European Journal of Sport Science, 2019
https://doi.org/10.1080/17461391.2019.1640289

ORIGINAL INVESTIGATION

A new field test to estimate the aerobic and anaerobic thresholds and maximum parameters

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Abstract
Evaluation of cardiorespiratory parameters is important in athletic population in order to monitor the training status and define training intensities. The aim of this study was to validate an easy-to-perform running test called RABIT® (Running Advisor Billat Training) for detecting aerobic (AerT) and anaerobic (AnT) threshold and maximum parameters. Fifteen trained runners completed a graded (GRAD) and RABIT test (four self-selected pace steps: (i) 10 minutes at free warm-up pace, (ii) 5 minutes at medium pace, (iii) 3 minutes at hard pace, (iv) 10 minutes at easy pace). We compared the cardiorespiratory parameters and running speed of the RABIT with those corresponding to AerT, AnT or maximum parameters obtained by the GRAD. The $\dot{V}O_2$max, HRmax, RERmax and running speed max measured during the 3-minute hard pace of the RABIT were not statistically different from the maximum parameters measured during GRAD ($p > 0.05$). The $\dot{V}O_2$, HR and RER measured during the medium and easy pace of the RABIT were not significantly different from the AnT and AerT parameters measured during GRAD. In conclusion, RABIT was validated for all the maximum parameters and for most of Ant- and AerT-related parameters and then it might be used for detecting training zones in athletes.

Keywords: *Running, aerobic power, RABIT test*

Highlights

- A new field test (RABIT(R)) for detecting aerobic, anaerobic threshold and maximum parameters was compared with a graded test (GRAD).
- Cardiorespiratory parameters measured during the RABIT were well related with parameters measured during GRAD.
- RABIT is a simple test for detecting maximum parameters, aerobic and anaerobic threshold without expensive laboratory equipment.

Introduction

Evaluation of cardiorespiratory parameters is important in athletic population to monitor the training status and define submaximal and maximal training intensities related to the maximal aerobic power ($\dot{V}O_2$max). Commonly, scientists perform evaluations by using expensive and not user-friendly devices that require specific knowledge. However, some simple and low-cost tests spread in the latest decades for evaluation or exercise prescription, especially for track and field athletes (Billat, Dalmay, Antonini, & Chassain, 1994; Conconi, Ferrari, Ziglio, Droghetti, & Codeca, 1982; Forte, Manchado-Gobatto, Rodrigues, Gallani, & Gobatto, 2018; Leite et al., 2018). Two of the most known are the Cooper Test and the Conconi Test (Conconi et al., 1982; Conconi et al., 1996; Cooper, 1968). The first estimates the $\dot{V}O_2$max during a 12-minute running test. Adopting the second, it is possible to detect the anaerobic threshold (AnT, according to Kindermann, Simon, and Keul (1979)) by using a heart rate (HR) belt to locate the deflection point from which the linear increment in HR with speed become curvilinear (Conconi et al., 1982). Conconi test is easy-to-perform by each athlete although some authors criticized this test and the deflection point corresponding to the AnT is not always detectable from the

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athletes or coaches themselves (Jeukendrup, Hesselink, Kuipers, & Keizer, 1997). Other authors proposed submaximal protocols for detecting the "so-called" aerobic threshold (AerT) or AnT (Billat et al., 1994; Forte et al., 2018) but they require blood lactate measurements, which are not always available in field conditions among the amateur population.

