

Heart rate deflection point determined by D_{\max} method is reliable in recreationally-trained runners

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Summary

Objectives: This study examined the test-retest reliability of the speed at the heart rate deflection point (sHRDP) determined by the maximal-deviation method (D_{\max}) method developed by Cheng *et al.*¹⁰ during incremental treadmill tests. It was also aimed to verify if the regression model (i.e., exponential-plus-constant and third-order polynomial regression models) and the initial HR point used to determine the sHRDP by the D_{\max} method (i.e., model considering HR values above $140 \text{ b}\cdot\text{min}^{-1}$ versus the model considering all the HR points) influence on the sHRDP reliability.

Methods: Twenty-eight male recreationally-trained runners performed on test-retest design two continuous incremental exercise tests on a motorized treadmill with initial speed of $8 \text{ km}\cdot\text{h}^{-1}$ and $1 \text{ km}\cdot\text{h}^{-1}$ increments each 3 min to determine the sHRDP by D_{\max} method and according to exponential-plus-constant and third-order polynomial regressions models (sHRDP_{exp} and sHRDP_{pol}). Furthermore, the sHRDP was also calculated considering HR values above $140 \text{ b}\cdot\text{min}^{-1}$ (sHRDP_{exp>140} and sHRDP_{pol>140}).

Results: The sHRDP values obtained from exponential-plus-constant regression model showed higher reliability than the sHRDP values derived from third-order polynomial regression model (ICC ≥ 0.83 ; SEM $\leq 0.37 \text{ km}\cdot\text{h}^{-1}$; CV $\leq 3.09\%$). The sHRDP_{exp} was the most reliable variable with ICC of 0.87, the lowest values of SEM ($0.17 \text{ km}\cdot\text{h}^{-1}$) and CV (1.46%), bias near zero and narrow limits of agreement. On the other hand, the sHRDP values derived from third-order polynomial regression model were less reliable (ICC ≤ 0.70 ; SEM $\geq 0.67 \text{ km}\cdot\text{h}^{-1}$; CV $\geq 5.77\%$). Additionally, HR values at the sHRDP_{exp} and at sHRDP_{exp>140} presented the highest reliability (SEM ≤ 3.74 and CV ≤ 2.30).

Conclusions: The sHRDP_{exp} is a highly reliable variable; however, because in some participants the HR-curve demonstrated a linear behavior and the sHRDP_{exp} occurred around the midpoint between initial and final speeds during incremental test, the exponential-plus-constant regression model should be used with caution.

Key words:

Reproducibility of results.
Exercise test.
Anaerobic threshold.
Running.

Punto de deflexión de la frecuencia cardíaca determinado por el método D_{\max} es reproducible en corredores de nivel recreacional

Resumen

Objetivos: Este estudio analizó la reproducibilidad test-retest de la velocidad en el punto de deflexión de la frecuencia cardíaca (vPDFC) determinado por el método de máximo desvío (D_{\max}) desarrollado por Cheng, *et al.*¹⁰, durante pruebas incrementales en tapiz rodante. Un segundo objetivo fue comprobar si el modelo de regresión (i.e., modelos de regresión exponencial-más-constante y polinómica de tercer-orden) y el punto inicial de la FC utilizado para determinar la vPDFC por el método D_{\max} (i.e., modelo considerando los valores de FC superiores a $140 \text{ lat}\cdot\text{min}^{-1}$ versus el modelo teniendo en cuenta todos los puntos de FC) tienen influencia en la reproductibilidad de la vPDFC.

Métodos: Veintiocho corredores recreacionales entrenados ejecutaron en un diseño test-retest mediante dos pruebas incrementales continuas en la cinta rodante con la velocidad inicial de $8 \text{ km}\cdot\text{h}^{-1}$ y con incrementos de $1 \text{ km}\cdot\text{h}^{-1}$ cada 3 min para determinar la vPDFC por el método D_{\max} y de acuerdo con los modelos de regresión exponencial-más-constante y polinómica de tercer-orden (vPDFC_{exp} y vPDFC_{pol}). Además, la vPDFC también fue calculada teniendo en cuenta los valores de FC superiores a $140 \text{ lat}\cdot\text{min}^{-1}$ (vPDFC_{exp>140} y vPDFC_{pol>140}).

Resultados: Los valores obtenidos de vPDFC por medio del modelo de regresión exponencial-más-constante mostró una mayor reproductibilidad en comparación a los valores de vPDFC derivados desde el modelo de regresión polinómico de tercer-orden (ICC $\geq 0,83$; SEM $\leq 0,37 \text{ km}\cdot\text{h}^{-1}$; CV $\leq 3,09\%$). La vPDFC_{exp} fue la variable más reproducible con ICC de 0,92, los valores más bajos de SEM ($0,17 \text{ km}\cdot\text{h}^{-1}$) y CV (1,46%), el sesgo cerca de cero y con estrechos límites de acuerdo. Por otro lado, los valores de vPDFC derivados del modelo de regresión polinómico de tercer-orden fueron menos reproducibles (ICC $\leq 0,70$; SEM $\geq 0,67 \text{ km}\cdot\text{h}^{-1}$; CV $\geq 5,77\%$). Además, valores de FC con la vPDFC_{exp} y con la vPDFC_{exp>140} presentaron mayor reproductibilidad (SEM $\leq 3,74$ y CV $\leq 2,30$).

Conclusiones: La vPDFC_{exp} es una variable muy reproducible; no obstante, debido a que en algunos participantes la curva de FC demostró comportamiento lineal y la vPDFC_{exp} ocurrió alrededor del punto medio entre las velocidades inicial y final durante el test incremental, el modelo de regresión exponencial-más-constante debe ser utilizado con precaución.

Palabras clave:

Reproducibilidad de resultados.
Prueba de esfuerzo.
Umbral anaeróbico. Carrera.

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Introduction

Variables determined during incremental exercise tests, such as lactate threshold and heart rate deflection point (HRDP) are predictors of endurance performance and are used as parameters for prescription and monitoring training intensities¹⁻³. The reliability of these variables is defined by the replication of the same result in one or more repeated trials by the same participant under similar conditions⁴.

