Heart-Rate Deflection Point and the Second Heart-Rate Variability Threshold During Running Exercise in Trained Boys

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The aim of the present investigation was to compare the accuracy of the heart-rate (HR) deflection point (HR\textsubscript{DP}) and the second HR variability threshold (HRV\textsubscript{Th2}) to predict anaerobic threshold in boys. HR\textsubscript{DP} was determined from slope trends of successive linear regressions. HRV\textsubscript{Th2} was determined from the high frequency’s peak and power-density trends. The second ventilatory threshold (V\textsubscript{Th2}) corresponding to the first decrease in PETCO\textsubscript{2}, with an increase in V\textsubscript{E}/VCO\textsubscript{2}, was used as the reference measure of AnT. Results show that VO\textsubscript{2} and HR were similar at HR\textsubscript{DP}, HRV\textsubscript{Th2}, and V\textsubscript{Th2}. HRV\textsubscript{Th2} and HR\textsubscript{DP} were highly correlated. It appears that HRV\textsubscript{Th2} is a good alternative to HR\textsubscript{DP} for assessing anaerobic threshold. HRV\textsubscript{Th2} and HR\textsubscript{DP} might rely on similar mechanisms.

The anaerobic threshold is a widely used concept in clinical and sports medicine (20). Anaerobic threshold is generally defined as “the intensity of exercise, involving a large muscle mass, above which the oxidative metabolism cannot account for all the required energy and the anaerobic contribution to energy demand increases” (32, p. 299). Although there is still an important debate on its theoretical basis, the anaerobic threshold is interesting because it has been advanced to be a better marker of endurance performance than VO\textsubscript{2max}. Anaerobic-threshold determination is also of interest to regulate the intensity of endurance-training sessions.

To determine anaerobic threshold, several methods have been proposed: maximal lactate steady state, onset of blood lactate accumulation, the so-called heart-rate (HR) deflection point (HR\textsubscript{dp}; evidenced by a break in the HR–time relationship), or the second ventilatory threshold (V\textsubscript{th2}). Usually, two remarkable break points of ventilation time course are observable during a graded maximal exercise. The first ventilatory threshold (V\textsubscript{th1}), called adaptation ventilatory threshold, results from the hyperpnea elicited by the increase in carbon-dioxide (CO\textsubscript{2}) metabolic production, which is linked to increased participation of anaerobic metabolism. V\textsubscript{th2}, called maladjustment ventilatory threshold or respiratory compensation point, is strongly related to anaerobic threshold (32). Because the hyperpnea is not sufficient to eliminate CO\textsubscript{2} metabolic production, ventilation increases more markedly (32). In young athletes the use of simple and noninvasive techniques to
approach anaerobic threshold is of primary importance. Lactate analysis requires frequent blood sampling and, thus, is not ideal for children and adolescents. $V_{Th2}$ determination requires expensive materials and might be unique in young athletes because of their particular respiratory patterns (19,34). HR-based methods, such as the inexpensive and noninvasive $HR_{dp}$ procedure, still appear to be an easy way to approach anaerobic threshold in young people (3,4,13).

Although the underlying physiological mechanisms of the old $HR_{dp}$ concept are unclear, this method is still a subject of debate and great interest, as indicated by the number of recent publications (8). No study has reported a direct and rational link between anaerobic threshold and $HR_{dp}$ but the occurrence of a HR threshold has been related to blood $K^+$ released from working muscles, catecholamine sensitivity of the myocardium, parasympathetic activity (8), and, more recently, to left ventricular ejection fraction (30) and stroke-volume evolution at high workloads (27). In adults, comparisons between $HR_{dp}$ and anaerobic threshold have been conflicting. Some authors have reported strong and significant relationships, and others have found no association (8). Another recurrent limitation is that $HR_{dp}$ is not always observable; the HR–work relationship is linear in a nonnegligible percentage of participants (8). Therefore, although most studies have confirmed the validity of the $HR_{dp}$ to predict anaerobic threshold in young people (3,4,8,13), a more sensitive and accurate method to determine an HR threshold would be welcome.