It is possible to detect AerT (~70–75% of $\dot{V}O_2max$) and AnT (~85–90% of ($\dot{V}O_2max$)) during an incremental test and establish basic training zones associated with heart rate, running pace, power, etc. Particularly, zone 1 (moderate intensity) is included between the onset of exercise through AerT. Zone 2 (heavy intensity) is included between AerT and AnT and zone 3 (severe intensity) is above AnT (Poole & Jones, 2012; Rossiter, 2011). Every zone corresponds to a specific effort perceived by the athlete (Kraemer, Fleck, & Deschenses, 2012). Indeed, rate of perceived exertion (RPE) is closely related to the concept of exercise intensity and more precisely it is "*the feeling of how heavy and strenuous a physical task is*" (Borg, 1998). It does not take into account exclusively the workload but included many other factors that affect the performance (temperature, humidity, energy supply). Moreover, RPE is a key mediator in the regulation of work rate (Tucker & Noakes, 2009). The importance of RPE in determining the self-selected exercise intensity (i.e. pacing) is underlined by authors (for details, see Abbiss and Laursen (2008)) who suggested that the brain processes a complex algorithm including peripheral feedback, previous experiences and the remaining workload (Abbiss & Laursen, 2005; St Clair Gibson et al., 2006).

Ceci and Hassmen (1991) showed that runners were able to self-adjust the running intensity at three different RPE values. These subjects adapted the speed in order to obtain an RPE of 11 ("light" on a 6–20 Borg scale) for 3 minutes, 13 ("somewhat hard") for 11 minutes, and 15 ("hard") for 5 minutes.

Combining the AerT and AnT concepts and the pacing strategy, the "Institut Billat Training" (Paris, France) proposed the so-called RABIT® track and field running test (Running Advisor Billat Training, www.billatraining.com) adapting Ceci & Hassmen, 1991 protocol. RABIT® uses a comparable self-paced protocol requiring to the athletes to run two steps of 10 minutes at easy pace (equivalent to an RPE 11) one step of 5 minutes at moderate pace (equivalent to an RPE 13) and one step of 3 minutes at hard pace (equivalent to an RPE 15) divided by 1 minute of passive recovery (Ceci & Hassmen, 1991).

This study aimed to verify if the RABIT® test is valid to be easily performed by all-level athletes without expensive devices. The advantage of this test should be that with only a verbal communication it would be possible to detect the different training zones.

Materials and methods

Participants

Fifteen trained runners (37.9 ± 10.9 years; 1.78 ± 0.05 m; 67.0 ± 9.1 kg) participated in the study. Their personal best 10-km time was 35:22 ± 03:27 minutes:seconds (range: 31:22–42:00). Athletes were informed about the protocol and we obtained a written informed consent. The review board of the local University approved the testing procedures. All tests were performed at the same hour of the day with similar weather conditions (temperature and humidity), and athletes performed only a light training or rest for 2 days preceding the testing sessions. All the runners were healthy, without recent injuries and did not take any medication.

Design

All runners completed two tests in a randomized order with 5–7 days of recovery between them. Prior the first test, the participants were visited by a medical doctor that gave his agreement in enrolling the runners. All tests were performed in the same homologated track (Paderno, Udine, Italy). The runners performed a free-15 minutes of warm up before each test and then they were equipped with a portable metabolimeter (K5, Cosmed, Italy) to collect cardiorespiratory parameters. After that, they underwent a graded exercise test (GRAD) or the new test (RABIT®) following described.

Graded exercise test (GRAD)

Starting from the speed corresponding to the ~70% of the speed of their personal record on 10.000 m, athletes increased the speed every minute by 0.5 km / h until the volitional exhaustion. A collaborator with a bike paced the runners and they were instructed to follow the bike. When the athletes were not able to maintain the draft of the bike (defined within a distance of ~10 m) the test was interrupted (mm:ss 12:02 ± 01:31). Oxygen uptake ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), ventilation and heart rate (HR) were collected using a portable mixing chamber metabolimeter (K5, Cosmed, Italy). Before each test O_2, CO_2 analysers and turbine were calibrated according to the manufacturer instructions. After the tests we transferred the data collected by the metabolimeter to the software provided by the manufacturer (Omnia) and then we exported the data to excel to be analysed. A levelling off of oxygen uptake