The HRDP, as an intensity related to the anaerobic threshold (AT)^{1,5,6} has demonstrated high correlations with endurance running performance^{1,7,8}. Conconi, *et al.*⁷ proposed a visual determination of the HRDP that has been used in many studies^{5,8,9}.

However, other studies preferred to determine the HRDP by the maximal-deviation method (D_{\max}) method, that was developed by Cheng, *et al.*¹⁰ and consider as AT the point on an intensity regression curve that is furthest away from a straight line which connects the first and last points of that curve, mainly because it is possible to determine this point in most subjects, different of the Conconi, *et al.*⁷ method which may not be identifiable due to a linear behavior^{1,11,12}. Furthermore, da Silva, *et al.*¹ showed that the speed associated with deflection point (sHRDP) determined by D_{\max} method was highly correlated with lactate threshold and with 10-km running performance in endurance recreationally-trained female runners.

Moreover, other factors could influence the determination of the HRDP by D_{\max} method, such as the regression model for fitting data (i.e. exponential-plus-constant model vs third-order polynomial model) and the number of heart rate (HR) points used (all points or those above 140 $\text{b}\cdot\text{min}^{-1}$)^{1,11}. Recently, da Silva, *et al.*¹ showed that the sHRDP obtained from exponential-plus-constant regression model resulted in a better estimation of lactate threshold which was better correlated with running performance than the one derived from the third-order polynomial regression model, independently of the HR values used (all points or those above 140 $\text{b}\cdot\text{min}^{-1}$), demonstrating that the regression model could influence the HRDP values obtained from D_{\max} method. However, the authors state that because the deflection point often occurred around the midpoint between initial and final speeds during the incremental test suggesting that the exponential-plus-constant may not be an appropriate regression curve.

Some studies have examined the reliability of the HRDP based on Conconi, *et al.*⁷ method^{13,14}. These studies reinforced the difficult to analyze reliability of the Conconi, *et al.*⁷ method because it is not possible to determine HRDP in all subjects. This lack of identification of the HRDP by Conconi, *et al.*⁷ method is explained by the behavior of the HR curve during incremental tests shows large inter-subject variability, which may reflect in a convex, concave or linear curve behavior, and influences the identification of a visual deflection point¹⁵. For instance, Jones and Doust¹⁴ only observed HRDP in 6 out of 15 participants in both test and retest.

Thus, the application of D_{\max} method could contribute to identifying HRDP in all subjects as showed in previous studies^{1,11,12}. However, the reliability of the HRDP determined by D_{\max} method is unknown. We hypothesized that the regression model and the number of HR points would influence the reliability of the sHRDP determined by D_{\max} method.

Therefore, the aim of this study was to examine the test-retest reliability sHRDP determined by D_{\max} method during incremental treadmill test-retest reliability of sHRDP. It was also aimed to verify if the regression model (i.e. exponential-plus-constant and third-order polynomial regression models) and the initial HR point used to determine the sHRDP by the D_{\max} method (i.e., model considering HR values above 140 $\text{b}\cdot\text{min}^{-1}$ versus the model considering all the HR points obtained) influence on the sHRDP reliability.

Material and methods

Participants

Twenty-eight male recreationally-trained runners with experience in 10-km running races and involved in systematic training were recruited. Characteristics of the participants (mean \pm SD) were: age 26.1 \pm 3.9 years, stature 177.1 \pm 7.0 cm, body mass 75.6 \pm 9.0 kg, body mass index (BMI) 24.1 \pm 2.6 $\text{kg}\cdot\text{m}^{-2}$ and body fat 14.1 \pm 4.2%. Body density (BD) was determined using the seven skinfolds protocol of Jackson and Pollock¹⁶ and subsequently, body fat percentage was calculated from BD using Siri's equation¹⁷. The training characteristics were experience 4.2 \pm 4.8 years, frequency 3.2 \pm 1.4 $\text{days}\cdot\text{wk}^{-1}$ and distance 25.8 \pm 16.9 $\text{km}\cdot\text{wk}^{-1}$. The 10-km running times of the participants were between 40 and 60 min (i.e. a pace between 10 and 15 $\text{km}\cdot\text{h}^{-1}$; \cong 44–66% of the world record). We used the following inclusion criteria: age between 18 and 35 years; be apparently healthy (without chronic medical complications such as diabetes, hypertension, asthma and/or cardiovascular diseases); practice running for at least six months; be able to complete 10-km between 40 and 60 minutes (recreational level). The exclusion criteria were the following: be a smoker; present health problems such as diabetes, hypertension, asthma and/or cardiovascular disease according to anamnesis screening. Before testing, written informed consent was obtained from all participants. The researchers responsible for the study were committed to perform the tests within the safety standards, being knowledgeable of procedures to be performed. Thus, there are no risks for the participants, only that they can felt possible discomfort after the tests such as tiredness, muscle pain, sweating that will be similar to the symptoms felt during the routine of physical exercise. The experimental protocol was approved by Human Research Ethics Committee of the State University of Maringá (# 719/2010) and is in accordance with the Declaration of Helsinki in 2008.

General Procedure

The anthropometric measures (e.g., body mass, height and skinfolds to predict body fat) were obtained in laboratory conditions during the first visit. The participants who were habituated to running tests performed two continuous incremental exercise tests on a motorized treadmill (Super ATL; Inbrasport, Porto Alegre, Brazil) set at a gradient of 1%. The tests were performed separated by one week. Participants were instructed to report for testing well-rested, well-nourished, and well-hydrated, wearing lightweight comfortable clothing and were also instructed to avoid eating two hours before the tests, to abstain from caffeine and alcohol, and to refrain from

the training routines and competitions during testing. Additionally, the participants not performed training or competition for at least 72 hours prior to the first test.

