Comparison between non-exhaustive critical velocity estimated by heart rate with exhaustive critical velocity and heart rate variability threshold

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Received: 17.04.2015
Accepted: 20.07.2015

Summary

The aim of this study was to compare the critical velocity determined by a non-exhaustive test (CV_{NE}) using heart rate (HR) as physiological variable with the exhaustive critical velocity (CV) and the heart rate variability threshold (HRVT). Twelve male subjects (20.1 ± 1.6 years; 73.4 ± 10.3 kg; 1.76 ± 0.06 m) physically active took part of this study and performed an incremental test to determination the peak velocity and HRVT, three constant-load exhaustive tests to CV estimates and three non-exhaustive tests with two bouts of three minutes to CV_{NE} determination. The percentages used to CV estimates were of 97%, 111% and 130% of peak velocity from incremental test and to CV_{NE} were used of 72%, 92% and 110% of peak velocity. The incremental test was also important to determine the HRVT. The difference between CV_{NE} vs HRVT (2.61 ± 12.84 km.h^{-1} vs 7.92 ± 1.16 km.h^{-1}) and the CV_{NE} vs CV (2.61 ± 12.84 km.h^{-1} vs 12.20 ± 1.38 km.h^{-1}; $p > 0.05$) was not statistically significative, but a significant difference was observed between the HRVT and CV (7.92 ± 1.16 km.h^{-1} vs 12.20 ± 1.38 km.h^{-1}) ($p < 0.01$). The CV_{NE} demonstrated low agreement and weak correlation with HRVT (bias ± limits of agreement = -5.31 ± 25.09 km.h^{-1}; r = 0.08) and CV (bias ± limits of agreement = -9.59 ± 25.94 km.h^{-1}; r = -0.23). Thus, the CV_{NE} estimated by HR is not a valid parameter to evaluation of metabolic transition and to prescribe aerobic exercise.

Key words:
Non-exhaustive method. Heart rate. Exhaustive test.

Comparación entre velocidad crítica no exhaustiva estimada por la frecuencia cardíaca con velocidad crítica exhaustiva y el umbral de la variabilidad de la frecuencia cardíaca

Resumen

El objetivo de este estudio fue comparar a velocidad crítica determinada por un test no exhaustivo (CV_{NE}) utilizando como variable fisiológica la frecuencia cardíaca (HR) con velocidad crítica exhaustiva (CV) y el umbral de la variabilidad de la frecuencia cardíaca (HRVT). Veinte sujetos hombres (20,1 ± 1,6 años; 73,4 ± 10,3 kg; 1,76 ± 0,06 m) físicamente activos participaron en el estudio y realizaron un test incremental para determinar la velocidad pico y HRVT, tres exhaustivos testes de carga constante para estimar a CV y tres testes no exhaustivos con dos episodios de tres minutos para determinar la CV_{NE}. Los porcentajes utilizados para estimar a CV fueron 97%, 111% y 130% de la velocidad pico del test incremental y en CV_{NE} fueron usados 72%, 92% y 110% de la velocidad pico. El test incremental también era importante para determinar la HRVT. La diferencia entre la CV_{NE} vs HRVT (2,61 ± 12,84 km.h^{-1} vs 7,92 ± 1,16 km.h^{-1}) y el CV_{NE} vs CV (2,61 ± 12,84 km.h^{-1} vs 12,20 ± 1,38 km.h^{-1}; $p > 0,05$) no fue estadísticamente significativa, pero él se observaron diferencias significativas entre el HRVT y la CV (7,92 ± 1,16 km.h^{-1} vs 12,20 ± 1,38 km.h^{-1}) ($p < 0,01$). El CV_{NE} demostró menor concordancia y correlación con HRVT (sesgo ± límites de acuerdo = -5,31 ± 25,09 km.h^{-1}; r = 0,08) y CV (sesgo ± límites de acuerdo = -9,59 ± 25,94 km.h^{-1}; r = -0,23). Por lo tanto, la CV_{NE} estimado por HR no es un parámetro válido para la evaluación de la transición metabólica y prescribir ejercicio aeróbico.

Palabras clave:
Método no exhaustivo. Frecuencia cardíaca. Test exhaustivo.

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Introduction

There are several protocols to evaluate aerobic fitness in athletes, such as ventilatory threshold, lactate threshold and maximal lactate steady state (MLSS). However, their application becomes infeasible to be used routinely, due the expensive material and/or blood collection. Other protocol to evaluation of aerobic fitness without expensive materials is the critical velocity (CV). CV is a non-invasive parameter that can be estimated by mathematical models between velocity and time to exhaustion relationship[1-3].

