COMPARISON OF VENTILATION THRESHOLD AND HEART RATE DEFLECTION POINT IN FAST AND STANDARD TREADMILL TEST PROTOCOLS

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SUMMARY – The purpose of this study was to compare two methods for determination of anaerobic threshold from two different treadmill protocols. Forty-eight Croatian runners of national rank (ten sprinters, fifteen 400-m runners, ten middle distance runners and thirteen long distance runners), mean age 21.7±5.1 years, participated in the study. They performed two graded maximal exercise tests on a treadmill, a standard ramp treadmill test *($T_{SR,}$* speed increments of 1 km•h^{-1} every 60 seconds*)* and a fast ramp treadmill test *($T_{FR,}$* speed increments of 1 km•h^{-1} every 30 seconds*)* to determine and compare the parameters at peak values and at heart rate at the deflection point (HR_{DP}) and ventilation threshold (VT). There were no significant differences between protocols (p>0.05) for peak values of oxygen uptake (VO_{2max}, 4.48±0.43 and 4.44±0.45 L•min^{-1}), weight related VO_{2max} (62.5±6.2 and 62.0±6.0 mL•kg^{-1}•min^{-1}), pulmonary ventilation (VE_{max}, 163.1±18.7 and 161.3±19.9 L•min^{-1}) and heart rate (HR_{max}, 192.3±8.5 and 194.4±8.7 bpm) (T_{FR} and T_{SR}, respectively). Moreover, no significant differences between T_{FR} and T_{SR} where found for VT and HR_{DP} when expressed as VO_2 and HR. However, there was a significant effect of ramp slope on running speed at VO_{2max} and at the anaerobic threshold (AnT) , independent of the method used (VT: 16.0±2.2 *vs* 14.9±2.2 km•h^{-1};HR_{DP}: 16.5±1.9 *vs* 14.9±2.0 km•h^{-1} for T_{FR} and T_{SR} respectively). Linear regression analysis revealed high between-test and between-method correlations for VO_2, HR and running speed parameters (r=0.78-0.89, *p*<0.01). The present study has indicated that the VT and HR_{DP} for running (VO_2, ventilation, and heart rate at VT/HR_{DP}) are independent of test protocol, while there is a significant effect of ramp slope on VT and HR_{DP} when expressed as running speed. Moreover, this study demonstrates that the point of deflection from linearity of heart rate may be an accurate predictor of the anaerobic threshold in trained runners, independently of the protocol used.

Key words: *Exercise test; Anaerobic threshold; Treadmill test; Heart rate; Pulmonary ventilation*

Introduction

All athletes can benefit from assessment of the 'anaerobic threshold' (AnT) expressed as either maximal lactate steady state (LT) or ventilatory compensation point (ventilatory anaerobic threshold, VT). The onset of anaerobic metabolism (the so-called 'aerobic threshold') is the point at which blood lactate concentration begins to increase above resting level during incremental exercise[1,39]. With further increase of exercise intensity a second threshold (LT) is reached, above which lactic acid production exceeds the rate of lactate removal. Central to the theory was the postulated link between the increase in blood lactate concentration and certain predictable changes in gas exchange parameters. These lead to the inference that the aerobic

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Received January 2, 2013, accepted February 24, 2014

and anaerobic (lactate) thresholds could be accurately determined from noninvasive gas exchange measurement[1-3] The VT, or respiratory compensation point is the point above the aerobic threshold when pulmonary ventilation and VCO_2 begin to increase in a disproportionate manner with respect to the increase in VO_2 during incremental exercise. Above VT if exercise intensity increases, oxygen delivery to the muscles no longer supports the oxygen requirements of oxidation, and to compensate for it, more energy is derived from anaerobic glycolysis. Wilmore and Costill[4] early speculated that the ventilatory break point might be related to the lactate threshold. These thresholds measure the ability to perform at optimal exercise intensity for extended periods of time[1,5,6]. The relationship of heart rate (HR) to LT or VT may provide an index for training prescription at or near these exercise intensities[7]. Invasive methods (i.e. blood lactate sampling for detecting LT) or specialized equipment (ventilation and metabolic measuring for detecting VT) are required to assess the AnT. An alternative method to identify the AnT using HR alone was originally suggested by Conconi *et al.*[8].

In sports science and clinical exercise laboratories, incremental exercise tests, popularized as the 'Conconi test'[8], are performed to assess the heart rate deflection point (HR_{DP}). HR_{DP}, as a marker of exercise intensity related to the AnT, is used to evaluate aerobic endurance, prescribe and monitor exercise intensity of healthy subjects and patients[8-16]. It is performed either as a field or as a laboratory test, with numerous modifications for different exercise modalities (field running, treadmill running, cycling, swimming, etc.), and it is based on the assumption that during progressive incremental exercise, a deflection in the linear heart rate/work relationship occurs; heart rate (HR) increases linearly with running speed up to the so-called deflection heart rate (HR_{DP}) and corresponding speed (v_{DP}) (Fig. 1). A recent work by Lepretre *et al.*[41] shows that the occurrence of HR_{DP}, when present, may be related to the attainment of maximal stroke volume. Conconi *et al.*[8,17] and other researchers[18-21] report a high correlation between v_{DP} and the lactate and ventilatory anaerobic thresholds, and recommend its use to evaluate endurance capacity and to assess training programs.

Subsequent to the original test[8], investigators have incorporated several modifications and methods to calculate the heart rate deflection point, and Conconi *et al.*[8,17] also have revised and updated the original protocol based on years of practical application, in order to increase the validity and reliability of the test. They report less than 1% of unsuccessful tests when performed by experienced athletes[17]. To consider the test successful, Conconi recommends that the increase in speed/work output should be as gradual as to increase the corresponding HR by less than 8 bpm each minute, in order to allow the cardiovascular system to adapt to the new work intensity. If the original procedure is followed, the duration of the test (with warm-up included) is often extended to over one hour, making it time consuming and less specific for sports disciplines with a significant anaerobic capacity component.

In our laboratory, when testing aerobic capacity, we perform a standard treadmill test (T_{SR}), usually with gas exchange data collection, with the same protocol (speed increments of 1 km•h^{-1} every 60 seconds) for all subjects – from 8-year children to elite, aerobically trained athletes. However, when the time assigned for the realization of laboratory tests is very limited and does not allow T_{SR} to be performed, we occasionally use a short ramp-like protocol (T_{FR}) on the treadmill with fast speed acceleration (speed increments of 1 km•h^{-1} every 30 seconds). With this protocol, in almost all tested subjects the HR increases by more than 8 bpm each minute[43]. Conconi *et al.*[17] tested a group of cyclists using a wind-load trainer, and report that although a faster speed acceleration (when HR increases by more than 8 bpm each minute) does not influence the appearance of HR_{DP}, it moves the HR/speed regression line to the right, with somewhat higher values of v_{DP} and maximal speed (v_{max}) achieved in the test, and lower values of HR_{DP} and maximal heart rate (HR_{max}). However, they present no data for running but for one subject to confirm those premises.