Recently, thanks to easy-to-use portable devices such as HR monitors, analysis of HR variability (HRV) during exercise has been of increasing interest. Several authors have shown that time-varying HRV analysis shows promise as a noninvasive method of assessing $V_{Th}$ (2,5,14). Although HRV analysis mostly depends on autonomic activity (33) at rest or during the night (12), it has been shown that short-term R-R intervals’ variability was more related to breathing patterns during exercise. Because of cardiorespiratory coupling between HRV and ventilation, known as the respiratory sinus arrhythmia phenomenon, both the mean peak of high-frequency (HF) power ($f_{HF}$) and the absolute HF power density ($HFp$) are influenced by breathing frequency (BF) and breathing depth (tidal volume, VT) (10). When the exercise intensity increases, especially above $V_{Th2}$, the rise in BF and VT leads to an increase in $f_{HF}$ and in $HFp$ density (18). Even if this new method looks promising, there are very limited data on HRV during exercise in young athletes (37), and, to our knowledge, no study has used the HRV methods for determining anaerobic threshold in young participants.

From a practical point of view, the usual methods of detecting HR threshold (i.e., visual examination of a break in the HR–work trend or the successive slope method for the $HR_{dp}$) are sometimes awkward and inconsistent. We hypothesized that HRV analysis would be more sensitive because it relies on different and valid physiological mechanisms. In particular, the HRV method could help determine anaerobic threshold from HR data alone in participants having a linear HR–work relationship. Therefore, the purposes of the present study, which was focused on trained boys during a running exercise, were (a) to confirm that the $HR_{dp}$ method, determined from beat-to-beat data with an objective procedure, is an accurate way of predicting $V_{Th2}$ and, thus, anaerobic threshold and (b) to investigate whether time-varying HRV analysis is a better alternative than $HR_{dp}$ for defining an HR-based index of anaerobic threshold. Moreover, an eventual association between $HRV_{Th2}$
and HR\textsubscript{DP}, would also add knowledge about the physiological bases underlying the HR\textsubscript{DP} occurrence.

**Methods**

**Participants**

Study participants were 72 trained boys (age 13.3 ± 1.3 years, height 158.9 ± 1.3 cm, weight 46.6 ± 11.2 kg) who were involved in various activities (soccer, squash, table tennis, athletics, 17.0 ± 1.0 hr/week) at a national sports institute. Parents of all athletes gave their written consent for participation. The local ethics committee approved the experiment.

**Testing Procedures.** Boys completed an incremental test to exhaustion on a treadmill (PPS-55 Sport-I, Woodway, Weil-am-Rhein, Germany) in standard environmental conditions, with the grade set at 1% (22). Following the recommendation of the American Thoracic Society, the initial velocity was 6.0 km/hr and was linearly increased by 1 km/h every minute for optimal determination of the ventilatory thresholds (1). It is worth noting that the protocol was also particularly well adapted for HR\textsubscript{DP} and HRV\textsubscript{Th2} assessment (6,31). At the end of the tests, participants indicated their rating of perceived exertion (RPE) by pointing to the number that corresponded with their perception of effort, based on the 6–20 Borg scale (9). One and three minutes after the completion of the test, fingertip capillary-blood samples (20 ml) were collected in capillary tubes and subsequently analyzed for lactate concentration using an automated analyzer (Biosen, EKF-diagnostic GmbH, Barleben, Germany). The highest value recorded was considered the peak lactate.

**Cardiorespiratory Measurements.** Gas exchange was measured using a breath-by-breath analyzer (Oxycon Pro, Jaeger, Hoechberg, Germany). The breath-by-breath samples were analyzed for VO\textsubscript{2} (L/min), carbon-dioxide production (VCO\textsubscript{2}, L/min), pulmonary ventilation (V\textsubscript{E}, L/min), end-tidal volume PO\textsubscript{2} (PETO\textsubscript{2} %), and PCO\textsubscript{2} (PETCO\textsubscript{2} %). The respiratory-exchange ratio was calculated from measurements of VO\textsubscript{2} and VCO\textsubscript{2}. The gas-analysis system was calibrated before each test using the manufacturer’s recommendations. During the incremental test, the breath-by-breath gas samples were averaged every 30 s. VO\textsubscript{2peak} was recorded as the highest 30-s average VO\textsubscript{2} (L/min) value and was expressed relative to body mass (ml · kg\textsuperscript{-1} · min\textsuperscript{-1}). Velocity at VO\textsubscript{2peak} was defined as the lowest velocity that solicited VO\textsubscript{2peak}.