Due the exhaustive characteristics of CV model, Chassain[4] proposed a method where the critical velocity can be determined by a non-exhaustive test (CV_{NE}). The CV_{NE} is a simple method that facilitates the evaluation mainly for frail and elderly people, because reduces the risks involved. Based on the analysis of the deltas of heart rate (HR) or blood lactate concentration ([La]) after double efforts, CV_{NE} is determined from a linear regression at intensity in which the delta of physiological variable is null.

According to Sid-Ali *et al.*[5] study, CV presented a strong correlation with the CV_{NE} using the [La] as physiology variable. Notwithstanding, Rosi *et al.*[6] showed that the value CV_{NE} estimated by HR was lower than MLSS. Therefore, it is not clear about the validity and if the CV_{NE} estimated by heart rate coincides with the first or second metabolic transition.

A way to identify the first metabolic transition is the heart rate variability threshold (HRVT). Karapetian *et al.*[7] showed that HRVT was not different and good correlated with first lactate threshold and ventilatory threshold. Thus, the aim of this study was to know if CV_{NE} predicted by HR could be considered similar to CV and/or HRVT. This information is important to better knowledge about the CV_{NE} physiological significance and its validity.

Material and methods

Subjects

Twelve male subjects (20.1 ± 1.6 years; 73.4 ± 10.3 kg; 1.76 ± 0.06 m) physically active took part of this study. The sample size was calculated by G*Power software (v.3.1.7) assuming $\alpha = 0.05$ and $\beta = 0.20$ based on a Rossi *et al.*[6] study. The subjects were considered physically active according to American College of Sports Medicine (ACSM)[8], which considers: to accumulate at least 30 minutes of moderate physical activity on five days a week or 20 minutes of vigorous physical activity on three days a week. A questionnaire was filled with the physical activities performed, period and times per week to guarantee these criteria. All participants were aware about the procedures of the experiment, and signed an informed consent previously approved by the local Ethics Committee in Human Research. In addition, the participants were instructed to not ingest alcohol and caffeinated beverages 24 hours preceding each test.

Experimental design

The procedures were performed at the same time of the day and consisted of an incremental test to determine the HRVT and the peak velocity, three tests with double submaximal efforts to estimate the CV_{NE}, and finally, three maximal tests to estimate the CV. Each test was performed on different days with at least 24 hours of interval between the tests.

Incremental test and HRVT determination

The participants underwent a progressive treadmill test (Inbramed Millennium, model ATL, Porto Alegre) to determine the peak velocity and the HRVT. The test started at 5 $km.h^{-1}$ with increments of 1 $km.h^{-1}$ every three minutes and constant slope of 1% until the voluntary exhaustion.

During the incremental test and all subsequent tests, the subjects used a portable heart rate monitor (Polar RS800, Kempele) fastened around the chest for continuous HR recordings. The RR were filtered automatically and visually examined to remove missing or premature beats. RR intervals were interpreted as premature beats when deviated from the previous qualified interval > 30%[9]. For the HRVT determination, root mean square differences of successive RR intervals (RMSSD) of the last 2 min of rest and each stage were analyzed plotting graphically against work rate. Then, a visual interpretation was made to locate the point at which there was no further decline in HRV, thereby indicating vagal withdrawal. Thus, this HRV deflection point was defined as the HRVT[7]. Based on the above criteria, two experienced researchers independently determined the HRVT. When there was a disagreement between them, a third experienced investigator was requested to HRVT determination. In all situations there was an agreement with at least two evaluators.

Critical Velocity determined by non-exhaustive tests

Each test consisted from two bouts of three minutes separated by a rest period of one and half minutes, which HR was continuously monitored[4]. The percentages of 72%, 92% and 110% of peak velocity were used to predict the CV_{NE}. The delta HR (ΔHR) value was calculated subtracting HR at the end of the second with HR at the end of the first bout. A linear regression was plotted with the values of ΔHR obtained in each load, permitting the determination of the ΔHR theoretically null. Thus, the value of CV_{NE} was considered as the Y-intercept of this linear interpolation (Figure 1).

Critical Velocity determined by exhaustive tests

The participants underwent three constant load tests to CV estimates at 97%, 111% and 130% of peak velocity and in which induced the individuals to exhaustion between 2-15 min. The CV was determined for all participants from the hyperbolic model by nonlinear regression between speed and time to exhaustion, where:

Time to exhaustion = anaerobic running capacity / (CV- speed)

The asymptote of the regression velocity-time was defined as CV and the curvature degree of the hyperbola was the anaerobic running capacity.