Incremental exercise tests

After a warm-up that comprised walking at $6 \text{ km}\cdot\text{h}^{-1}$ for three minutes, the continuous tests started with a speed of $8 \text{ km}\cdot\text{h}^{-1}$, followed by an increase of $1 \text{ km}\cdot\text{h}^{-1}$ among each successive stage of three minutes, following the recommendation of Conconi, et al.¹⁸ and Pokan, et al.¹³ of small increments in speed and fixed stage duration. Furthermore, sub-maximal HR values obtained during protocols with three minutes stage duration are highly reproducible¹⁹. Each participant was encouraged to give maximum effort until volitional exhaustion. To minimize circadian variations in performance, the tests were performed at the same time of the day in the morning, under stable laboratory conditions (temperature = $20-22 \text{ }^\circ\text{C}$ and relative humidity = $50-60\%$). No feedback of the results was given to participants. The reliability of sHRDP was assessed by means of a test-retest design.

Heart rate (HR) was measured throughout the incremental test by a HR monitor (Polar RS800, Kempele - Finland) and rating of perceived exertion (RPE) was assessed by the Borg scale (6-20)²⁰. At the end of each stage (i.e., exactly during the last 15 s of the stage) of the incremental test, the HR values were registered. The maximal HR (HR_{max}) was defined as the highest HR value recorded during the tests and the highest RPE was adopted as the maximal RPE (RPE_{max}). Steady HR points at the end of each stage were included in the analysis. Earlobe capillary blood samples ($25 \mu\text{L}$) were collected into a capillary tube after the end of each test at the fifth minute of passive recovery during which participants sat in a comfortable chair, for the determination of post-exercise peak blood lactate concentration. From these samples, blood lactate concentration was subsequently determined by electroenzymatic methods using an automated blood lactate analyzer (YSI 2300 STAT, Ohio, USA) that was calibrated according to manufacturer's instructions. The peak treadmill speed (V_{peak}) was considered as the speed of the last complete stage added to the product of the speed increment and the completed fraction of the incomplete stage²¹ ($V_{\text{peak-f}}$), calculated according to the equation $V_{\text{peak-f}} \cdot P = V_{\text{complete}} + (\text{Inc} \cdot t/T)$, in which V_{complete} is the running speed of the last complete stage, Inc the speed increment (i.e., $1 \text{ km}\cdot\text{h}^{-1}$), t the time in seconds sustained during the incomplete stage, and T the time in seconds required to complete a stage (i.e., 180 s).

Maximal effort was deemed to have been achieved if the incremental test produced two of the following criteria: 1) peak blood lactate concentration $\geq 8 \text{ mmol}\cdot\text{L}^{-1}$; 2) $\text{HR}_{\text{max}} \geq 95\%$ of endurance-trained age-predicted HR_{max} (APMHR) using the age-based equation $[206 - (0.7 \times \text{age})]$ ²² and 3) RPE ≥ 19 in the 6–20 Borg scale²³.

Determination of the speed and heart rate values at the heart rate deflection points by the D_{max} (sHRDP and HR at sHRDP)

Data were fitted by two different models: 1) the exponential-plus-constant regression curve²⁴ and 2) third-order polynomial regression curve¹⁰ based on all points of HR and HR points above $140 \text{ b}\cdot\text{min}^{-1}$ (Fig-

re 1). The calculations of both models were based on a previous study.¹

The determination of HR values at sHRDP determined by D_{max} method were analyzed by linear interpolation considering the HR values and the speed above and below sHRDP_{exp}, sHRDP_{exp>140'}, sHRDP_{pol} and sHRDP_{pol>140'}.

Statistical analyses

Data are presented as mean \pm SD and were analyzed using the Statistical Package for the Social Sciences 17.0 software (SPSS Inc., USA) and spreadsheets of Hopkins²⁵. Normality of data distribution was tested according to the Shapiro-Wilk test. Considering that data distribution was normal we used parametric analysis. Variables were compared using Student's t-test for dependent samples to identify systematic differences. Residual analysis (plotting the absolute differences between test and retest against the individual means) was applied to examine heteroscedasticity²⁶. Relative reliability was examined using the intra-class correlation coefficient (ICC; two-way mixed model, consistency, single measures)^{27,28}. The reliability was considered high for ICC values, moderate for values between 0.80 and 0.89 and questionable for values below 0.80²⁹. The absolute reliability was determined based on SEM and coefficient of variation (CV). The SEM was calculated by dividing the SD of the differences between the variables of the test and retest by the square root of two ($\sqrt{2}$)^{4,30}. The CV was determined by obtaining the SEM of the natural logarithm of the variables (SEM_{\ln}). Thereafter, the CV was calculated using the formula $\text{CV} (\%) = 100 \times [\exp(\text{SEM}_{\ln}^{-1})]$, where exp is the natural exponential function⁴. The magnitude of differences (effect size) estimated from the ratio of the mean difference to the pooled standard deviation was calculated to assess meaningfulness of differences and was interpreted as trivial (≤ 0.2), small (0.21 to 0.5), moderate (0.51 to 0.8) and large (>0.8)³¹. Bland Altman plots were used to check agreement. Statistical significance was set at $p < 0.05$.

Results

The variables obtained during the maximal incremental tests (mean \pm SD) were: $V_{\text{peak}} = 15.2 \pm 0.8 \text{ km}\cdot\text{h}^{-1}$ (test) and $15.2 \pm 0.8 \text{ km}\cdot\text{h}^{-1}$ (retest); $\text{HR}_{\text{max}} = 192 \pm 7.8 \text{ b}\cdot\text{min}^{-1}$ (test) and $190 \pm 8.3 \text{ b}\cdot\text{min}^{-1}$ (retest); percentage of age-predicted maximal heart rate (%APMHR) = $102.1 \pm 4.2\%$ (test) and 101.1 ± 4.2 (retest); $\text{RPE}_{\text{peak}} = 20 \pm 0.5$ (test) and 20 ± 0.3 (retest); $\text{LA}_{\text{peak}} = 7.5 \pm 2.0 \text{ mmol}\cdot\text{L}^{-1}$ (test) and $7.6 \pm 1.9 \text{ mmol}\cdot\text{L}^{-1}$ (retest). These variables did not differ significantly between the two tests (test and retest) ($p > 0.05$).