Measurement of the ventilatory threshold or lactate threshold simply by assessing heart rate during graded exercise has considerable importance in the way that sophisticated laboratory instruments are not necessary. Although the heart rate deflection and ventilation threshold may be assessed by different types of protocol[22], to our knowledge, the relationship between HR_{DP} and related ventilation and metabolic parameters measured with different treadmill protocols has not been investigated yet.

The aim of this study was to investigate the relationship between two methods of determination of anaerobic thresholds, one based on gas exchange parameters and the other one based on heart rate parameters, and the effect of two incremental treadmill protocols (fast ramp and slow ramp) in trained runners.

Materials and Methods

Subjects

Forty-eight Croatian runners of national rank participated in the study (ten sprinters, fifteen 400 m runners, ten middle distance runners and thirteen long distance runners). Subjects admitted in the study were engaged in strenuous training at least 10 h *per* week for at least 3 years, and were currently active in competition. The measurement procedures and potential risks were verbally explained to each subject prior to obtaining a written informed consent according to the Helsinki Declaration. The study was approved by the institutional Ethics Committee. Subject characteristics are presented in Table 1.

Table 1. Physical characteristics of subjects

	Mean±SD
Age (yrs)	21.7±5.1
Weight (kg)	71.9±6.9
Height (cm)	181.1±5.7

SD = standard deviation

Experimental protocols

Subjects were asked to refrain from strenuous exercise for 24 h prior to each exercise test. Each runner had previous experience in treadmill running and testing. After warm-up and stretching, based upon the subject's habits, one of the incremental protocols on a calibrated treadmill (Run Race 900, Tehnogym, Italy) with 1.5% inclination was applied. The order of ramp protocols was randomized and tests were separated by at least 48 hours.

Standard ramp treadmill test protocol (T_{SR})

The starting speed was 3 km•h^{-1}, with speed increments of 1 km•h^{-1} every 60 seconds. The subjects walked the first five steps (up to 7 km•h^{-1}) and continued running from 8 km•h^{-1} until volitional exhaustion. During recovery after each test protocol, the subjects walked at 5 km•h^{-1} for 5 minutes. The last half or full stage the subject could sustain (for either 30 or 60 s) was defined as the subject's maximal speed.

Fast ramp treadmill test protocol (T_{FR})

All subjects performed the other incremental treadmill test using the same procedures as in T_{SR}, with the exception of faster speed acceleration – the running speed was increased by 1 km•h^{-1} every 30 seconds.

Expired gas analysis

Expired gas was sampled continuously and O_2 and CO_2 concentrations in expired gas were determined (Quark b^2 *breath-by-breath* gas exchange system, COSMED, Italy), with analyzers calibrated prior to each test using precision reference gases. Heart rate was collected continuously during the tests using telemetric heart rate monitor (Polar Electro, Kempele, Finland) and stored in PC memory. The testing was performed in morning hours (between 9 a.m. and 11 a.m.) in thermo-neutral conditions. Expired airflow was measured with a digital turbine flow meter (COSMED, Italy), which was calibrated prior to each test using a 3 L syringe at flow rate and volumes in the expected physiological range.

After completion of the tests, all measured parameters were averaged at 30 second (T_{SR}) and 15 second (T_{FR}) intervals. Different averaging intervals were used to obtain the same resolution (two data points *per* stage) in each test.

Determination of anaerobic threshold

Ventilatory anaerobic threshold (VT) was determined by combining two common methods: 1) the simplified V-slope method (the point above the aerobic threshold at which a steeper increase of $\dot{V}CO_2$ as compared to $\dot{V}O_2$ occurred)[39, 42]; and 2) ventilatory equivalent method (the increase in the ventilatory equivalents of oxygen and carbon dioxide). In brief, two experienced experimenters assessed each subject's graphic data. Values for $\dot{V}O_{2\,VT}$ were determined by simultaneously evaluating graphs of the data plotted for each of the two methods. The evaluators used both graphs to assess concurrent break points. End-of-test criteria for determination of maximal oxygen uptake ($\dot{V}O_{2\,max}$) included two of the following: 1) volitional exhaustion; 2) achieving a plateau in $\dot{V}O_2$ (highest values were calculated as arithmetic means of the two consecutive highest 30 s values); and 3) HR ≥90% of age-predicted maximum. The heart rate deflection point (HR_{DP}) and corresponding running speed (v_{DP}) were determined as reported in a previous study[43].

Statistical analysis

The collected data were stored and analyzed with the SPSS statistical software (v18.0, SPSS Inc., Chicago, IL). The significance of differences between variables of T_{SR} and T_{FR} and two methods for determination of anaerobic threshold (VT and DP) were determined by the two-sided paired Student's *t*-test. The strength of the relationships between the variables of the two tests was analyzed with the Pearson product moment correlation. The Bland-Altman plots[23], where the individual subject differences between the two readings for each variable were plotted against the respective individual means, are provided with limits of agreement (LoA) and 95% confidence intervals (CI) for the mean difference between tests to investigate the level of agreement of HR_{AnT}, and v_{AnT}. The estimated 95% LoA provide a range that is likely to capture 95% of the differences between any two measurements. A P<0.05 was considered statistically significant.

The variables of the test were as follows:

VO_{2max}, maximal oxygen uptake (mL·kg^{-1}·min^{-1} and L·min^{-1}),

VO_{2VT}, oxygen uptake at the anaerobic ventilation threshold (mL·kg^{-1}·min^{-1} and L·min^{-1}),

$\%VO_2$, % of maximal oxygen uptake at the anaerobic ventilation threshold (%),

HR_{max}, maximal heart rate achieved in the test (bpm),

HR_{VT}, heart rate at the anaerobic ventilation threshold (bpm),

HR_{DP}, heart rate at the deflection point (bpm),

HR_{an}, anaerobic heart rate range (bpm) = HR_{max} - HR_{DP},

v_{max}, maximal running speed (km·h^{-1}),

v_{VT}, running speed at the anaerobic ventilation threshold (km·h^{-1}),

v_{DP}, running speed at the heart rate deflection point (km·h^{-1}),

v_{an}, anaerobic speed range (km·h^{-1}) = $v_{max} - v_{DP}$.

*at subscript, index SR was added for values from TSR protocol, and FR for values from TFR protocol.