**V\textsubscript{Th2} Assessment.** The V\textsubscript{Th2} was determined as described by Whipp et al. (36). It corresponded to the first decrease in PETCO\textsubscript{2}, with a corresponding increase in VE/VCO\textsubscript{2} after a steady-state period. All measurements of V\textsubscript{Th2} were made by visual inspection of graphs by two experienced exercise physiologists; the results were compared and then averaged. The difference in the values determined by the two assessors was <2%.

**Beat-To-Beat HR Analyses**

**Materials.** An electrode transmitter belt (T61, Polar Electro, Kempele, Finland) was fitted to the chest of each participant, as instructed by the manufacturer. A
Polar 810s HR monitor (Polar Electro, Kempele, Finland) was used to continuously record beat-to-beat HR during exercise (24).

**HR\textsubscript{dp} Determination.** HR\textsubscript{dp} was determined by a method adapted from Conconi et al. (13,17). The beat-to-beat HR versus the exercise–time relationship was graphed, and the slope (a) of the straight-line equation formed by the first 512 points was calculated (a\textsubscript{0-512}). The subsequent a values were obtained by shifting the regressed 512 points by one subsequent R-R value, and so on (i.e., a\textsubscript{1-513}, a\textsubscript{2-514} . . .). The HR\textsubscript{dp}, which is the transition from the linear phase of the HR–time relationship to the curvilinear phase (13), was visually determined by one experienced investigator as the point at which a started to decrease (Figure 1).

**HRV Analysis.** R-R series were extracted with the Polar Precision Performance program (SW 4.02, Polar Electro, Kempele, Finland). Occasional ectopic beats were visually identified and manually replaced with interpolated adjacent R-R-interval values. The instantaneous HF\textsubscript{p} trend as a function of time and frequency over the entire exercise period was then calculated from R-R-interval series using a time-varying short-term Fourier transform method with 64-s moving windows (Matlab software 6.5.1, Mathworks Inc.) (14). A time shift of 3 s was chosen between two successive spectrogram windows. Because each spectrogram window was made of 256 successive R-R periods, the time between R-R periods after resampling was 0.25 s. HF\textsubscript{p} range was extended from resting recordings ( >0.15–0.5 Hz to >0.15–1.8 Hz) in order to remain in the high BF ranges reached at high exercise intensity. We verified that, as previously reported (5,6), f\textsubscript{HF} and BF were significantly correlated in all participants, with a mean coefficient correlation of .47 ± .10 (p < .001). Fitting (Sigmaplot 8.0, ESPSS Science, Chicago, IL) f\textsubscript{HF} to a third-order model automatically corrected artifacts, so the relationship between modeled f\textsubscript{HF} (f\textsubscript{HFm}) and BF was significantly higher (r = .68 ± .13, p < .001). HF\textsubscript{p} and f\textsubscript{HFm} were retained from each periodogram and then averaged with a 5-s interval. The f\textsubscript{HFm} × HF\textsubscript{p} product was then calculated by multiplying the f\textsubscript{HFm} index with HF\textsubscript{p}. The f\textsubscript{HFm} × HF\textsubscript{p} was finally log transformed to increase the readiness of its instantaneous changes over time (Ln(f\textsubscript{HFm} × HF\textsubscript{p})).

**HRV\textsubscript{Th2} Determination.** HRV\textsubscript{Th2} was visually determined from the Ln(f\textsubscript{HFm} × HF\textsubscript{p}) curve versus time by a second experienced investigator who was not aware of the HR\textsubscript{dp} assessment. As presented in the introduction (14), the final abrupt increase in the Ln(f\textsubscript{HFm} × HF\textsubscript{p}) index over time was defined as HRV\textsubscript{Th2} (Figure 1).

**Statistical Analyses**

Descriptive data are presented as $M \pm SD$. Student $t$ tests for paired data and Pearson’s coefficient correlation ($r$) calculated from linear regressions were used to compare VO\textsubscript{2}, $\%VO_{2peak}$, and HR; $\%HR_{max}$ between HR\textsubscript{dp} and V\textsubscript{Th2}; and $\%HR_{max}$ between HR\textsubscript{dp} and HR\textsubscript{dp}. Bland–Altman plots were graphed to illustrate the intraindividual agreement in HR between HR\textsubscript{dp} and V\textsubscript{Th2} and between HRV\textsubscript{Th2} and HR\textsubscript{dp} (7). Normality of the distribution was verified via the Shapiro Wilk’s test, and a 95% confidence interval was calculated. The level of significance was set at $p < .05$. Statistical analyses were carried out using Minitab 13.2 Software (Minitab Inc; Paris, France).
Figure 1 — Example of the two heart-rate (HR)-based thresholds’ determination from beat-to-beat HR, successive linear-regression slopes (a), peak HF frequency (f_{HF}, Hz), modeled peak HF frequency (f_{HFm}, Hz), absolute high-frequency power density (HFp), and the Ln(f_{HFm} · HFp) index in a representative participant.
Results