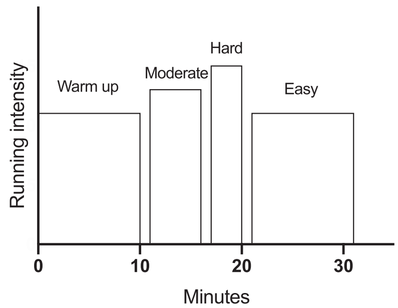

Figure 1. The four steps of RABIT® protocol. Warm up: run 10 minutes at easy pace. Moderate: run 5 minutes at medium pace. Hard: run 3 minutes at hard pace. Easy2: run 10 minutes at easy pace. Between each step subjects rested for 1 minute.

(defined as an increase of no more than 1 ml·kg^{-1}·min^{-1}) was observed in all subjects during the last 1 or 2 minutes of the exercise test, indicating that $\dot{V}O_2$max had been attained. The AerT and AnT were determined with the V-slope method (Beaver, Wasserman, & Whipp, 1986).

RABIT test

This test consisted in four self-selected pace steps (Figure 1) in which an operator gave the following instructions to the athletes: (i) run 10 minutes at free warm-up pace, (ii) run 5 minutes at medium pace (RPE = 13), (iii) run 3 minutes at hard pace (RPE = 15), (iv) run 10 minutes at easy pace (RPE = 11). Between each step athletes recovered 1 minute by standing. We asked to the subject to run without the watch in order to avoid external influences. During all the RABIT, the participants wore the K5 to collect cardiorespiratory parameters. Then, we averaged the data of the last minute of each step and we compared the step 4 (easy pace) with the AerT, the step 2 (medium pace) with AnT and the step 3 (hard pace) with maximum values.

Statistical analysis

We performed statistical analysis by using Graphpad Prism 8. Mean and standard deviation were calculated independently for every measured parameter ($\dot{V}O_2$, RER, HR, speed, pace) in GRAD and in RABIT test. Since the first step was used as a warm-up phase, we did not analyse this part of the protocol. We compared the AerT-related parameters ($\dot{V}O_2$, RER, HR, speed, pace) detected during GRAD with the parameters obtained in the last step of RABIT test (easy pace). We compared the AnT-related parameters with the parameters obtained during the 5 minutes at medium pace. Also, we compared the maximum parameters with those obtained during the three minutes at hard pace.

Considering a previous study (Metaxas, Koutlianos, Kouidi, & Deligiannis, 2005), in which authors compared the estimated $\dot{V}O_2$max with the measured $\dot{V}O_2$max we calculated that to obtain a statistical power of 0.80 with an alpha of 0.05 15 subjects were enough. We tested the normal distribution of the data using the Kolmogorov–Smirnov test. Sphericity (homogeneity of covariance) was verified by the Mauchly's test. When the assumption of sphericity was not met, the significance of the F-ratios was adjusted according to the Greenhouse–Geisser procedure. GRAD and RABIT results were compared using a paired T-test. Bland–Altman test was performed to validate the obtained parameters during the RABIT test and $p < 0.05$ was defined as statistically significant (Bland & Altman, 1986). Pearson coefficient was used to verify the correlation between GRAD and RABIT with correlation considered low (r = 0.30–0.50), moderate (r = 0.50–0.70) high and very high (r = 0.70–1.00) (Atkinson & Nevill, 1998). In addition, prediction accuracy was defined as the percentage of subjects whose RABIT parameters were predicted to be within ±5% of GRAD parameters. This error limit on prediction accuracy was accepted empirically as being consistent with calorimetry measurement errors of 5% or less (Phang, Rich, & Ronco, 1990). Differences between RABIT and GRAD higher than ±5% were considered as prediction errors and are reported as percentages of subjects whose parameters were overestimated or underestimated. The effect sizes (ES) between the parameters of the RABIT and GRAD were calculated using the Cohen's d (0 < d < 0.20 *small*; 0.20 < d < 0.50, *medium*; 0.50 < d, *large*).