Results

The HR deflection and the ventilation anaerobic threshold were evident in all 48 subjects in both tests. The HR/speed relationship in both tests performed by one subject is shown in Figure 1. The HR deflection

Table 2. Peak values, t-test (t) and correlation coefficients (r) in slow and fast ramp treadmill protocols

Variable	T_{FR}	T_{SR}	t^{Ω}	r
VO_{2max} (L•min^{-1})	4.48±0.43	4.44±0.45	ns	0.91†
VO_{2max} (mL•kg^{-1}•min^{-1})	62.52±6.17	62.04±6.03	ns	0.94†
HR_{max} (bpm)	192.35±8.46	194.44±8.66	ns	0.84†
VEmax (L•min^{-1})	163.09±18.69	161.29±19.92	ns	0.86†
RQ_{max}	1.25±0.08	1.18±0.04	&	0.56†
v_{max}	22.15±1.98	19.99±2.05	&	0.94†

Values are mean±standard deviation; TFR = fast ramp protocol; TSR = standard ramp protocol; &significant TFR:TSR P<0.01; $^{\Omega}$2-tailed, paired t-test, $^{\dagger}P$<0.01, ns = nonsignificant; VO_{2max} = maximal oxygen uptake; HR_{max} = maximal heart rate; VE_{max} = maximal ventilation; v_{max} = maximal running speed

Table 3. Values obtained at anaerobic threshold (VT and HR_{DP}) in slow and fast ramp treadmill protocol, t-test (t) and correlation coefficients (r)

	Ventilation threshold		HR deflection point				
	T_{FR}	T_{SR}	T_{FR}	T_{SR}	t^{Ω}	r_1	r_2
VO_2 ($L \cdot min^{-1}$)	3.88±0.36	3.83±0.42	3.91±0.43	3.81±0.40	ns	$0.80^{\dagger}$	$0.83^{\dagger}$
RVO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	54.2±5.7	54.49±5.82	54.23±5.53	53.15±5.68	ns	$0.84^{\dagger}$	$0.83^{\dagger}$
$\%VO_2$ (%)	86.7±3.4	86.18±3.51	86.87±5.32	85.89±5.60	ns	0.33^{π}	$0.55^{\dagger}$
HR (bpm)	174.8±9.9	176.23±10.15	177.81±9.16	177.52±9.88	ns	$0.78^{\dagger}$	$0.88^{\dagger}$
HR_{an} (bpm)	17.6±4.7	17.98±4.61	14.54±3.63	16.96±3.96	*, α	$0.47^{\dagger}$	$0.49^{\dagger}$
%HR (%)	90.8±2.5	90.62±2.71	92.43±1.93	91.32±2.13	*	$0.47^{\dagger}$	$0.46^{\dagger}$
v ($km \cdot h^{-1}$)	16.0±2.2	14.94±2.22	16.46±1.92	14.95±1.99	&	$0.88^{\dagger}$	$0.89^{\dagger}$
v_{an} ($km \cdot h^{-1}$)	6.1±1.2	5.04±0.80	5.69±0.98	5.04±0.91	&	$0.51^{\dagger}$	$0.50^{\dagger}$

Values are mean±standard deviation; T_{FR} = fast ramp protocol; T_{SR} = standard ramp protocol; ns = nonsignificant; *significant VT:DP in T_{FR} $P<0.01$; &significant T_{FR}:T_{SR} in both methods $P<0.01$; αsignificant T_{FR}:T_{SR} in DP method $P<0.01$; r_1 = correlation coefficients for the T_{SR} and T_{FR} test at the VT; r_2 = correlation coefficients for the T_{SR} and T_{FR} test at the HR_{DP}; Ω2-tailed, paired t-test, †$P<0.01$; π$P<0.05$; VO_{2max} = maximal oxygen uptake; RVO_{2max} = relative maximal oxygen uptake; $\%VO_2$ = % of maximal oxygen uptake at anaerobic ventilation threshold; HR = heart rate; HR_{an} = anaerobic heart rate range; v = running speed; v_{an} = anaerobic speed range

points and VT differing between observers were determined upon adjudication. In 45 subjects, a first turn point (between the starting speed and VT) was evident in the V-slope curve, while an early deflection in the HR data (between the starting speed and HR_{DP}) was evident in only half of all subjects. This first turn point/deflection was presumed to be related to the first (aerobic) threshold and was not considered for analysis. The peak values of the variables for all subjects are reported in Table 2. In almost half of all tests, a phasic flattening (plateau) of the HR curve was apparent at the HR deflection point, followed by another curvilinear or linear rise with decreased slope. There was no evidence of any significant differences in metabolic parameters such as

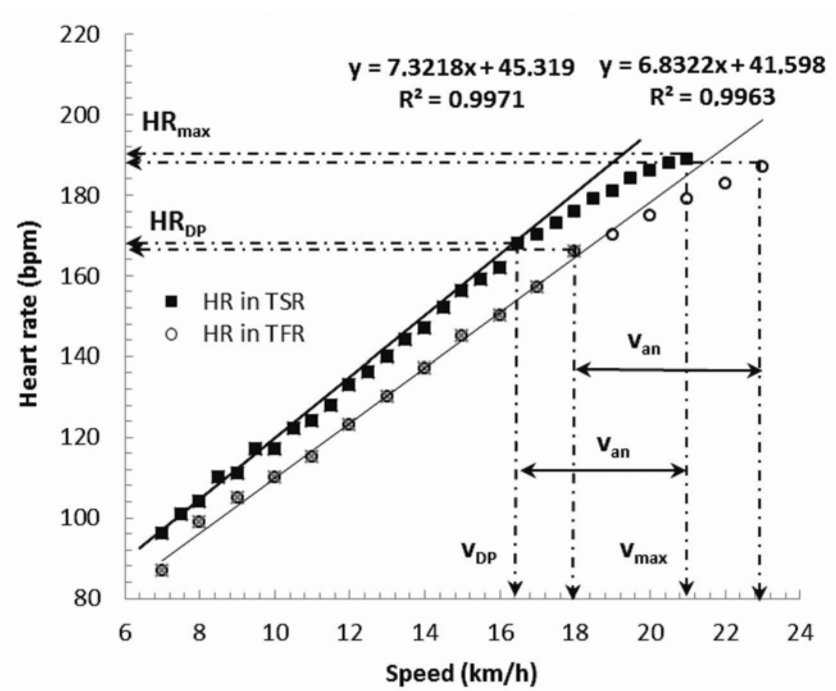

Fig. 1. HR/speed relationship and variables of the standard (T_{SR}) and fast (T_{FR}) test for one subject; HR_{DP} = heart rate deflection point; HR_{max} = maximal heart rate; v_{DP} = running speed at HR_{DP}; v_{max} = maximal running speed; v_{an} = speed range from v_{DP} to v_{max}.