The maximal values of oxygen uptake, HR, and velocity at VO_{2peak} were 54.1 ± 5.3 ml · min⁻¹ · kg⁻¹, 202.7 ± 5.4 beats/min, and 15.1 ± 1.8 km/hr, respectively. The maximal nature of the graded running test can be estimated by the values of [La]_{max} = 8.1 ± 2.8 mmol/L and RPE_{max} = 17.1 ± 2.1.

V_{Th2}, HR_{DP}, and HRV_{Th2} Assessments

V_{Th2}, HR_{DP}, and HRV_{Th2} were determined in 100% of the tests. Mean VO₂ was 47.6 ± 6.2 (88.1 ± 7.2 %VO_{2peak}), 48.2 ± 4.9 (88.9 ± 0.1 %VO_{2peak}), and 48.7 ± 5.4 ml · min⁻¹ · kg⁻¹ (89.5 ± 6.1 %VO_{2peak}), and mean HR was 186.9 ± 8.7 (92.1 ± 0.4 %HR_{max}), 188.0 ± 7.4 (93.5 ± 3.0 %HR_{max}), and 188.6 ± 9.0 beats/min (94.0 ± 3.2 %HR_{max}) for V_{Th2}, HR_{DP}, and HRV_{Th2}, respectively.

Comparison of HR_{DP} and V_{Th2}

VO₂ and HR were similar between HR_{dp} and V_{Th2}. Coefficient correlations between VO₂ or HR at HR_{dp} and V_{Th2} were significant (p < .001) but moderate (r = .51 and .61; Table 1). Figure 2 illustrates the Bland–Altman analysis of HR between HR_{dp} and V_{Th2}. It demonstrated minimal bias—almost all differences remained in the 95% confidence interval (2.12 [–11.82 to 16.08] beats/min for HR at HR_{dp}). A difference in HR of more than 5 beats/min between V_{Th2} and HR_{DP} was observed in 29 (36.7%) boys (Table 1).

Comparison of HRV_{Th2} and V_{Th2}

VO₂ and HR were similar at HRV_{Th2} and V_{Th2}. Coefficients correlation between VO₂ and HR at HRV_{Th2} or V_{Th2} were significant (p < .001, r = .63 and .75; Table 1). Figure 2 illustrates the Bland–Altman analysis of differences in HR between HRV_{Th2} and V_{Th2}. It demonstrated minimal bias because almost all differences remained in

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Note. Pearson coefficient correlation (r), absolute differences between HRV_{Th2} vs. HR_{DP} (Δ) in oxygen consumption (VO₂) and heart rate (HR). Number (%) of participants presenting differences higher than 5% in VO₂ or higher than 5 beats/min in HR at the second ventilatory threshold (V_{Th2}) vs. the heart-rate deflection point (HR_{dp}) and vs. the second heart-rate variability threshold (HRV_{Th2}), and at the HR_{dp} vs. HRV_{Th2}.

*p < .001.
the 95% confidence interval (2.82 [-9.47 - 15.13] beats/min for HR at HRV_{Th2}). A difference in HR by more than 5 beats/min between V_{Th2} and HRV_{Th2} was observed, however, in 28 (35.4%) boys (Table 1).

Comparison of HRV_{Th2} and HR_{DP}

VO_2 and HR were similar at HRV_{Th2} and HR_{DP}. The relationship between VO_2 or HR at HRV_{Th2} versus HR_{DP} was good and significant (r = .88 and .85, p < .001; Table 1). As shown in Figure 3, Bland–Altman analysis of HR between HR_{DP} and
HRV_{Th2} demonstrated minimal bias because almost all differences remained in the 95% confidence interval (0.89 [−8.49 to 10.26] beats/min for HR). A difference in HR of more than 5 beats/min between HRV_{Th2} and HR_{DP} was observed in 32 (40.5%) boys (Table 1).