The comparisons between test and retest for the variables related to the sHRDP and the HR at the sHRDP obtained during the incremental tests are presented in Table 1. The sHRDP determined by D_{max} from the exponential-plus-constant regression model using HR values above $140 \text{ b}\cdot\text{min}^{-1}$ (i.e., sHRDP_{exp>140'}) and the HR at the sHRDP determined by D_{max} from the exponential-plus-constant regression model using all HR values (i.e. sHRDP_{exp}), were significantly different between the test and retest ($p < 0.05$). Furthermore, the percentage in which sHRDP_{exp>140'} corresponds to V_{peak} and the percentage in which HR values at sHRDP_{exp} corresponds to HR_{max} were different between test and retest.

The measures of test-retest reliability (i.e., ICC, SEM, CV and ES) of the speeds at the heart rate deflection point are given in Table 2. The sHRDP

Figure 1. Determination of the sHRDP by D_{max} method from exponential-plus-constant regression model considering all HR values (A) and values above 140 $b \cdot \text{min}^{-1}$ (B) and from third-order polynomial regression model considering all HR values (C) and values above 140 $b \cdot \text{min}^{-1}$ (D).

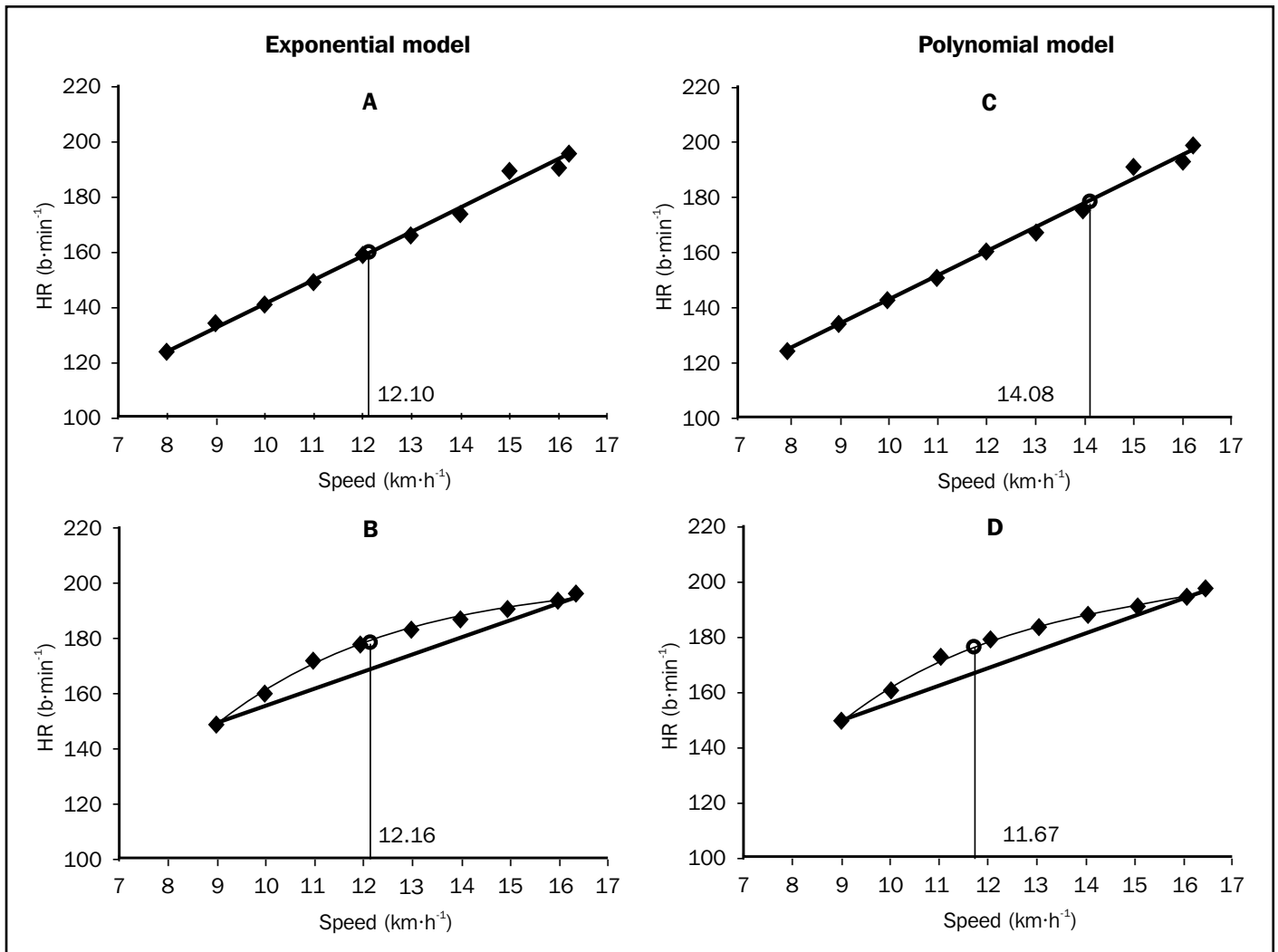


Table 1. Variables obtained during incremental treadmill tests (test-retest).