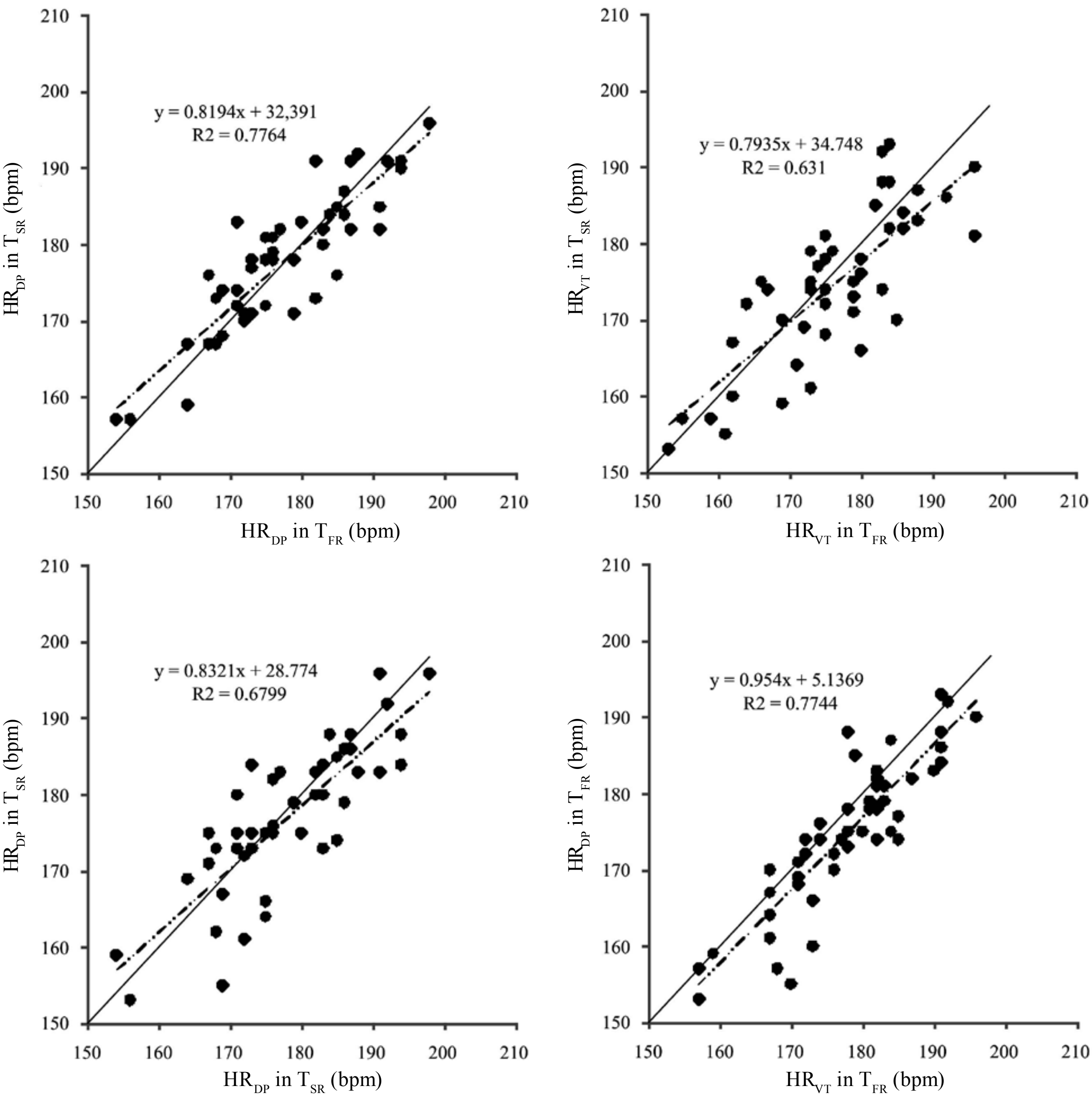

Fig. 2. Four scatter plots of the relationship between HR_{DP} and HR_{VT} for both tests (T_{SR} and T_{FR}) with line of equality (solid, y=x) and line of best fit (dashed); HR_{DP} = heart rate at deflection point; HR_{VT} = heart rate at ventilation threshold.

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VO_{2max}, VO_{2VT}, VO_{2DP} or VE_{max} measured in both, T_{FR} and T_{SR}. Significantly greater values in T_{FR} than in T_{SR} were found for RQ_{max} and all speed variables (v_{AnT}, v_{an} and v_{max}), independently of the method of anaerobic threshold determination (DP and VT)(Tables 2 and 3). In the T_{SR} test, the HR increased by less than 8 bpm each minute, while in the T_{FR} test HR increased by 10.2±1.8 bpm every minute, which is more than recommended by Conconi for test acceptability. Figures 2-4 present scatter plots of the relationship between HR, v and VO_2 values obtained with DP and VT methods for the T_{SR} and T_{FR} tests. Figures 5 and 6 present the Bland-Altman plots with 95% limits of agreement for HR and v in both methods.

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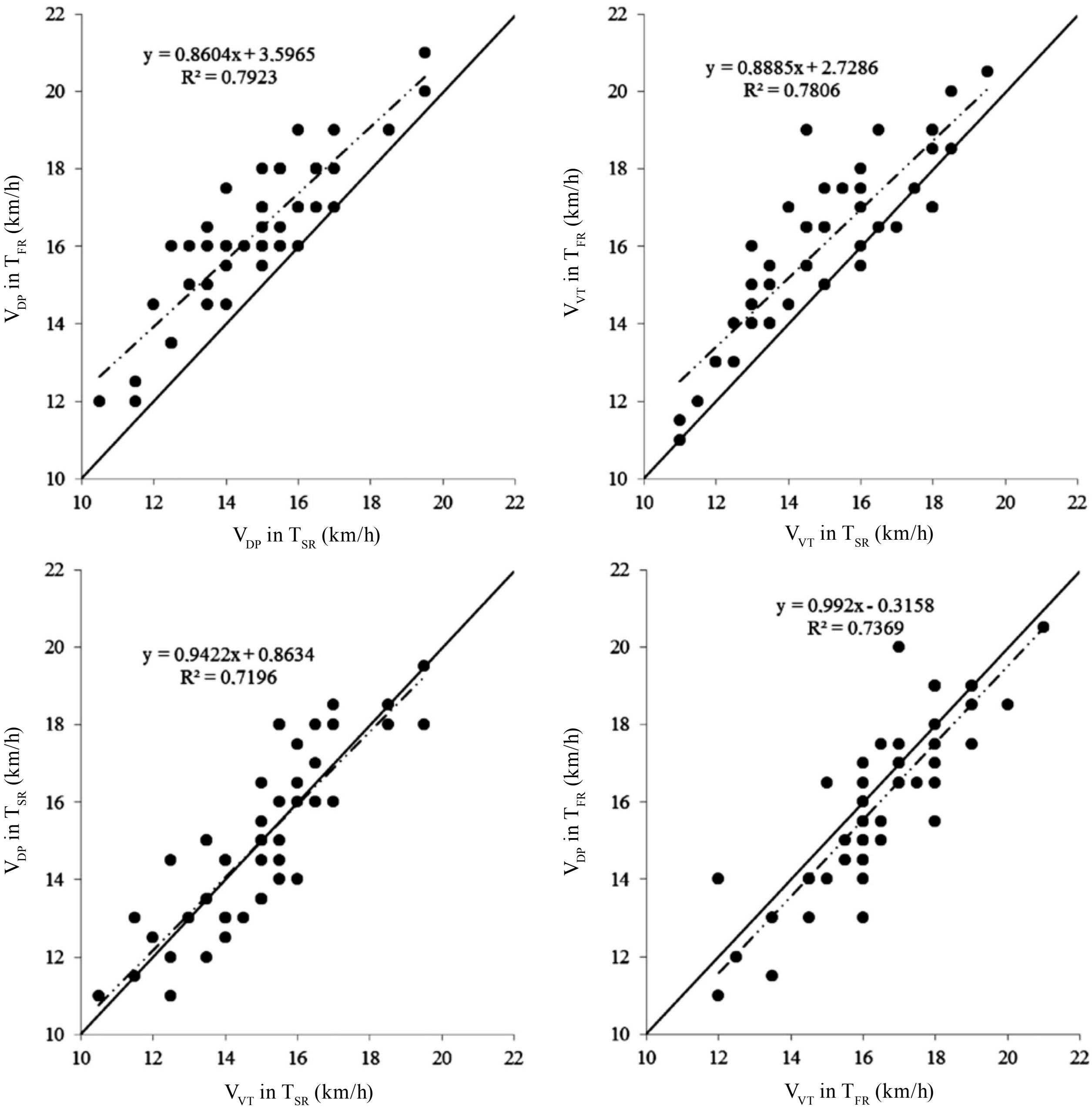

