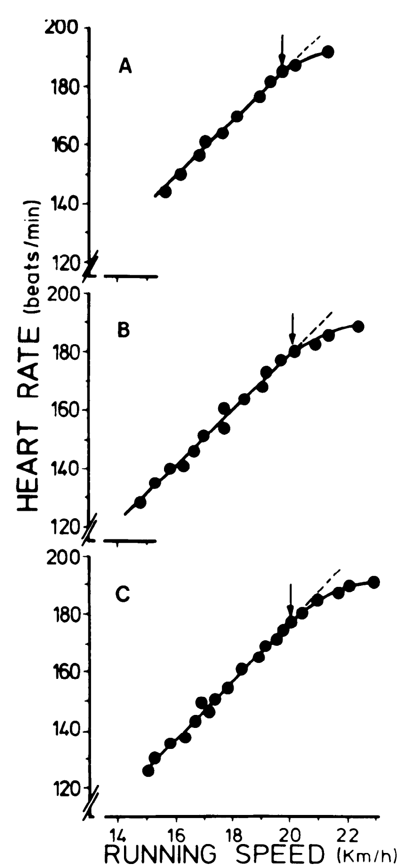

FIG. 2. Relationship between running speed and heart rate in a long-distance runner (best time for 5,000 m, 14 min:12 s). Variations in speed were after fractions of 1,000 m (*A*), 400 m (*B*), and 200 m (*C*).

tocol. V_d may be slightly lower (up to 0.4 km/h) when determined following the 1,000-m protocol.

In the 210 athletes considered HR at V_d was 5–20 (mean 10.6) beats/min lower than the highest HR registered at submaximal velocity. In 10 untrained individuals examined with the field test described here, V_d was 20–27 heart beats/min lower than highest HR registered. When the field test is repeated in the same subject within a few days and the experimental conditions (i.e., running suits, body weight, air temperature and humidity, absence of wind) are kept constant, identical data are obtained. This is shown by Fig. 3, which correlates the V_d measured in 26 subjects tested twice within 1 wk; the reproducibility of the test is demonstrated by the correlation coefficient of 0.99.

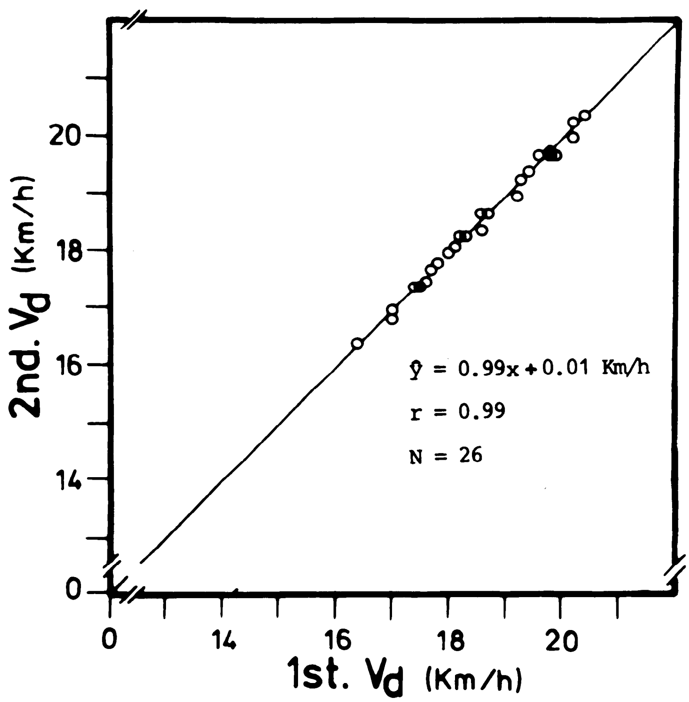

FIG. 3. Correlation of deflection velocity (V_d) values obtained in 2 subsequent tests in 26 runners. Tests were performed within a few days of each other. Two values are coincident.

Of the 210 athletes considered, 147 were tested from 3 to 80 times. The results obtained show that the RS-HR relationship and V_d are modified predictably by training and detraining or by diseases (e.g., Fig. 4, *A* and *B*).