Results

Maximum parameters

The $\dot{V}O_2$max, HRmax, RER max and running speed max measured during the three minutes hard pace of the RABIT test were not significantly different from the corresponding parameters measured during the GRAD (Table 1 and Figure 2A–C). The correlation coefficients between GRAD and RABIT for $\dot{V}O_2$max, HRmax, RER max and running speed max were $r^2 = 0.83$ ($p < 0.001$), $r^2 = 0.94$ ($p < 0.001$), $r^2 = 0.17$ ($p = 0.268$) and $r^2 = 0.93$ ($p < 0.001$) respectively. The accurate prediction was 71% for $\dot{V}O_2$max, 94% for HRmax, 56% for RER and 71% for running speed. The ES for $\dot{V}O_2$max, HRmax, RER max and running speed max were 0.07, 0.08, 0.03 and 0.13 (*small*), respectively. The

Table 1. Parameters obtained during the RABIT test and GRAD test.

	RABIT test	Graded test	Differences (%)	95% Limits of agreement		Accurate prediction	*p*
Maximum – hard pace							
Oxygen uptake (ml/kg/min)	67.1 ± 8.6	66.5 ± 8.6	0.9±6.4	−7.3	8.6	71	0.544
Respiratory exchange ratio	1.07 ± 0.06	1.07 ± 0.07	0.1 ± 8.1	−0.2	0.2	56	0.927
Heart rate (bpm)	173.8 ± 14.3	175 ± 13.0	−0.7 ± 2.1	−8.0	5.7	94	0.231
Speed (km/h)	17.5 ± 1.9	17.8 ± 1.8	−1.5 ± 3.1	−1.3	0.8	71	0.084
Pace (min:ss/km)	03:28 ± 00:25	03:25 ± 00:21	1.6 ± 3.3	−00:10	00:17	71	0.081
Anaerobic threshold – medium pace							
Oxygen uptake (ml/kg/min)	61.9 ± 9.5	60.5 ± 8.7	2.6 ± 8.3	−7.0	9.9	62	0.221
Respiratory exchange ratio	0.98 ± 0.09	0.96 ± 0.09	3.3 ± 17.5	−0.3	0.3	56	0.624
Heart rate (bpm)	166.5 ± 15.6	168.1 ± 12.8	−1.0 ± 3.8	−13.4	10.2	87	0.322
Speed (km/h)	15.8 ± 1.8	16.3 ± 1.9	−2.9 ± 3.8	−1.7	0.7	71	0.008
Pace (min:ss/km)	03:52 ± 00:26	03:44 ± 00:27	3.1 ± 4.0	−00:11	00:24	71	0.013
Aerobic threshold – second easy pace							
Oxygen uptake (ml/kg/min)	55.9 ± 6.6	54.8 ± 8.9	3.2 ± 11.2	−10.0	12.2	37	0.473
Respiratory exchange ratio	0.88 ± 0.08	0.89 ± 0.10	0.7 ± 15.4	−0.2	0.2	25	0.866
Heart rate (bpm)	161.2 ± 16.0	156.4 ± 13.8	3.4 ± 9.9	−24.4	34.0	31	0.233
Speed (km/h)	14.0 ± 1.3	15.0 ± 1.9	−6.8 ± 5.6	−2.8	0.7	25	0.001
Pace (min/km)	04:19 ± 00:26	04:03 ± 00:32	7.1 ± 5.9	−00:10	00:42	25	0.001

All values are expressed as mean ± standard deviation.
Accurate prediction: percentage of all subjects whose RABIT parameters were within 95% to 105% of GRAD parameters.