Fig. 3. Four scatter plots of the relationship between v_{DP} and v_{VT} for both tests (T_{SR} and T_{FR}) with line of equality (solid, y=x) and line of best fit (dashed); v_{DP} = speed at heart rate deflection point; v_{VT} = speed at ventilation anaerobic threshold.

There was no evidence of any significant bias or lack of agreement for HR_{DP} between the two tests. In contrast, the 95% confidence interval for v_{DP} shows completely positive (1.51±0.92 km•h^{-1}) population mean bias, indicating the mean v_{DP} in the T_{FR} test were likely to be between 0.60 km•h^{-1} to 2.43 km•h^{-1} higher than the corresponding v_{DP} determined in the standard test (T_{SR}). A positive bias, but with slightly better agreement between TFR and TSR was achieved for v_{VT} (Figure 6).

Discussion

Sentija *et al.*[43] proposed that the heart rate deflection point, as an estimate of the anaerobic threshold

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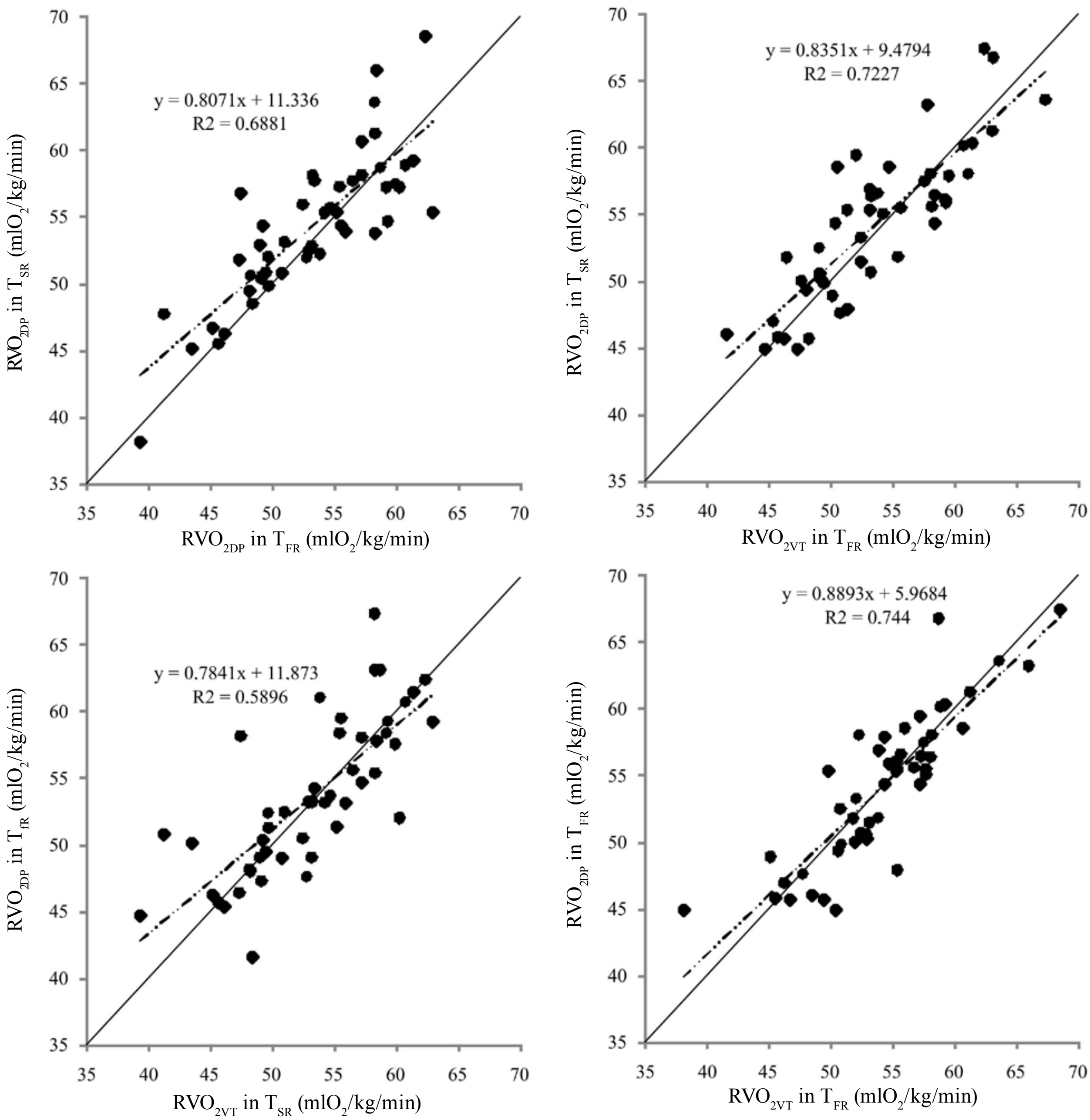

Fig. 4. Four scatter plots of the relationship between RVO_{2DP} and RVO_{2VT} for both tests (T_{SR} and T_{FR}) with line of equality (solid, y=x) and line of best fit (dashed); RVO_{2DP} = relative oxygen consumption at heart rate deflection point; RVO_{2VT} = relative oxygen consumption at ventilation anaerobic threshold.

for running is independent of the ramp work rate slope used in graded exercise tests. Weston *et al.*[22] found that VO_{2max} and parameters related to the anaerobic ventilation threshold (VO_2, ventilation, and heart rate at VT) in trained cyclists were also independent of the ramp slope on a cycle ergometer. The results of this study extend these findings to trained runners and treadmill running, confirming that the VT for running (VO_2, ventilation, and heart rate at VT) is independent of the ramp slope. Moreover, this study demonstrates that the HR_{DP} is in good agreement and highly correlated with the ventilation anaerobic threshold.