Variables	Test	Retest	% from V_{peak} ($\text{km} \cdot \text{h}^{-1}$) or HR_{max} ($b \cdot \text{min}^{-1}$) (test)	% from V_{peak} ($\text{km} \cdot \text{h}^{-1}$) or HR_{max} ($b \cdot \text{min}^{-1}$) (retest)
sHRDP _{exp} ($\text{km} \cdot \text{h}^{-1}$)	11.5 ± 0.5	11.4 ± 0.5	75.6 ± 1.3	75.5 ± 1.8
sHRDP _{exp>140} ($\text{km} \cdot \text{h}^{-1}$)	12.1 ± 0.8	12.4 ± 1.0 ^a	79.8 ± 3.8	81.7 ± 4.1 ^a
sHRDP _{pol} ($\text{km} \cdot \text{h}^{-1}$)	11.4 ± 1.1	11.5 ± 1.1	75.1 ± 7.3	75.6 ± 8.7
sHRDP _{pol>140} ($\text{km} \cdot \text{h}^{-1}$)	11.4 ± 1.1	11.8 ± 1.2	75.4 ± 7.4	77.5 ± 6.7
HR at sHRDP _{exp} ($b \cdot \text{min}^{-1}$)	164 ± 9.3	160 ± 10.5 ^a	85.5 ± 3.0	84.5 ± 3.6 ^a
HR at sHRDP _{exp>140} ($b \cdot \text{min}^{-1}$)	170 ± 5.5	168 ± 6.6	88.5 ± 2.1	88.8 ± 1.9
HR at sHRDP _{pol} ($b \cdot \text{min}^{-1}$)	164 ± 11.2	160 ± 13.0	85.4 ± 5.1	84.6 ± 6.2
HR at sHRDP _{pol>140} ($b \cdot \text{min}^{-1}$)	164 ± 9.7	163 ± 11.9	85.7 ± 5.2	86.1 ± 4.3

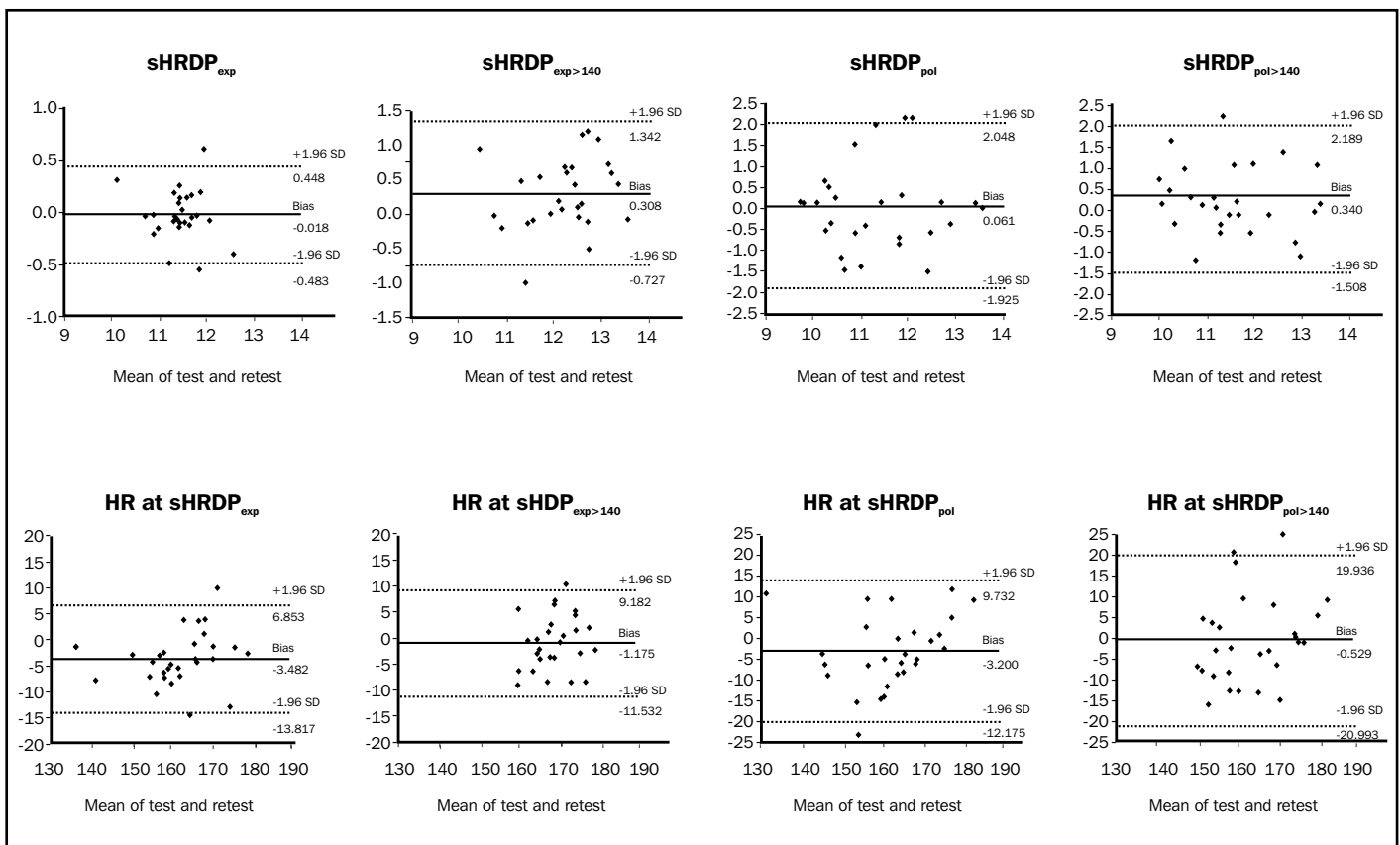
Values are mean ± SD, n=28. sHRDP_{exp}, speed at heart rate deflection point determined by D_{max} from the exponential-plus-constant regression model using all HR values; sHRDP_{exp>140}, speed at heart rate deflection point determined by D_{max} from the exponential-plus-constant regression model using HR values above 140 $b \cdot \text{min}^{-1}$; sHRDP_{pol}, speed at heart rate deflection point determined by D_{max} from the third-order polynomial regression model using all HR values; sHRDP_{pol>140}, speed at heart rate deflection point determined by D_{max} from the third-order polynomial regression model using HR values above 140 $b \cdot \text{min}^{-1}$; HR_{max} , maximal heart rate, V_{peak} , peak speed at incremental test. ^ap < 0.05 compared with test.

Table 2. Reliability of the speeds and heart rate values at heart rate deflection point determined during incremental treadmill tests.