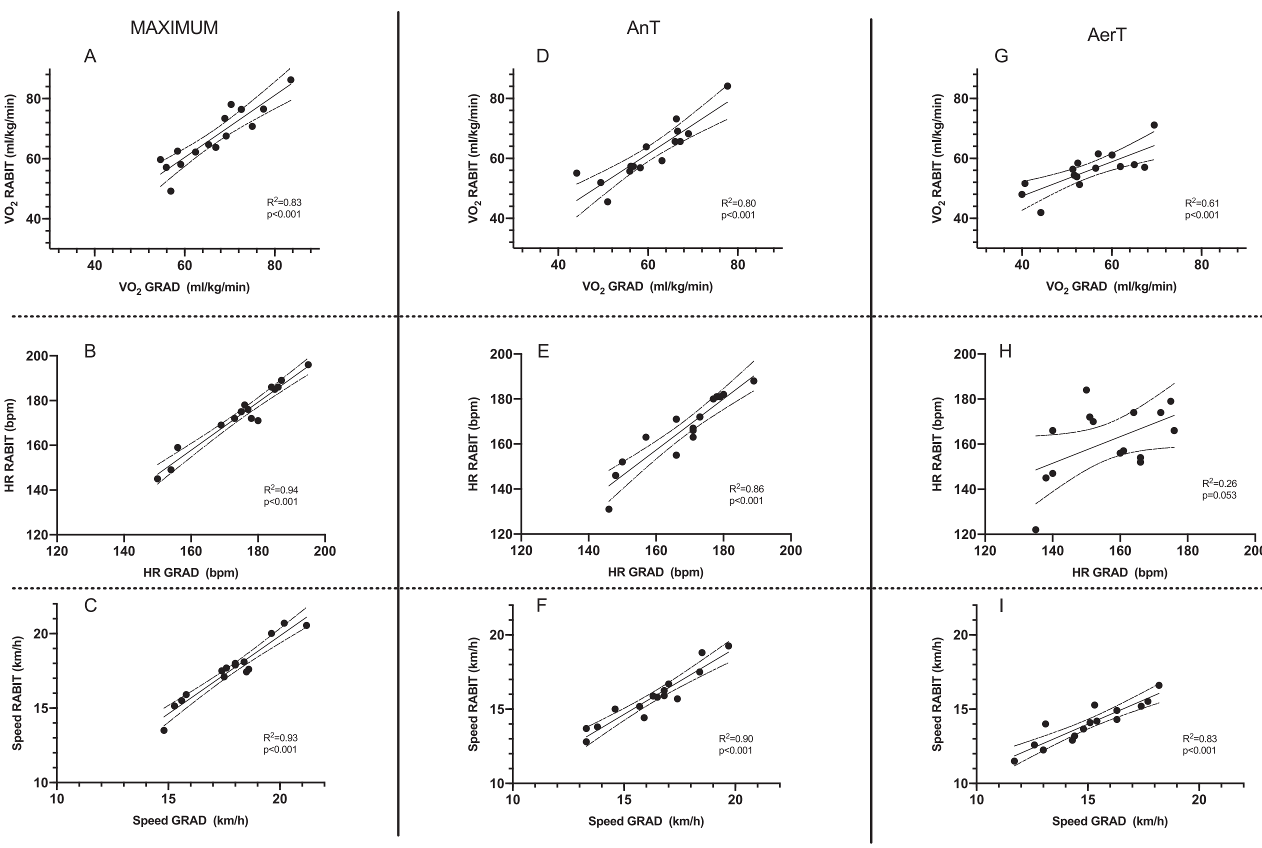

Figure 2. Correlation and confidence intervals (95%) between the results of RABIT vs. GRAD test in the cardiorespiratory parameters at three intensities (Maximum: A, B, C; AnT: D, E, F; AerT: G, H, I). $\dot{V}O_2$: oxygen uptake; HR: heart rate; AerT: aerobic threshold; AnT: anaerobic threshold.

95% confidence intervals (CI) were −2.9 to1.6 for $\dot{V}O_2$max, −0.8–3.1 for HRmax, −0.04–0.05 for RER max and −0.04–0.6 for running speed max.