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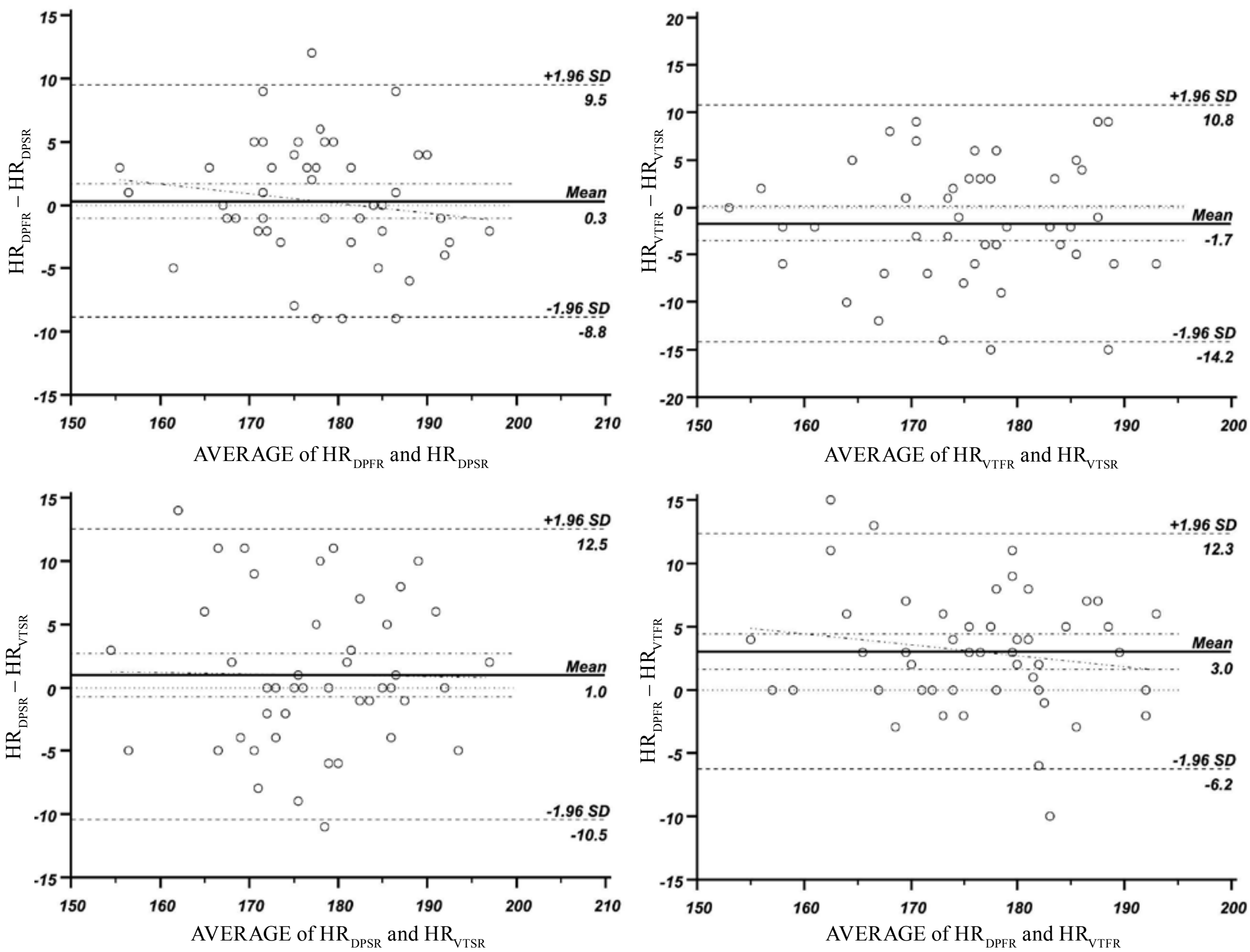

Fig. 5. Bland-Altman plot with estimated mean bias and 95% limits of agreement for difference in the HR_{AnT} data between the two methods, DP and VT, in T_{FR} and T_{SR} test plotted against the mean (no evidence of a systematic error, and random error independent of variable value); HR_{DP} = heart rate at deflection point; HR_{VT} = heart rate at ventilation anaerobic threshold.

From a practical point of view, HR_{DP} is an attractive method to assess the anaerobic threshold because it is noninvasive, the methodology is relatively simple to implement and can be conducted in field, as well as in laboratory settings. Traditionally, visual inspection has been used to identify HR_{DP}. The calculation of the HR deflection point made by visual inspection varies little from mathematical determination, when it is performed by experienced observers[9], as in this study. Although treadmill running is not as natural as field running, it allows easy control of running speed up to v_{max}, so that there is no need for the final acceleration phase as proposed in the original field test by Conconi[17,25,43], the beginning of which is based on subjective, and therefore unreliable, signs of near-maximal effort such as 'burning muscles' or 'breathing difficulties'. The continuous and uniform increase in exercise intensity in T_{FR} and T_{SR} is preserved up to the maximal running speed, enabling estimation of the anaerobic endurance. The range of running speed from the anaerobic threshold (HR_{DP} and/or VT) to maximal velocity (v_{an}) depends primarily on anaerobic capacity of the subjects[43,44], and the short duration of T_{FR} increases the significance of the anaerobic capacity for success in the test.