**Discussion**

This study is the first to compare different HR-based markers of anaerobic threshold, such as the HR_{DP} and the HRV_{Th2}, in trained boys. Our results show that (a) the HR_{DP}, when determined with an objective beat-to-beat technique, appears to be an accurate way to approach anaerobic threshold because it is well correlated with V_{Th2} and (b) the HRV method appears to be as sensitive as HR_{DP} in detecting anaerobic threshold and leads to comparable results. Finally, because HRV_{Th2} and HR_{DP} were closely related, one might suggest that HR_{DP} occurrence might be influenced by mechanically induced changes in myocardial function.

**HR_{DP} and V_{Th2}**

The significant correlation between HR_{DP} and V_{Th2} (r = .61 for HR, p < .001) confirms previous findings reported by Baraldi et al. in young participants (r = .85 for HR at HR_{DP} vs. V_{Th2}) (4). Moreover, in the present study the HR_{DP} was identified in all participants, which is higher than the percentages commonly reported in adults. Indeed, a linear HR–speed relationship (i.e., an absence of HR_{DP}) is occasionally

![Figure 3](image-url) — Bland–Altman plot showing individual differences between heart rate measured at HRV_{Th2} and HR_{DP}.
found in a subgroup of participants. This proportion ranges from 6% to 54% (8).
In young people, there is very limited information (3,4,16), but it seems that HR_{DP} observation is more frequent (100% in the 12-year-olds \([n = 274]\) investigated by Ballarin et al. [3]). In addition, HR_{DP} is probably easier to determine because of the improved method used in the present study. First, beat-to-beat HR data were used to calculate the regressions instead of 5-s averaged HR values. Second, the regression slopes were calculated over a longer period (512 R-R intervals corresponding to 3 min 24 s with a mean R-R of 400 ms at 150 beats/min, or 2 min 41 s with an R-R interval of 315 ms at 190 beats/min) than in previous studies (i.e., a fixed twenty 5-s points = 1-min 40-s period [17]).

**Time-Varying HRV Indexes During Incremental Running Exercise in Young Boys**

Our results show that the peak HF frequency and the absolute-power density of the HF band display similar evolution in young athletes during running exercise and in adults during cycling exercise (2,5,6,14). The relationship reported between fr_HF and BF is in agreement with previous investigations (5,6), although the present correlation was weaker \((r = .68 \text{ vs. } r = .96)(6)\). Signal-processing disparities and the high variability of breathing patterns during running exercise in youngsters (19,34), when compared with adults, could explain these differences. Some authors (2,6) have recently proposed that BF could be accurately estimated from R-R interval series because of the respiratory sinus arrhythmia phenomenon and the association between fr_HF and BF. Similarly, because it has been noticed that ventilatory thresholds, especially the V_{Th2}, could be detectable with BF alone (21,28), Anosov et al. (2), followed by Blain et al. (6), proposed to assess anaerobic threshold without gas analysis by using fr_HF instead of BF. More recently, by observing that the fr_HF curve versus time was sometimes linear, Cottin et al. (14) proposed to multiply this latter index by HFp in order to improve the accuracy of the HRV_{Th} assessment. The resulting fr_{HFm} index has been shown to be more sensitive than fr_HF alone (14), because it also takes into account changes in tidal volume on which HFp depends (33). These methodological changes were first tested in cycling, but we speculate that they constitute an even greater methodological improvement in running exercise because the treadmill test appears less conducive than the cycle ergometer (41.6% vs. 92.6%) to detect a break point in BF alone (28). During the cycling test the pedaling rate is often kept constant, but during treadmill exercise the stride frequency increases with exercise intensity, which influences BF. Therefore, the exercise mode might have different incidences of breathing patterns. Nevertheless, very limited information is available on adults or younger individuals, and the influence of rib-cage motion on BF is not clear (35).