Variables	ICC (CI 95%)	SEM (CI 95%)	CV (%) (CI 95%)	ES
sHRDP _{exp} (km·h ⁻¹)	0.87 (0.75-0.94)	0.17 (0.13-0.23)	1.46 (1.15-1.99)	0.04
sHRDP _{exp>140} (km·h ⁻¹)	0.83 (0.66-0.92)	0.37 (0.30-0.51)	3.09 (2.44-4.23)	0.34
sHRDP _{pol} (km·h ⁻¹)	0.70 (0.45-0.85)	0.72 (0.57-0.98)	6.46 (5.07-8.89)	0.05
sHRDP _{pol>140} (km·h ⁻¹)	0.68 (0.41-0.84)	0.67 (0.53-0.91)	5.77 (4.54-7.94)	0.29
HR at sHRDP _{exp} (b·min ⁻¹)	0.86 (0.72-0.93)	3.73 (2.95-5.08)	2.30 (1.81-3.14)	-0.35
HR at sHRDP _{exp>140} (b·min ⁻¹)	0.62 (0.33-0.80)	3.74 (2.95-5.09)	2.24 (1.77-3.07)	-0.19
HR at sHRDP _{pol} (b·min ⁻¹)	0.75 (0.52-0.88)	6.12 (4.84-8.33)	3.96 (3.12-5.43)	-0.26
HR at sHRDP _{pol>140} (b·min ⁻¹)	0.54 (0.21-0.76)	7.38 (5.84-10.05)	4.64 (3.65-6.37)	-0.05

n=28; CI, confidence interval; CV, coefficient of variation; ES, effect size; ICC, intraclass correlation coefficient; SEM, standard error of measurement; sHRDP_{exp}, speed at heart rate deflection point determined by D_{max} from the exponential-plus-constant regression model using all HR values; sHRDP_{exp>140}, speed at heart rate deflection point determined by D_{max} from the exponential-plus-constant regression model using HR values above 140 b·min⁻¹; sHRDP_{pol}, speed at heart rate deflection point determined by D_{max} from the third-order polynomial regression model using all HR values; sHRDP_{pol>140}, speed at heart rate deflection point determined by D_{max} from the third-order polynomial regression model using HR values above 140 b·min⁻¹.

Figure 2. Bland-Altman statistics relating to the comparison of variables between test and retest.



All the vertical axes of the figures corresponds to: Difference (retest-test).

values obtained from exponential-plus-constant regression model (i.e., sHRDP_{exp} and sHRDP_{exp>140}) showed higher reliability than the sHRDP values derived from third-order polynomial regression model (i.e., sHRDP_{pol} and sHRDP_{pol>140}). Furthermore, the sHRDP_{exp} was the most reliable variable, presenting the lowest values of SEM, CV and ES. On the other hand, the sHRDP values derived from third-order polynomial regression model were less reliable, mainly because the ICC value below

0.80 and the higher CV values. Effect size (ES) interpretations were that sHRDP_{exp} and sHRDP_{pol} were trivial, and the sHRDP_{exp>140} and sHRDP_{pol>140} were small.

For the HR values at the different sHRDP, it was demonstrated a similar response to the reliability of the speeds related to the HRDP, in which the HR values at sHRDP_{exp} and at sHRDP_{exp>140} were more reliable (i.e., SEM ≤ 3.74 b·min⁻¹ and CV ≤ 2.30%) than the HR values at sHRDP_{pol}

and at $sHRDP_{pol > 140}$ (i.e., $SEM \geq 6.12 \text{ b}\cdot\text{min}^{-1}$ and $CV \geq 3.96\%$). The ES values were considered trivial for HR at $sHRDP_{exp > 140}$ and at $sHRDP_{pol > 140}$ and small for the HR at $sHRDP_{exp}$ and at $sHRDP_{pol}$.

Systematic bias and the random variation as 95% limits of agreement are shown in Figure 2 for $sHRDP$ and HR at $HRDP$. The Bland-Altman analyses indicated a high reliability for the $sHRDP_{exp}$, in which the systematic bias was near zero and the range in the limits of agreement was narrow. For the HR values at the $sHRDP$, the best agreement between the test and retest were demonstrated by HR at $sHRDP_{exp > 140}$ given the lower bias associated with lower limits of agreement. Despite HR at $sHRDP_{pol > 140}$ presented lower bias, its limit of agreement were higher.

Discussion

The aim of this study was to examine the test-retest reliability of $sHRDP$ determined by D_{\max} method during incremental treadmill tests. It was also aimed to verify if the regression model (i.e., exponential-plus-constant and third-order polynomial regression models) and the initial HR points used to determine the $sHRDP$ by D_{\max} method (i.e., model considering HR values above $140 \text{ b}\cdot\text{min}^{-1}$ versus the model considering all the HR points obtained) influence the $sHRDP$ reliability.

The main finding was that the $sHRDP$ presented high reliability when derived from exponential-plus-constant regression model, in which the $sHRDP_{exp}$ was the most reliable variable ($ICC = 0.87$; $SEM = 0.17 \text{ km}\cdot\text{h}^{-1}$; $CV = 1.46\%$; $ES = 0.04$; $Bias = -0.018$). Furthermore, HR values at the $sHRDP_{exp}$ ($ICC = 0.86$; $SEM = 3.73 \text{ b}\cdot\text{min}^{-1}$; $CV = 2.30\%$) and at $sHRDP_{exp > 140}$ ($ICC = 0.62$; $SEM = 3.74 \text{ b}\cdot\text{min}^{-1}$; $CV = 2.30\%$) presented the highest reliability. It seems that the regression model influenced the reliability of the $sHRDP$ values and HR values at $sHRDP$. Moreover, the number of HR points slightly influenced the reliability estimates.