Anaerobic threshold

The $\dot{V}O_2$, HR and RER measured during the 5 minutes at medium pace of the RABIT test were not significantly different from the corresponding parameters measured at AnT during the GRAD (Table 1 and Figure 2D–F). The running speed during RABIT was slower than the speed at AnT measured during GRAD (−2.9 ± 3.8%, $p = 0.008$). The correlation coefficients between GRAD and RABIT for $\dot{V}O_2$, HR, RER and running speed were $r^2 = 0.80$ ($p <$ 0.001), $r^2 = 0.86$ ($p < 0.001$), $r^2 = -0.16$ ($p = 0.278$) and $r^2 = 0.90$ ($p < 0.001$), respectively. The accurate prediction was 62% for $\dot{V}O_2$, 87% for HR, 56% for RER and 71% for running speed. The ES for $\dot{V}O_2$, HR, RER and running speed were 0.15, 0.11, 0.19 (*small*) and 0.26 (*medium*), respectively. The 95% confidence intervals (CI) were −3.82–0.96 for $\dot{V}O_2$, −1.74–4.94 for HR, −0.10–0.06 for RER and 0.15–0.82 for running speed.

Aerobic threshold

The $\dot{V}O_2$, HR and RER measured during the *second-10* minutes at easy pace of the RABIT test were not significantly different from the corresponding parameters measured at AerT during the GRAD (Table 1 and Figure 2G–I). The running speed during RABIT was slower than the speed at AerT measured during GRAD (−6.4 ± 5.6%, $p < 0.001$). The correlation coefficients between GRAD and RABIT for $\dot{V}O_2$, HR, RER and running speed were $r^2 = 0.61$ ($p = 0.003$), $r^2 = 0.25$ ($p = 0.020$), $r^2 =$ 0.87 ($p = 0.333$) and $r^2 = 0.83$ ($p < 0.001$), respectively. The accurate prediction was 37% for $\dot{V}O_2$max, 31% for HRmax, 25% for RER and 25% for running speed. The ES for $\dot{V}O_2$max, HR, RER and running speed were 0.14, 0.32, 0.05 (*small*) and 0.61 (*large*), respectively. The 95% confidence intervals (CI) were −4.21–2.06 for $\dot{V}O_2$, −13.05–3.45 for HR, −0.06–0.07 for RER and −0.54–1.51 for running speed.

Discussion

The aim of the study was to validate a simple field test for detecting the parameters related to AerT, AnT and maximum intensities. The results show that (i) for maximum intensity there are no significant differences in the parameters measured with the two tests, (ii) for the AnT-related parameters the test is valid, with the exception of the running speed, which is slightly slower during RABIT and (iii) for the AerT-related parameters the test is valid (even if the accurate prediction is low), with the exception of the running speed, which is slower during RABIT.

The test we proposed is an easy-to-perform and low-cost test that does not require the assistance of an operator and every athlete can use for obtaining information to determine his/her training zones. Regarding the maximum values there were no differences in any of the analysed parameters when the two tests are compared with an accurate prediction of ~70% or more. Thus it can be used by athletes and coaches for obtaining information about the data related to the maximum intensity and for planning interval trainings when the improvement in $\dot{V}O_2$max or in the velocity associated with it (v$\dot{V}O_2$max) are the targets. Interval training involves repeated short bouts at high or very high intensity alternated by low intensity active recovery. During short bouts (<120 seconds) the intensity ranges between 100% and 130% of the velocity at $\dot{V}O_2$max (Billat, 2001). In this case, athletes cannot use the HR to plan the intensity, since it does not reach a steady state (Zuccarelli, Porcelli, Rasica, Marzorati, & Grassi, 2018) and the delay in the adaptation makes it useless. Therefore, from a practical point of view, the parameter most useful is the speed (or pace). Indeed, at this intensity the speed detected during RABIT was only ~1% slower than the speed measured during GRAD. Other authors reported that the time to exhaustion at 100% v$\dot{V}O_2$max is ~6 minutes (Billat, Renoux, Pinoteau, Petit, & Koralsztein, 1994) and our results sustain that 3 minutes are enough to measure the v$\dot{V}O_2$max and the $\dot{V}O_2$max in this population. The 3-minute step may be used for detecting the $\dot{V}O_2$max. It is also possible to obtain an estimation of $\dot{V}O_2$max applying the equation:

$$VO_2\,\text{max estimated} = 3.019x\text{mean speed(km/h)} + 13.58(r^2 = 0.49;\, p = 0.004)$$