Statistical analyses

The data are presented as mean ± standard deviation. The Gaussian distribution was observed by Kolmogorov-Smirnov test. ANOVA

Figure 1. Linear regression between velocity and the difference of HR between the double efforts (ΔHR) of a subject.

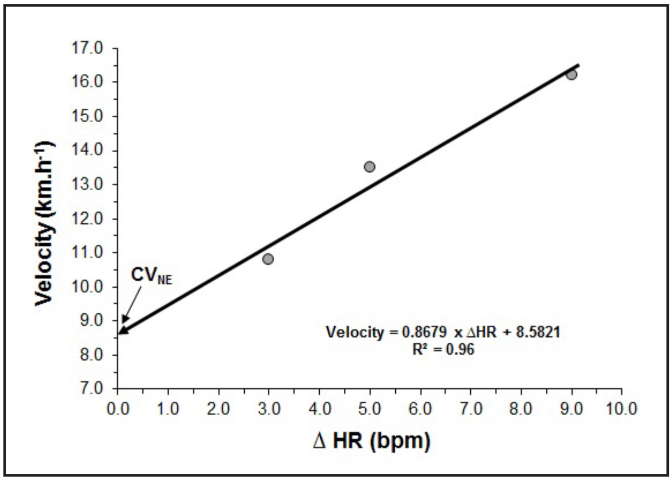
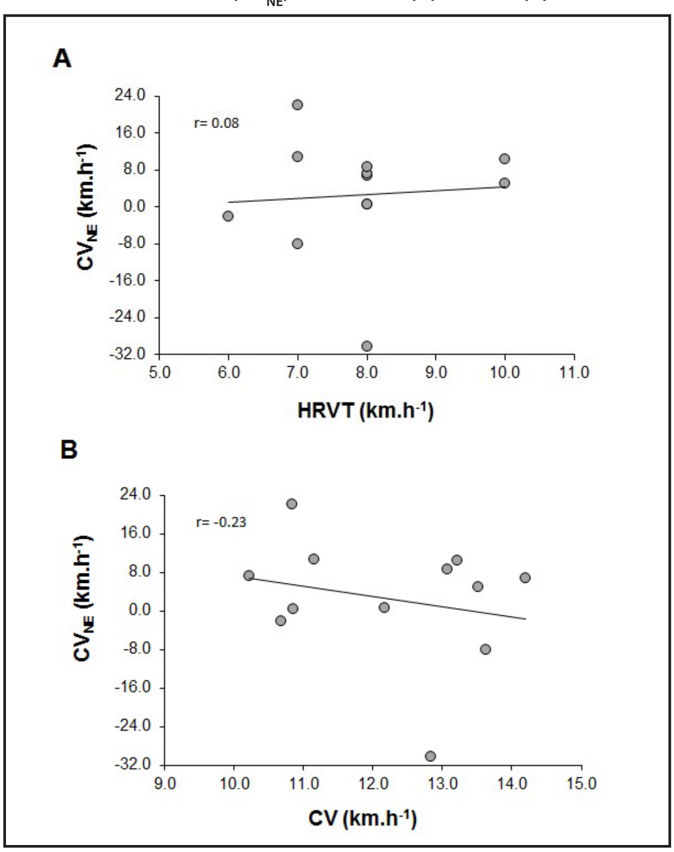


Figure 2. Relationships between critical velocity determined by a non-exhaustive test (CV_{NE}) with HRVT (A) and CV (B).



for repeated measures was used to compare the CV, HRVT and CV_{NE} velocity. The sphericity was observed by Mauchly's test followed by Greenhouse-Geisser. Differences were identified by Bonferroni correction. Moreover, the relation between the aerobic variables was verified through Pearson correlation, and the agreement by Bland-Altman plot. Data were considered statistically significant when $p < 0.05$.

Table 1. Mean and standard deviation of velocities corresponding the three intensities from predictive trial to CV_{NE} and CV estimates.

		CV_{NE}	
Percentage of peak power Mean ± SD ($km.h^{-1}$)	72% 9.78 ± 1.02	92% 12.18 ± 1.22	110% 14.60 ± 1.48
		CV	
Percentage of peak power Mean ± SD ($km.h^{-1}$)	97% 13.33 ± 1.29	111% 15.48 ± 1.68	130% 17.71 ± 1.75

Table 2. Mean and standard deviation values of CV_{NE}, HRVT and CV.