**HRV_{Th2} and V_{Th2}**

HRV_{Th2} was well related to V_{Th2} \((r = .75 \text{ for HR, } p < .001)\), which suggests that anaerobic threshold can be accurately assessed through time-varying HRV analysis during a running exercise in boys. We found HRV_{Th2} at 89.5% ± 6.1% of VO_{2peak}, which is slightly higher than in previous studies with adults (82.3% ± 4.9% [5] and 81.0% ± 7.0 [15] VO_{2peak}). Despite differences in exercise protocols and in
time-varying analysis methods, the characteristics of the present participants might explain why the intensity of HRV_{Th2} was slightly higher. Accordingly, it has been shown that young individuals display anaerobic threshold at a higher percentage of VO_{2peak} than adults (23,29). Moreover, a treadmill induces higher values than an ergometer in children (26). Nevertheless, we can postulate that the mechanisms underlying HRV_{Th2} appearance are similar in children and in adults. When the exercise intensity overcomes V_{Th2}, the increase in blood return to the right side of the heart that occurs during each respiratory cycle provokes greater mechanical and stretch feedbacks on the heart pacemaker. This direct, mechanically induced electrical phenomenon (25), known as the Bainbridge reflex (18), increases short-term R-R variability and HFp in absolute (5) and normalized units (11,15), independent of any autonomic activity. The dramatic increase of ventilation at V_{Th2} is then responsible for the HRV_{Th2} appearance.

**HRV_{Th2} Compared to HR_{DP}**

This study is the first to demonstrate that the HRV method provides an accurate alternative to HR_{DP} in assessing a HR-based index of anaerobic threshold. Indeed, there was no difference in VO_{2} or HR and a significant relationship between these variables at HRV_{Th2} versus HR_{DP} (r = .88 and .85 for VO_{2} and HR, respectively, p < .001). We expected that the HRV method would be more sensitive (i.e., inducing a determination of the threshold in a higher percentage of the participants than with the old HR_{DP} method) because it relies on clearer physiological mechanisms, but because none of the 72 participants in the present study presented a linear HR–work relationship (and, therefore, HR_{DP} was found in all of them), the questions of sensitivity and ease of detection for these two methods remains unanswered. Because detecting HRV_{Th2} requires complex mathematical modeling requiring particular expertise, however, one would encourage the use of the simple HR_{DP} method (with beat-to-beat data acquisition) in many cases. The comparison of these two methods showing an absence of HR_{DP} in older participants will, nevertheless, be of great interest.

**HRV_{Th2} and HR_{DP}: A Link of Causality?**

Such a correlation raises the question of whether both phenomena rely on similar physiological mechanisms. The physiological bases of the HR_{DP} remain partly unresolved, and no explicative investigation has been done with young participants. The HR_{DP} occurrence has been related to blood K^{+} released from working muscles; catecholamine sensitivity of the myocardium; parasympathetic activity (8), especially to left-ventricular ejection fraction (LVEF) (30); and stroke-volume evolution at high workloads (27). Pokan et al. (30) found during bicycle testing in healthy adults that a decreased LVEF might be compensated for by an increase in HR, leading to an absence of HR_{DP}. In contrast, Lepretre et al. (27) recently reported that slowing HR might help maintain optimal cardiac work by preventing the decrease in diastolic filling time. This was motivated by the significant correlation found between the HR_{DP} occurrence and the stroke volume’s flattening in highly trained athletes. As stated previously, in response to changes in ventilation patterns, the HRV_{Th2} is the marker of a sudden increase in mechanical and stretch influences on the heart.
We could postulate that, on HRV$_{Th2}$, the increased variability of HR rhythm might also perturb myocardial efficiency via diverse processes (i.e., decreased diastolic filling time, diminished efficacy of Franck-Starling mechanisms). Although further investigations are still warranted to observe the incidence of respiration-induced rhythm alteration on LVEF and stroke-volume flattening, we suggest that all the mechanisms compromising myocardium function at high exercise intensity might be concomitantly involved in both HR$_{DP}$ and HRV$_{Th2}$ occurrence.

In conclusion, the present study confirms that HR$_{DP}$, if objectively determined from beat-to-beat data, is suitable to evaluate anaerobic threshold in young boys during graded running exercise. Time-varying HRV analysis leads to comparable results of HR$_{DP}$ and, therefore, provides an accurate alternative for assessing a HR threshold. Finally, because HRV$_{Th2}$ and HR$_{DP}$ are closely related, one might speculate that the mechanically induced alterations in myocardial rhythm, induced by the marked changes in ventilation characterizing V$_{Th2}$ and responsible for HRV$_{Th2}$ incidence, are also involved in HR$_{DP}$ occurrence. Further investigations to improve our knowledge of the myocardium performance (LVEF, stroke volume, etc.) at this intensity might help improve our understanding of the HR-based anaerobic-threshold-detection principles.

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References