V_d and AT. To establish a possible coincidence between V_d and AT, the amount of lactate present in the blood 5 min after 1,200-m fractions, run at various given constant speeds, was determined. Figure 5 shows the results obtained in a long-distance runner. V_d and AT are almost coincident. This is emphasized by the results of Fig. 6, showing a highly significant correlation ($r = 0.99$) between the two variables.

V_d and velocity in various running events. The relationship between the average RS maintained in competition and V_d was determined in 55 marathon runners, in 31 athletes who entered a 1-h race, and in 19 athletes who entered a 5,000-m race. In the latter case eight determinations were done during the winter season, the

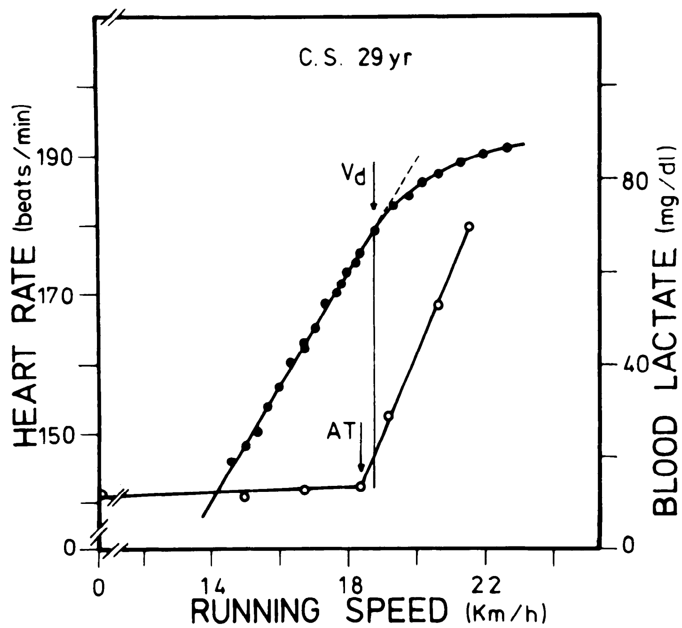

FIG. 5. Running speed-heart rate relationship and blood lactate levels at various speeds.

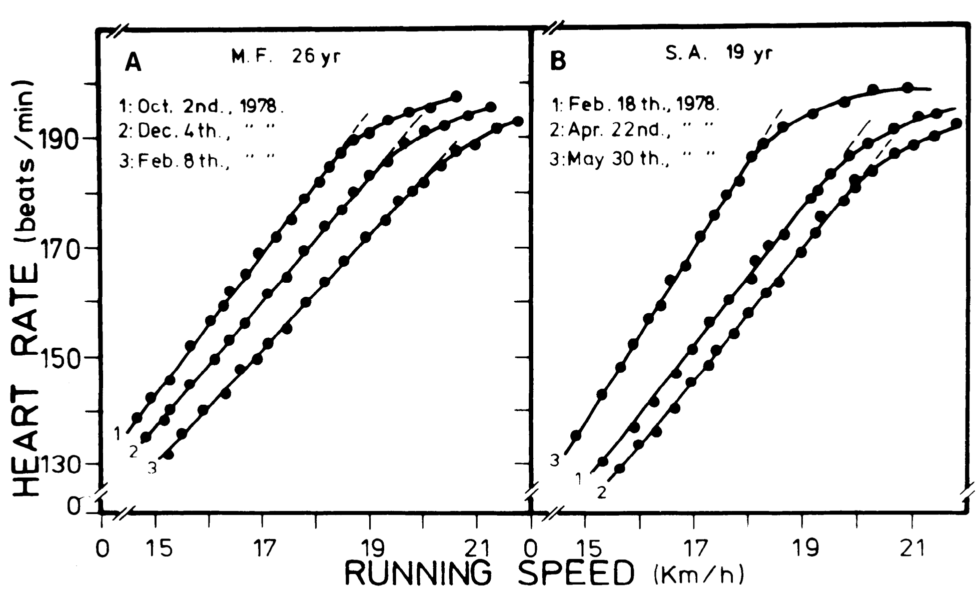

FIG. 4. Modifications of running speed-heart rate relationship with time following training in 2 runners (*A* and *B*). Third examination in *subj SA* (*B*) was carried out a few days before clinical and serological identification of an infectious mononucleosis.