	CV_{NE} ($km.h^{-1}$)	HRVT ($km.h^{-1}$)	CV ($km.h^{-1}$)
Mean	2.61	7.92*	12.20
SD	12.84	1.16	1.38

*Significant different from CV ($p < 0.001$).

Results

The mean the peak velocity during the incremental test was 13.08 ± 1.51 $km.h^{-1}$. The velocities from the predictive trials to CV_{NE} and CV estimates are presented in Table 1.

The CV_{NE} was not significant different when compared with HRVT and CV ($p > 0.05$). However, there was difference between HRVT and CV (Table 2). Additionally, weak correlation was observed between CV_{NE} with HRVT and CV (Figure 2). The bias ± limits of agreement between CV_{NE} and HRVT was -5.31 ± 25.09 $km.h^{-1}$ and between CV_{NE} and CV was -9.59 ± 25.94 $km.h^{-1}$. The value the anaerobic running capacity was 735.45 ± 182.53 m.

Discussion

This study wanted to compare different methods that indicate the aerobic capacity. The main results of this study were that the CV_{NE} was not statistically different of HRVT and CV. Furthermore, CV_{NE} showed weak correlation and low agreement with both HRVT and CV.

According to the physiological response during the exercise, it is observed three different domains of effort[10]. The moderate domain is laid below the first metabolic threshold[11]. It comprises the intensities that can be sustained without inducing significant increase of [La] and there is a monoexponential increase of VO_2 during the approximately three initial minutes, reaching a steady state thereafter. The intense domain corresponds the intensities in which there is a late stabilization from VO_2 and [La] with the upper limit the second metabolic transition[11]. Above this intensity is called severe domain, in which the physiological variables increase until the exhaustion[11].

The HRVT corresponds the transition between moderate to intense domains and the CV the transition between intense to severe domains. Some studies have demonstrated that both methods are validated for aerobic fitness evaluation[1,7]. Our results showed that the CV_{NE} was not different of HRVT and CV. It probably occurred because the high variability of CV_{NE}, that can be observed by standard deviation, with three subjects with negative estimates. Furthermore, the correlations and agreement of CV_{NE} with HRVT and CV were low. Sid-Ali *et al*.[5] found different results, which the CV_{NE} (17.31 ± 1.85 km.h^{-1}) was not different in relation to CV (17.32 ± 1.11 km.h^{-1}), with a strong correlation (r = 0.97). However, the study by Sid-Ali *et al*.[5], the physiological variable used to CV_{NE} estimates was the [La], and in our study the physiological variable used was the HR. Notwithstanding, in Rosi *et al*.[6] study, it was observed that CV_{NE} estimated by [La] and HR was significantly lower than MLSS. Additionally, the correlations of CV_{NE} estimated by [La] and HR with MLSS were weak and not significant (r = 0.36, r = -0.12; respectively). Thereby, considering the Rosi *et al*.[6] and our results, it indicates that CV_{NE} is not a good tool to aerobic parameters estimates and to prescribe the velocity of training.

In comparison of HRVT with CV, it was observed that the HRVT was lower than CV. It occurred because the HRVT corresponds to the first metabolic transition, whereas CV is equivalent to the boundaries of second metabolic transition. The HRVT is an indirect method, noninvasive and of easy application for identification aerobic threshold speeds[7]. Karapetian *et al*.[7] presented similar VO_2 at HRVT and at ventilatory threshold. Dourado *et al*.[12] corroborate these results, in which the speed at ventilatory threshold (5.04 ± 1.00 km.h^{-1}) was not different from HRVT (5.10 ± 1.04 km.h^{-1}) and presented strong correlation (r= 0.89).

The other metabolic transition indicator analyzed in our study was CV. There is some contradictory finding about CV, in which some authors showed that CV is the upper limit of heavy domain and corresponds to anaerobic threshold and MLSS[13,14]. However, other studies have showed that CV is considered the lower limit of severe domain, considering the initial intensity that there is not metabolic steady state[15,16]. The critical velocity model was previously applied in different situation, such as running[1], cycling[13,17] and swimming[3], presenting high correlation with performance[3,17]. Thus, the CV is a reliable parameter for evaluation as well as for aerobic prescription.

In our study, the CV was similar to Cruz *et al*.[18] study (13.32 ± 2.30 km.h^{-1}) but lower than compared to those obtained by Denadai *et al.*[19] (14.4 ± 1.10 km.h^{-1}), Sid-Ali *et al*.[5] (17.31 ± 1.11 km.h^{-1}). It is probably occurred due the characteristics of population, in which in our study was used moderate physical active subjects or recreational athletes and other authors used soccer players[19] and runners[5].