Since $HRDP$ was proposed by Conconi, *et al.*⁷, some studies observed high correlations among this variable and other AT methods, and for this reason the $HRDP$ determined by Conconi, *et al.*⁷ was considered an accurate predictor of the AT (i.e., ventilation and lactate thresholds)^{5,6,8}; however other works found that $HRDP$ overestimated the AT^{9,14,32}. For example, while Vucetic, *et al.*⁵ observed a good relationship, demonstrated by coefficient of determination (R^2), between the ventilation threshold and $HRDP$ in forty-eight trained runners who performed two treadmill test protocols ($R^2 = 0.72$ and 0.74), Jones and Doust¹⁴ and Vachon, *et al.*⁹ found that $HRDP$ was significantly higher than AT. Regarding the D_{\max} method, few studies investigated the relationship between the $HRDP$ determined by D_{\max} and AT or maximal lactate steady state (MLSS)^{1,11,33}. Da Silva, *et al.*¹ and Siahkoughian and Meamarbashi¹¹ showed high correlations among AT determined by lactate concentrations and $HRDP$ obtained by D_{\max} ($0.82 \leq r \leq 0.95$). On the other hand Silveira, *et al.*³³ assessed 13 runners and found that the $HRDP$ was not significantly different from the MLSS, but it was not found correlation between these variables ($r = 0.42$).

However, only few studies previously examined the reliability of $HRDP$ ^{7,13,14}, but none of them were based on D_{\max} method. Despite Conconi, *et al.*⁷ and Jones and Doust¹⁴ have found a high correlation between test-retest ($r = 0.99$ and 0.89 , respectively), there are other statistical approaches to be applied when reliability was analyzed (e.g.,

relative and absolute reliability)^{4,30}. Moreover, the $HRDP$ obtained by Conconi, *et al.*⁷ and Jones and Doust¹⁴ did not occur in the entire sample and there are significant differences both within observers^{7,14}. This weak point of the method proposed by Conconi *et al.*⁷ was highlighted on other studies^{6,9,12,14}. For example, Vachon *et al.*⁹ observed only in four of the eight subjects no signs of HR deflection on a treadmill incremental test, and Hoffman *et al.*⁶ in 14% of their sample showed no deflection or inverse deflection of the HR curve. Jones and Doust¹⁴ investigated 15 well-trained runners in test and retest and only in six subjects the HR deflection point was determined; in four subjects no deflection point from HR linearity could be discerned in either test.

In the Conconi *et al.*⁷ method the linear behavior of the HR-curve not allow the identification of the visual deflection point. The same weak point was observed for the $HRDP_{\max}$ determination in ten participants of our study. It is important to emphasize that in this cases (i.e., linear HR-curve) the $HRDP_{\max}$ often occurred at the midpoint between initial and final speeds during the incremental test. Additionally, it seems that $HRDP_{\max}$ don't occurs between midpoint and final speed in a concave downward exponential-plus-constant model because the D_{\max} is a mathematical model highly dependent on the shape of the curve³⁴.

Previous studies used the D_{\max} method to obtain the $HRDP$ ^{1,11,12}. Siahkoughian and Meamarbashi¹¹ determined the HR value at the $HRDP$ in 15 active male during incremental cycle ergometer test using all HR points ($L.D_{\max}$) and with points above $140 \text{ b}\cdot\text{min}^{-1}$ ($S.D_{\max}$). The authors showed significant correlation between the $S.D_{\max}$ and the criterion method (i.e., lactate threshold) ($r = 0.94$) and no significant correlation between $L.D_{\max}$ and the criterion ($r = 0.16$), concluding that the $S.D_{\max}$ method is an accurate alternative to substitute the lactate method. Moreover, Kara, *et al.*¹² reinforce the use of the D_{\max} method mainly because this point can be easily and objectively found in all subjects, differently from the Conconi, *et al.*⁷ method.

Recently, da Silva, *et al.*¹ examined the relationship between $sHRDP$ values calculated by D_{\max} (i.e., $sHRDP_{\max}$) method and 10-km endurance running performance in female recreational runners, and found that only the $sHRDP_{\max}$ determined by the exponential-plus-constant regression model correlated with 10km ($sHRDP_{exp}$, $r = 0.96$; $sHRDP_{exp > 140}$, $r = 0.79$). Correlations with lactate threshold showed similar results, in which the $sHRDP_{\max}$ derived from exponential-plus-constant regression model showed higher correlations than the $sHRDP_{\max}$ derived from third-order polynomial regression model. However, the authors concluded that despite the high correlations with performance, the exponential-plus-constant regression model seems not be an appropriate regression curve because this regression model very often occurred around the midpoint between initial and final speeds during the incremental test.

It is important to emphasize that a variable must be highly reliable for its application in training prescription^{4,30}. One measure to demonstrate reliability is the coefficient of variation. In the present study, this value was 1.46% for $sHRDP_{exp}$. Despite we cannot compare it to other values of $HRDP$ reliability, the reliability of the lactate and ventilatory thresholds determined during incremental exercise tests are well reported in previous studies^{30,35,36}, in which CV values between 1.6 and 3.3% were found. Hence, reliability of the $sHRDP_{exp}$ can be considered very high and recommendable for practical and scientific purposes.

In conclusion, the sHRDP determined by D_{\max} method from exponential-plus-constant regression model considering all the HR values and those above $140 \text{ b}\cdot\text{min}^{-1}$ (i.e., $\text{sHRDP}_{\text{exp}}$) is a highly reliable variable. Additionally, the HR values at the $\text{sHRDP}_{\text{exp}}$ and at $\text{sHRDP}_{\text{exp}>140}$ were highly reliable. However, in some participants the HR-curve demonstrated a linear behavior and the $\text{sHRDP}_{\text{exp}}$ occurred around the midpoint between initial and final speeds during incremental test. Thus, despite the high reliability, the exponential-plus-constant regression model should be used with caution and when the HR-curve is linear this regression curve seems not be appropriate. In contrast, sHRDP_{\max} determined by the third-order polynomial regression model presented a moderate reliability. Future studies are required to analyze the practical application of sHRDP to prescribe endurance training and monitor adaptations.