RABIT can also be useful at medium intensity, even if its reliability is lower than at high intensity. HR compared with GRAD was not significantly different, suggesting that it can be used for planning training sessions. Above the AerT, some authors reported the presence of slow component in HR (Zuccarelli et al., 2018). However, comparing the HR at the end of the 3rd and 4th minutes during the medium pace step, we did not detect HR slow component ($p = 0.54$) demonstrating that these athletes reached the steady state. Probably, the high training status of the participants allowed them to run at intensity close to the AnT without having slow component and thus delaying the fatigue status. This intensity can be maintained for 30–60 minutes (Billat, 2001) and in our study it corresponds to ~90% of $\dot{V}O_2$max, v$\dot{V}O_2$max and ~95% of HRmax. The HR can be particularly useful when planning training session on hilly terrain. Indeed, in this case the speed has to be adapted to the different incline of terrain and HR may be the only parameter easily accessible for adjusting training intensity, even if it is not always reliable (Born, Stoggl, Swaren, & Bjorklund, 2016).

The speed (and running pace) corresponding to AnT resulted statistically different between the two tests. However, the difference was only ~3% between RABIT and GRAD, with an accurate prediction of ~70% and the correlation was high. From a practical perspective, this difference can be irrelevant, and it can be used for planning the training when HR is not available and training sessions are performed on level terrain.

At low intensities (easy pace), the RABIT resulted less correct than during higher intensities. Even in this case, HR was the most accurate parameter with a difference between two tests of ~3%. However, the variability was higher than other parameters (with an accurate prediction lower than 40%) and the correlation was low, suggesting that the determination of AerT with an easy-to-perform test remains a target to achieve. Intensity close to AerT is usually maintained for 150–180 minutes and it is related to marathon performance (Billat, 2001; Meyer, Lucia, Earnest, & Kindermann, 2005). In our study, it corresponds to ~80% of $\dot{V}O_2$max, v$\dot{V}O_2$max and ~90% of HRmax. We proposed two steps at easy-pace. If we compare the two easy-steps we do not find differences in the analysed parameters suggesting that the RABIT may be shorten excluding the last 10-minutes easy pace. However, the first step may be used as a warm-up phase that elevate the muscle temperature and create some physiological adaptation for optimizing the following steps (McGowan, Pyne, Thompson, & Rattray, 2015). The nearness of AerT and AnT (~12 bpm and ~6 ml/O_2/kg) may be interpreted as an optimal ability to work at high intensity for the athletes participating in the study (Lucia, Hoyos, & Chicharro, 2001).

In conclusion, we proposed a new field test that provides information about parameters (speed, pace, HR) related to training zones. From a practical point of view, this test can be useful to those athletes who look for a simple test to locate three intensities for planning their trainings. However, RABIT test should be used with caution for AerT determination since the low prediction of the results. To our knowledge, there are field test for detecting maximum or AnT-related parameters but there are not easy-to-perform test for detecting the AerT. Our attempt to propose a test for detecting the AerT-related parameters was based on solid premises. However, the results are not totally satisfactory, leaving the gap about the determination of AerT open. Also, we suggest combining the use of HR and the speed to have more precise information for optimize trainings.

Acknowledgements

The authors thank the athletes who agreed to participate to the study. The study was supported by Fondazione Pietro Pittini (Trieste, Italy).

Disclosure statement

No potential conflict of interest was reported by the authors.

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