The main limitation of the present study was not to evaluate the physiological responses (e.g. lactate and oxygen uptake) at the CV_{NE}, HRVT and CV. Furthermore, probably the CV_{NE} estimates is protocol dependent, and the selection of intensities can modify the HR behavior. However, more studies are necessary to verify the influence of different intensities combinations to predict CV_{NE}. Thus, it can be concluded that CV_{NE} estimated by HR cannot be considered valid and a good tool to verify the aerobic fitness, presenting a weak correlation and very low agreement with HRVT and CV. Thereby, the CV_{NE} does not coincide nor with the first neither with second metabolic transition.

References

1. Keir DA, Fontana FY, Robertson TC, Murias JM, Paterson DH, Kowalchuk JM, *et al*. Exercise Intensity Thresholds: Identifying the Boundaries of Sustainable Performance. *Med Sci Sports Exerc*. 2015. In press.
2. Hill, DW. The critical power concept. *Brit J Sport Med*.1993;16:237-54.
3. Papoti M, Zagatto AM, Mendes OC, Gobatto CA. Utilização de métodos invasivo e não invasivo na predição das performances aeróbia e anaeróbia em nadadores de nível nacional. *Rev Port Cien Desp*. 2005;5:7-14.
4. Chassain, A. Méthode d'appréciation objective de la tolérance de l'organisme á l'effort: application á la mensure despuissances de la frequence cardiaque et de lalactatémie. *Sci Sports*.1986;1:41-8.
5. Sid-Ali B, Vandewalle H, Chaïr K, Moreaux A, Monod, H. Lactate steady state velocity and distance-exhaustion time relationship in running. *Arch Int Physiol Bio*.1991;99:297-01.
6. Rossi FE, Kalva-Filho CA, Gravassa de Araújo R, Gerosa Neto J, Campos, EZ, Pastre, CM, *et al*. Critical velocity determined by a non-exhaustive method in menopausal women. *Sci Sports*. 2015; 30:17-22.
7. Karapetian, GK, Engels, HJ, Gretebeck, RJ. Use of heart rate variability to estimate LT and VT. *Int J Sports Med*. 2008; 29:652-7.
8. ACSM. American College of Sports Medicine position stand. The Recommended Quantity and Quality of Exercise for Developing and Maintaining Cardiorespiratory and Muscular Fitness, and Flexibility in Healthy Adults. *Med Sci Sports Exerc*. 2011; 41:687-8.
9. Tulppo MP, Makikallio TH, Talaka T, Seppanen T, Huikuri HV. Vagal modulation of the heart rate during exercise: effects of age and physical fitness. *Am J Physiol*.1998; 274:424-9.
10. Gaesser GA, Poole D. The slow component of oxygen uptake kinetics in humans. *Exercise Sport Sci R*. 1996;24:35-71.
11. Nakamura FY, Brunetto AF, Hirai DM, Roseguini BT, Kokubun E. O limiar de esforço percebido (LEP) corresponde à potência crítica e a um indicador de máximo estado estável de consumo de oxigênio. *Rev Bras de Med Esporte*. 2005;11:197-02.
12. Dourado VZ, Banov MC, Marino MC, De Souza VL, Antunes LC, Mcburnie MA. A simple approach to assess VT during a field walk test. *Inter J Sports Med*. 2010;31:698-03.
13. Poole DC, Ward SA, Gardner GW, Whipp BJ. Metabolic and respiratory profile of the upper limit for prolonged exercise in man. *Ergonomics*. 1988;31:1265-79.
14. Jones AM, Carter H. The effect of endurance training on parameters of aerobic fitness. *Sports Med*. 2000;29:373-86.
15. Pringle JS, Jones AM. Maximal lactate steady state, critical power and EMG during cycling. *Eur J Appl Physiol*. 2002;88:214-226.
16. Brickley G, Doust J, Williams CA. Physiological responses during exercise to exhaustion at critical power. *Eur J Appl Physiol*. 2002;88:146-51.
17. Smith JC, Dangelmaier BS, Hill DW. Critical power is related to cycling time trial performance. *Int J Sports Med*. 1999;20:374-88.
18. Cruz R, Da Silva SF. Indicadores de parâmetros de controle de treinamento e ciclo circadiano. *Acta Bras Mov Hum*. 2011;1:33-41.
19. Denadai BS, Gomide EB, Greco CC. The relationship between onset of blood lactate accumulation, critical velocity, and maximal lactate steady state in soccer players. *J Strength Cond Res*. 2005;19:364-8.