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References

- da Silva DF, Peserico CS, Machado FA. Relationship between heart rate deflection point determined by D_{\max} method and 10-km running performance in endurance recreationally-trained female runners. *J Sports Med Phys Fitness*. 2015;55:1064-71. Retrieved from: <http://www.ncbi.nlm.nih.gov/pubmed/24823346>.
- Faude O, Kindermann W, Meyer T. Lactate Threshold Concept: How Valid are they? *Sports Med*. 2009;39:469-90.
- Midgley AW, Mcnaughton LR, Jones AM. Training to enhance the physiological determinants of long-distance running performance. *Sports Med*. 2007;37:857–80.
- Hopkins WG. Measures of reliability in sports medicine and science. *Sports Med*. 2000; 30:1-15.
- Vucetic V, Sentija D, Sporis G, Trajkovic N, Milanovic Z. Comparison of ventilation threshold and heart rate deflection point in fast and standard treadmill test protocols. *Acta Clin Croat*. 2014;53:190-203.
- Hofmann P, Pokan R, von Duvillard SP, Seibert FJ, Zweiker R, Schmid P. Heart rate performance curve during incremental cycle ergometer exercise in healthy young male subjects. *Med Sci Sports Exerc*. 1997;29:762-8.
- Conconi F, Ferrari M, Ziglio PG, Droghetti P, Codeca L. Determination of the anaerobic threshold by a noninvasive field test in runners. *J Appl Physiol*. 1982;52:869-73.
- Petit MA, Nelson CM, Rhodes EC. Comparison of a mathematical model to predict 10km performance from the Conconi test and ventilatory threshold measurements. *Can J Appl Physiol*. 1997;22:562-72.
- Vachon JA, Basset DR, Clarke S. Validity of the heart rate deflection point as a predictor of lactate threshold during running. *J Appl Physiol*. 1999;87:452–9.
- Cheng B, Kuipers H, Snyder AC, Keizer A, Jeukendrup A, Hesselink M. A new approach for the determination of ventilatory and lactate thresholds. *Int J Sports Med*. 1992;13:518-22.
- Siahkouhian M, Meamarbashi A. Advanced methodological approach in determination of the heart rate deflection point: S.Dmax versus L.Dmax methods. *J Sports Med Phys Fitness*. 2013;53:27-33.
- Kara M, Gokbel H, Bediz C, Ergene N, Uçok K, Uysal H. Determination of the heart rate deflection point by the D_{\max} method. *J Sports Med Phys Fitness*. 1996;36:31-4.
- Pokan R, Hofmann P, von Duvillard SP, Smekal G, Hogler R, Tschan H, et al. The heart rate turn point reliability and methodological aspects. *Med Sci Sports Exerc*. 1999;3:903-7.
- Jones AM, Doust JH. Lack of reliability in Conconi's heart rate deflection point. *Int J Sports Med*. 1995;16:541–4.
- Bodner ME, Rhodes EC. A review of the concept of the heart rate deflection point. *Sports Med*. 2000;30:31-46.
- Jackson AS, Pollock ML. Generalized equations for predicting body density of men. *Br J Nutr*. 1978;40:497-504.
- Siri WE. Techniques for measuring body composition. Washington. National Academy Press; 1961. p.223.
- Conconi F, Borsetto C, Casoni I, et al. The Conconi test: methodology after 12 years of application. *Int J Sports Med*. 1996;17:509-19.
- Peserico CS, Zagatto AM, Machado FA. Reproducibility of heart rate and rating of perceived exertion values obtained from different incremental treadmill tests. *Sci Sports*. 2015;30:82-8.
- Borg GA. Psychophysical bases of perceived exertion. *Med Sci Sports Exerc*. 1982;14: 377-81.
- Kuipers H, Rietjens G, Verstappen F, Schoenmakers H, Hofman G. Effects of stage duration in incremental running tests on physiological variables. *Int J Sports Med*. 2003;24: 486-91.
- Tanaka H, Monahan KD, Seals DR. Age-predicted maximal heart rate revisited. *J Am Coll Cardiol*. 2001;37:153-6.
- Howley ET, Bassett DR Jr, Welch HG. Criteria for maximal oxygen uptake: review and commentary. *Med Sci Sports Exerc*. 1995;27:1292-301.
- Hughson RL, Weisiger KH, Swanson GD. Blood lactate concentration increases as a continuous function in progressive exercise. *J Appl Physiol*. 1987;62:1975–81.
- Sportscience - A Peer-Reviewed Journal and Site for Sport Research. Analysis of reliability with a spreadsheet. Available at <http://sportsoci.org/index.html>. Accessed 22 May 2014.
- Atkinson G, Nevill AM. Statistical methods for assessing measurement error (reliability) in variables relevant to sports medicine. *Sports Med*. 1998;26:217-38.
- McGraw KO, Wong SP. Forming inferences about some intraclass correlation coefficients. *Psychol Methods*. 1996;1:30-46.
- Shrout PE, Fleiss JL. Intraclass correlations: Uses in assessing rater reliability. *Psychol Bull*. 1979;86:420-8.
- Vincent WJ. Statistics in Kinesiology. Champaign, *Human Kinetics*; 2005. p.194-7.
- Hopkins WG, Schabert EJ, Hawley JA. Reliability of power in physical performance tests. *Sports Med*. 2001;31:211-34.
- Cohen J. Statistical Power Analysis for the Behavioral Sciences. Hillsdale. Lawrence Erlbaum; 1988. p.567.
- Bourgeois J, Coorevits P, Dannels L, Witvrouw E, Cambier D, Vrijens J. Validity of the heart rate deflection point as a predictor of lactate threshold concepts during cycling. *J Strength Cond Res*. 2004;18:498-503.
- Silveira BH, Aguiar RA, Alves TL, Caputo F, Carminatti LJ. Comparação do ponto de deflexão da frequência cardíaca com a máxima fase estável de lactato em corredores de fundo. *Rev Motriz*. 2012;18:1-8.
- Machado FA, Nakamura FY, Moraes SM. Influence of regression model and incremental test protocol on the relationship between lactate threshold using the maximal-deviation method and performance in female runners. *J Sports Sci*. 2012;30:1267-74.
- Coen B, Urhausen A, Kindermann W. Individual anaerobic threshold: methodological aspects of its assessment in running. *Int J Sports Med*. 2001;22:8-16.
- Gavin JP, Willems MET, Myers SD. Reproducibility of lactate markers during 4 and 8 min stage incremental running: A pilot study. *J Sci Med Sport*. 2014;17:635-9.

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