The basic difference between our short test (T_{FR}) and the standard protocols proposed for HR_{DP} and VT determination[17,39] is the duration (speed acceleration) of the test. Faster speed acceleration in this study did not influence the appearance of VT and HR_{DP}. In the

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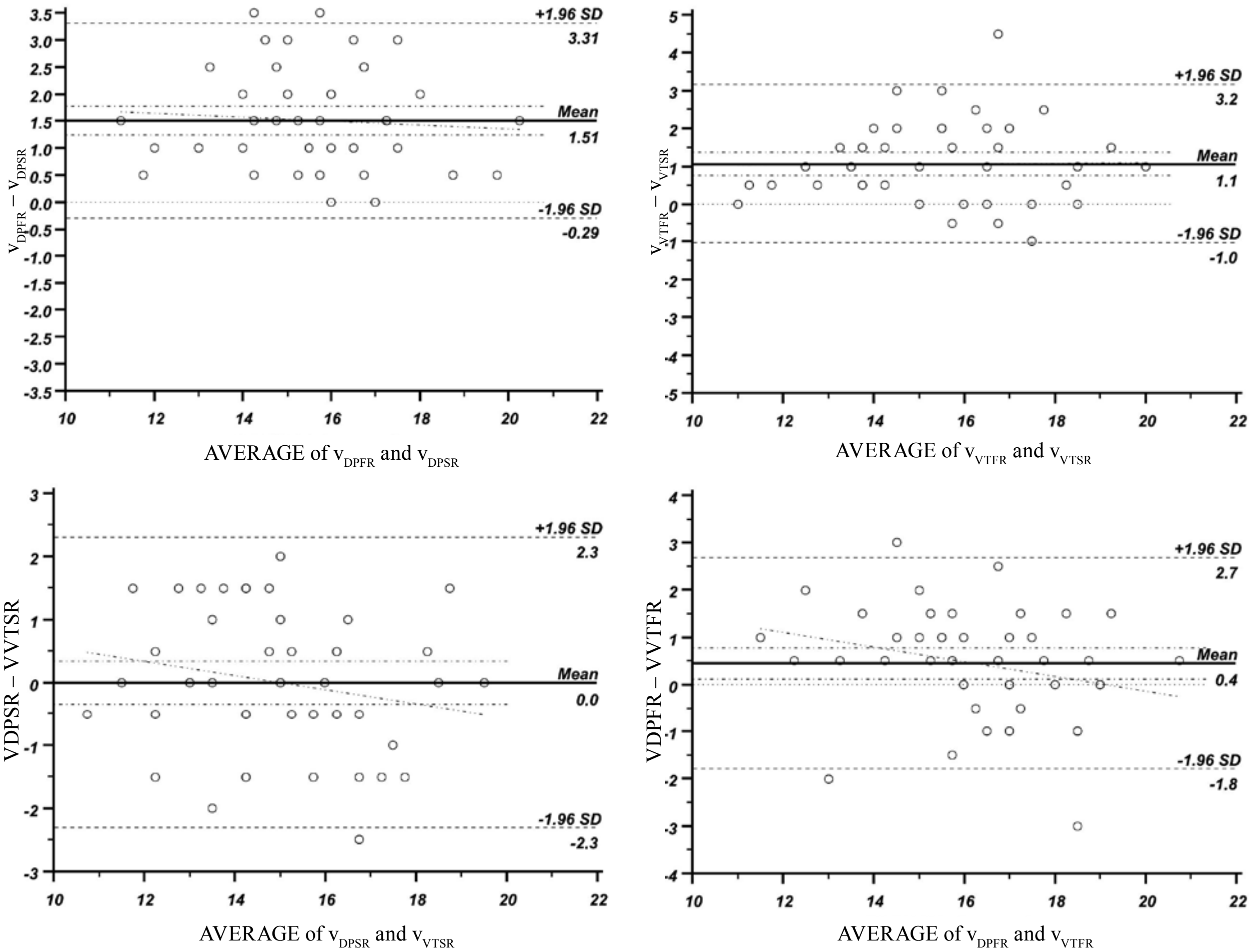

Fig. 6. Bland-Altman plot with estimated mean bias and 95% limits of agreement for difference in the v_{AnP} data between the two methods, DP and VT, in T_{FR} and T_{SR} test plotted against the mean (a systematic error, random error independent of variable size); v_{DP} = speed at deflection point; v_{VT} = speed at ventilation anaerobic threshold.

only published study with fast power output acceleration (HR increments more than 10 bpm each minute) in elite cyclists, Conconi *et al.*[17] report that the fast protocol moves the HR/v regression line to the right, with significantly higher values of HR_{DP}, v_{DP}, HR_{max} and v_{max}. The mean HR_{DP} achieved in T_{SR} and T_{FR} in this study, however, have a similar value and are highly correlated. Different data averaging may cause significant HR_{DP} difference between tests; if HR data are averaged according to equal time increments instead of speed increments (i.e. every 30 s in both tests), a slight, but significant difference appears. We performed an informal comparison of HR_{DP} calculated for 30 s averaging in both tests and obtained small, but significantly different mean values ($P<0.05$).

HR_{VT} was highly correlated to HR_{DP} in both test protocols (r=0.88 in T_{FR} and r=0.83 in T_{SR}; $P<0.01$) (Fig. 2). HR_{DP} was greater than HR_{VT} by 3.0 bpm in T_{FR} and by 1.0 bpm in T_{SR}, but the differences were not significant ($P>0.05$). At the same time, a high correlation was assessed for HR_{max} (r=0.84, $P<0.01$), HR_{DP} (r=0.88, $P<0.01$) and HR_{VT} (r=0.79) ($P<0.01$) obtained in the two tests. These data are consistent with the results of previous reliability studies of HR_{DP} (r=0.82-0.97)[12,13,26,27] and of HR at the anaerobic ventilation threshold (r=0.81-0.96)[28,29]. Brisswalter and Legros[30] report daily heart rate variations of 1%-3% (1-5 bpm) in trained runners, for continuous treadmill running at 70% VO_2max (r≥0.85). The high correlation for HR_{DP} and VT parameters between T_{SR} and

T_{FR} in this study, even higher than in some reliability studies, may be related to the fitness status of the subjects tested, as fitter individuals produce more reproducible results[29].

The Bland-Altman plots (Fig. 5) show the 95% limits of agreement (LoA) for HR_{DP} and for HR_{VT} between the two tests. If day-to-day biological variability of gas exchange and heart rate data are considered, we can conclude that the maximal allowable error limits (LoA) in heart rate at the deflection point and at the ventilation threshold are likely to be acceptable, with practically no evidence for a significant bias between the two tests. Several environmental and physiological factors (i.e. hydration, nutritional status, changes in environmental conditions, prior physical activity) appear to influence gas exchange and HR variability[12,26,31,32,39]. If this relatively large component of biological HR and ventilation variability is considered, the results suggest that HR_{VT} and HR_{DP}, determined in fit subjects with the fast ramp protocol used in this study, may be used for practical purposes.