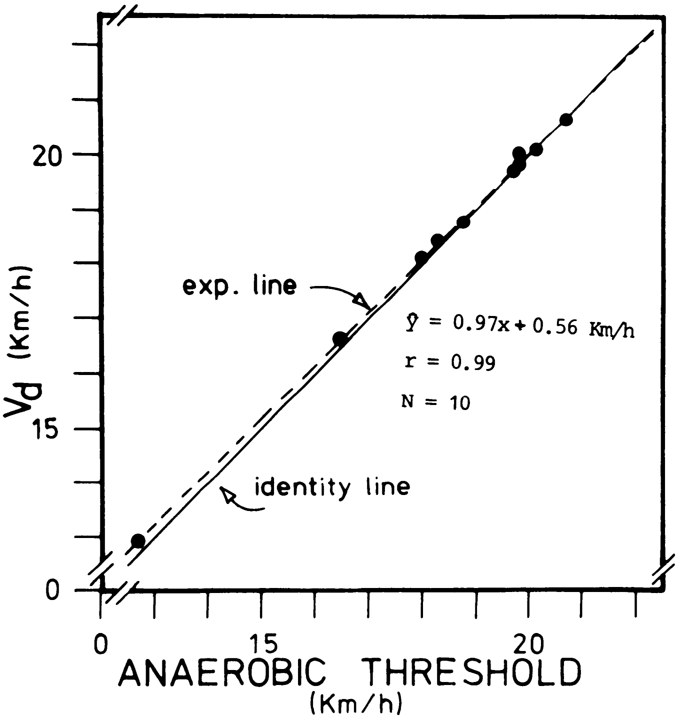

FIG. 6. Correlation between anaerobic threshold (AT) and deflection velocity (V_d). AT has been determined through blood lactate measurement as indicated in Fig. 5.

others during the summer. The field tests were performed a few days before each race. The results obtained are shown in Fig. 7, *A–C*. A highly significant correlation between competition average RS and V_d has been demonstrated for the three events.

V_d and other sports activities. The RS-HR relationship has been determined in other sports [walking (n = 20), canoeing (n = 4), rowing (n = 3), cycling (n = 7), roller-skating (n = 8), cross-country skiing (n = 10)]; V_d has been demonstrated in all cases. Coincidence between V_d and AT has been shown in one cyclist and in two roller-skaters.

DISCUSSION

The field test we developed demonstrates that the linear relationship between RS and HR, described by several investigators [1 (p. 356–357), 2, 14, 25], is sharply lost at high RSs. Since there is a highly significant correlation between V_d and AT (see Fig. 6), the departure from linearity of the RS-HR relationship is at least in part explained by the addition of the anaerobic mechanisms of ATP production to the aerobic ones. Part of the phenomenon probably depends on an increase in $\dot{V}O_2$ higher than the augmentation in HR and cardiac output, which has been shown to occur at high work loads (9, 20).

It is worth mentioning that the observed deflection from linearity is as sharp as the modifications of the

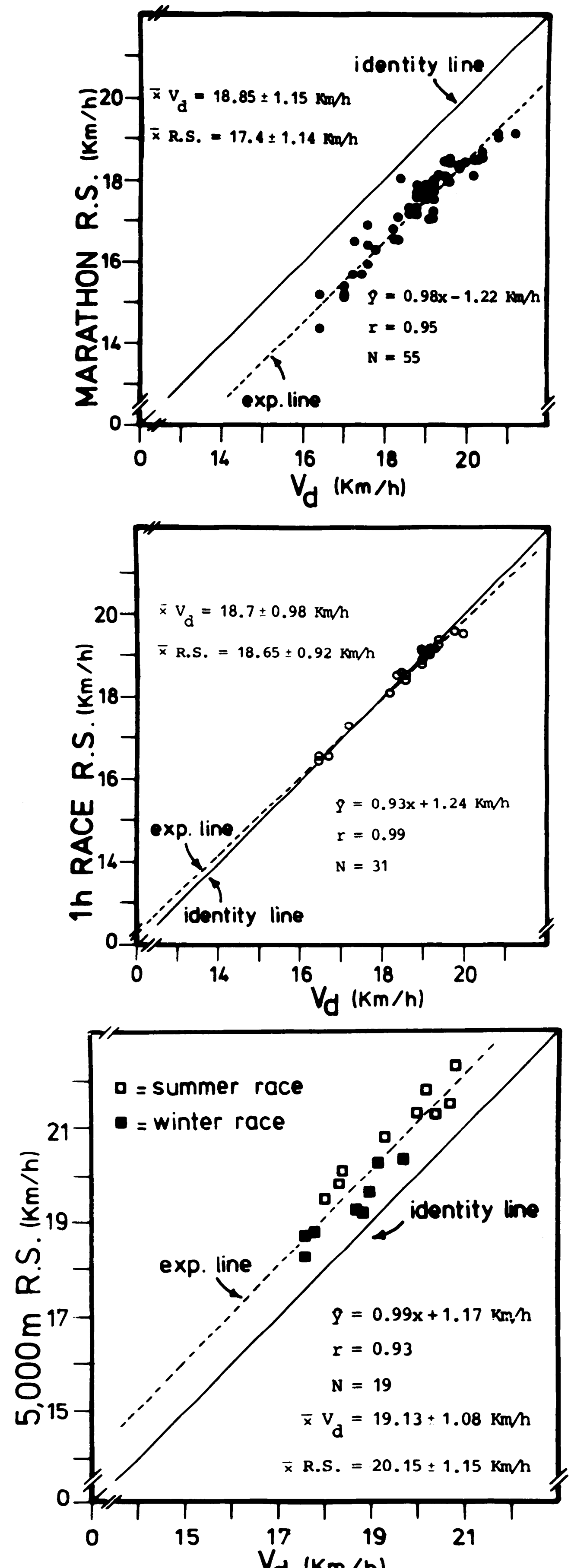

FIG. 7. *A:* Correlation between deflection velocity (V_d) and running speed (RS) in marathon runners; 3 values are coincident. *B:* Correlation between V_d and RS in athletes who entered 1-h race; 9 values are coincident. *C:* correlation between V_d and RS in athletes who entered 5,000-m event; 2 values are coincident.

respiratory variables and the increase in blood lactate demonstrated by Wasserman and McIlory (24) and by Davis et al. (11) above AT. In runners V_d is a simple physiological signal useful for the indirect and noninvasive determination of AT.

AT has been indicated as an important factor in limiting the utilization of $\dot{V}O_{2\,max}$ and therefore in determining the work intensity that an athlete can maintain in endurance competitions (5, 7). This is confirmed by the highly significant correlation we have found between V_d and RS in the 5,000-m event ($r = 0.93$), in the marathon ($r = 0.95$), and in the 1-h race ($r = 0.99$). A good correlation between distance-running performance and onset of plasma lactate accumulation ($r = 0.91$) has been recently found by Farrell et al. (12); the correlation was lower for $\dot{V}O_{2\,max}$ ($r = 0.83$), running economy ($r = 0.49$), and muscle fiber composition ($r = 0.47$). The good correlation between V_d and velocity in competition indicates that V_d, and therefore AT, plays a crucial role in determining the running pace in the events considered. Although in the 1-h race V_d and RS are almost the same, in the other two events the values obtained are different from V_d, being clearly higher in the 5,000-m event and lower in the marathon. This is no surprise, because in the 5,000-m event the anaerobic mechanisms for ATP production are employed and RSs above AT are to be expected. The anaerobic contribution to this event has been reported to be approximately 10% by Åstrand and Rodahl [1 (p. 317–326)]. This value is confirmed by our results showing a running speed exceeding V_d on the average of 5.8% (range = 3–9%). The smaller excesses over V_d have been found in winter performances (see Fig. 7*C*) in athletes who had reduced their specific anaerobic training. Finally, in the marathon several factors come into play in lowering the running pace below AT, such as the inadequacy of metabolic adaptations to endurance [3, 6, 14, 22 (p. 289)] and external factors (marathon course, temperature, humidity, wind).

In conclusion, the determination of the RS-HR relationship provides a means for measuring AT. This determination is noninvasive and has the advantage of being carried out while the athlete performs his usual physical activity. This test is potentially useful for following the training programs of single athletes. Available data indicate that the test can be applied to other sports activities.

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