The present study demonstrated that oxygen uptake values at HR_{DP} and VT in both test protocols had similar mean values and were significantly related (r=0.86 for T_{SR} and r=0.77 for T_{FR}) (Fig. 4) (Table 3). This finding is in line with other HR_{DP} and gas exchange threshold studies. Several studies[18,21,24] report high correlations between VO_{2HRDP} and VO_{2VT}, ranging from 0.71 to 0.95. Only one study, by Zacharogiannis and Farrally[33] reports that VO_2 was significantly greater at HR_{DP} than at VT despite a strong correlation (r=0.92) between the two variables. In our study, the mean VO_{2max} values in T_{FR} at HR_{DP} and VT were similar, as well as the VO_2 values in T_{SR} (P>0.05) All VO_2 values at HR_{DP} or VT in both protocols were achieved at approximately 86% (range 85.9%-86.9%) of VO_{2max}, without any significant differences (Table 3). This is in disagreement with several studies[21,24,27,33] indicating that VO_2 values at HR_{DP} demonstrate a wider scope of % maximum values, ranging from 59% to 93%. Most probably, such a broad range is consistent with the diverse fitness status of the subjects tested. The trained runners in our study had high $\%VO_{2max}$ values at DP and VT, similar to the values reported for trained runners in the studies by Bunc *et al.* (85.9%)[24], Maffuli *et al.* (78.5%)[12] and Zacharogiannis and Farrally (83.9%)[33].

Running speed (v) is the most direct indicator of exercise intensity in many sports, especially in running. Information about running speed at the AnT is, with HR, one of the most important parameters for planning and controlling intensities in training. In the present study, the mean v_{AnT} (14.9 km•h^{-1} in T_{SR} and 16.3 km•h^{-1} in T_{FR}) was equivalent to 74% of maximum achieved running speed in the test, similar to the values reported in previous HR_{DP} investigations (71% to 75% of peak power in cyclists studied).

Several authors[8,16,19,20,24,27,34-37] report a high correlation between v_{DP} and the anaerobic threshold. The lack of coincidence between v_{DP} and v at VT reported in some studies can be attributed to methodological problems and protocols used (acceleration was based on fixed distance instead of fixed time stages, or the physiological variables at v_{DP} were not derived concurrently from the same testing procedure)[1,32,34]. Also, AnT is often mixed up with the first (lactate or ventilatory) threshold as defined by Wasserman *et al.*[1], the "… single most common methodological error in the literature", a statement made by McLellan[38] twenty years ago, but still valid. A framework for exercise prescription based on the two (aerobic and anaerobic) thresholds concept is given in the review by Meyer *et al.*[39]. Although HR_{VT} and HR_{DP} values measured in T_{SR} and T_{FR} were independent of ramp slope, v_{VT} and v_{DP} in this study increased significantly with a faster ramp function. A constant, proportional bias is evident for v_{VT} and v_{DP} in the fast test (Fig. 6), as the running speed at HR_{VT} and HR_{DP} were approximately by 7%-10% higher than in the standard test. Grant *et al.*[29] found similar values of random error and limits of agreement (±1.35 km•h^{-1}) for reliability of the lactate anaerobic threshold, with poorer reproducibility in unfit, and better in fitter subjects. As can be seen from Figure 3, a simple equation can be used to estimate the T_{SR} running speed at the HR_{DP} from the T_{FR} test:

$$v_{DP}\,(T_{FR}) = 0.86\ v_{DP}\,(T_{SR}) + 3.6$$

The assessment of anaerobic (lactate and gas exchange) threshold is also dependent upon the type of protocol and ramp rate used; the threshold intensity (but not the equivalent heart rate) moves towards higher work rates if the work output/speed is more rapidly increased[22,40].

Conclusions

The results of this investigation show that, in trained runners, there is good agreement for the ventilation anaerobic threshold and HR_{DP} between incremental treadmill tests with fast and slow speed acceleration, when expressed as corresponding oxygen uptake, ventilation or heart rate values. In contrast, there was a significant effect of ramp slope on RQ_{max}, and the VT and HR_{DP} when expressed as running speed. The running speed at VT and HR_{DP} were on average 7-10% higher during fast ramp compared to the slow ramp protocol, and caution is warranted regarding practical applicability of v_{VT} and v_{DP}, as they are protocol dependent. From a practical viewpoint, caution should be exercised when standard and fast protocols are used interchangeably, as there may be considerable random error for some individual measurements. It is a major challenge for future researchers to examine the sources of this rightward drift in threshold intensity and the underlying physiological mechanisms.

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Sažetak

USPOREDBA CONCONIJEVOG I VENTILACIJSKOG ANAEROBNOG PRAGA ODREĐENOG KRATKIM I STANDARDNIM PROTOKOLOM TESTA NA POKRETNOJ TRACI

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Cilj istraživanja bio je usporediti dvije metode za utvrđivanje anaerobnog praga u dva različita protokola opterećenja. U istraživanju je sudjelovalo 48 trkača hrvatskog nacionalnog ranga (10 sprintera na 100 m, 15 sprintera na 400 m, 10 srednjeprugaša i 13 dugoprugaša) srednje dobi 21,7±5,1 god. Ispitanici su testirani dvama različitim protokolima maksimalnog opterećenja na pokretnoj traci: standardnim progresivnim protokolom opterećenja (T_{SR}, brzina trake povećava se svake minute za 1 km/h) i brzo-rastućim progresivnim testom opterećenja (T_{FR}, brzina trake povećava se za 1 km/h svakih 30 sekunda), u cilju mjerenja i usporedbe vršnih vrijednosti i vrijednosti pri ventilacijskom anaerobnom pragu (VT) i točki defleksije frekvencije srca (HR_{DP}). Vršne vrijednosti izmjerene u dva protokola (T_{FR}:T_{SR}) nisu se značajno razlikovale za primitak kisika (VO_{2max}, 4,48:4,44 L/min), relativni VO_{2max} (62,5:62,0 mL/kg/min), minutni volumen disanja (VE_{max}, 163,1:161,3 L/min) i frekvenciju srca (192,3:194,4 otkucaja/min). Značajne razlike između T_{FR} i T_{SR} nisu utvrđene niti za VT i HR_{DP} izražene primitkom kisika i frekvencijom srca. Međutim, utvrđen je značajan utjecaj protokola testa (akceleracije brzine trake) na brzine trčanja pri maksimumu i pri anaerobnom pragu, neovisno o primijenjenoj metodi (VT: 16,0±2,2 prema 14,9±2,2 km•h^{-1}; HRDP: 16,5±1,9 prema 14,9±2,0 km•h^{-1} za T_{FR} i T_{SR}). Linearnom regresijskom analizom utvrđene su visoke pozitivne korelacije između protokola i između metoda određivanja praga za parametre primitka kisika, frekvencije srca i brzine trčanja (r=0,78-0,89, p<0,01). Rezultati rada pokazuju da su VT i HR_{DP} za trčanje (VO_2, VE i HR pri VT/HR_{DP}) neovisni o protokolu testa, dok je značajan utjecaj protokola (brzine porasta brzine trake) na VT i HR_{DP} izražene brzinom trčanja. Nadalje, ovo istraživanje pokazuje da se točka defleksije frekvencije srca (Conconijev test) može pouzdano koristiti za predviđanje anaerobnog praga u treniranih trkača neovisno o primijenjenom protokolu testa.

Ključne riječi: *Test opterećenja; Anaerobni prag; Pokretna traka, test; Srčana frekvencija; Plućna ventilacija*