



Critical velocity as a noninvasive method to estimate the lactate minimum velocity on cycling*

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ABSTRACT

The lactate minimum velocity (LMV) represents the equilibrium point between blood lactate (lac) production and removal. With the purpose of analyzing the validity of critical velocity (CV) as a non-invasive method to estimate the LMV on outdoor cycling, 15 cyclists (67.9 ± 5.7 kg; 1.70 ± 0.1 m; 26.7 ± 4.2 years) performed all-out tests on distances of 2, 4 and 6 km on velodrome. The CV was identified by distance-time model from combinations of 2 and 4 km ($CV_{2/4}$), 2 and 6 km ($CV_{2/6}$), 4 and 6 km ($CV_{4/6}$) and 2, 4 and 6 km ($CV_{2/4/6}$). The LMV was identified during 6 x 2 km incremental bouts after a lactic acidosis induced by the all-out 2 km. The lower lac during test identified the LMV visually (LMVv) and by applying a polynomial function (LMVp). No differences were observed between LMVv (33.3 ± 2.5 km.h⁻¹) and LMVp (33.1 ± 2.6 km.h⁻¹). Apart from $CV_{4/6}$ (34.6 ± 3.5 km.h⁻¹), the values of $CV_{2/4}$ (38.0 ± 2.2 km.h⁻¹), $CV_{2/6}$ (36.1 ± 2.4 km.h⁻¹) and $CV_{2/4/6}$ (36.1 ± 2.5 km.h⁻¹) differed from LMVp and LMVv ($P < 0,001$). The authors concluded that, besides being ~1 km/h above the LMV, the CV determined through predictive series of longer duration (4 and 6 km – approximately 6 and 10 min) did not differ statistically from LMV and presented a high correlation and agreement to each other. However, it is necessary to investigate whether the CV reflects the balance between lac production and removal during long-term exercise on outdoor cycling.

INTRODUCTION

Davis and Gass⁽¹⁾, observed during incremental test performed after high intensity exercise that the blood lactate concentrations decreased in the first incremental loads until a minimum point and returned to increase in the subsequent loads. These authors concluded that the exercise intensity corresponding to the balance point between blood lactate production and removal could be identified during incremental bouts performed after induction of metabolic acidosis. Later, this protocol was improved and called minimum lactate⁽²⁾ (ML). Moreover, several subsequent studies⁽³⁻⁹⁾ were conducted in order to verify its validity.

Simões *et al.*⁽⁵⁾, analyzing the relation between ML and other protocols proposed for identification of the maximal lactate steady phase (MLSP) in runners, did not find statistically significant differences between the minimum lactate velocity (VLM) and the velocities corresponding to the individual anaerobic threshold and to the steady concentration of 4 mM of blood lactate. These authors also observed that the MLV did not differ from the running velocity in which blood lactate steady phase was observed during long duration exercise.

MacIntosh *et al.*⁽⁴⁾ verified in a study with 14 cyclists/triathletes of both sexes, that the ML protocol was valid for prediction of

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physical exercise intensities corresponding to the MLSP. Bacon and Kern⁽⁹⁾ also evidenced that the MLSP and MLV intensities, identified during running tests in physically active individuals, were not different from each other.

Although it is an interesting method for identification of an exercise intensity which represents the MLSP, the determination of the MLV depends on costly equipment and evaluators skilled in blood collection and lactate dosing, which makes its wide application not viable.

An alternative would be the use of indirect methods⁽¹⁰⁾ for identification of velocities similar to the MLV and MLSP. Among these methods we find the determination of the critical velocity (CV) CV has been suggested as the intensity of physical exercise which can be sustained for an extensive period of time without exhaustion⁽¹¹⁾. Moreover, its determination involves non-invasive and expensive procedures which may be easily applied on field tests.

The VC validity in estimating the MLSP is still very controversial. Wakayoshi *et al.*⁽¹²⁾ observed that the CV could identify the MLSP in swimmers. In this study, the participants performed repeated series of 400 meters in velocities corresponding to 98, 100 and 102% of the CV, being 4 series at each intensity. It was verified that in exercises performed at 100% of the CV the lactate concentrations stabilized, while at 102% of the CV the concentrations increased between the first and fourth series. It was concluded hence, that the CV could represent the MLSP. Kokubun⁽¹³⁾ evidenced similar results in his study with 48 swimmers from both sexes. The study showed that during 5 series of 400 meters with 30 seconds of pause no alterations in the lactate concentrations were observed when the series were performed at 100% of the CV. On the other hand, when these series were performed at intensities higher than the CV, accumulation of blood lactate was observed.

Although some studies have established that the CV may estimate the MLSP in swimming, studies performed with other exercise modalities show that the critical velocity-power overestimates the intensities corresponding to individual anaerobic threshold, MLSP and minimum lactate^(8,14). In a study performed with 20 runners, Simões *et al.*⁽⁵⁾ observed that the CV ($292,1 \pm 17,5$ m.min⁻¹) overestimated the MLV ($281,0 \pm 14,8$ m.min⁻¹). Similarly, Denadai, Gomide and Greco⁽¹⁵⁾ verified that the CV determined in running in soccer players overestimated the MLSP.

As far as we know, no study has compared the CV determined on outdoor cycling with other protocols of aerobic evaluation such as anaerobic threshold, ML and MLSP, where the majority of the studies were performed in cycle ergometer with power measured in Watts. McLellan and Cheung⁽¹⁴⁾ verified in 14 individuals that the CP determined in cycle ergometer by the power-1/time linear relation overestimated in 13% the MLSP. However, the CV may also suffer influence of the mathematical model applied⁽¹⁶⁻¹⁷⁾ and the predictive series combinations used for its determination. Nevertheless, there are few studies investigating the effects of different combinations of predictive series over the CV identification as well

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as its comparison with other protocols which propose the identification of the MLSP, especially on outdoor cycling.

Considering that laboratory tests usually lose in specificity, we propose in this study the utilization of tests which reach for the highest specificity in the sport, namely track tests with the utilization of the cyclist's own bicycle. Therefore, the aim of the present study was to compare the values of CV identified by different combinations of predictive series on field tests performed on cycling as well as the CV values identified by different combinations of predictive series with velocities of minimum lactate determined by visual inspection and by the application of polynomial function.

METHODS

Fifteen cyclists with $6,3 \pm 3,2$ years of practice participated in the research, whose characteristics are represented in table 1. The participants answered a questionnaire of anamnesis and signed a free and clarified consent form about the study's procedures. Each participant was instructed to remain hydrated as well as to have the last meal 3 hours prior to the tests sessions. Ingestion of alcoholic beverages and intense physical exercises were not allowed during the 24 hours prior to the tests. The methods used in the present study were approved by the Ethics in Human Research Committee of the Catholic University of Brasilia.

TABLE 1

Mean \pm standard-deviation results concerning age; weight; height and time of practice in cycling of the individuals who participated in the study (n = 15)

	Age (years)	Weight (kg)	Height (m)	Cycling practice (years)
Mean	26,7	67,9	1,7	6,3
\pm SD	4,2	5,7	0,1	3,2

Performed tests

All tests were performed in a velodrome in of 400 meters in Brasilia – DF, with the volunteers using their own bicycles. The procedures were always conducted at the same time of the day and consisted of 3 tests with the purpose to measure performance in the 2, 4 and 6 km distances, besides an incremental bout after hyperlactatemia induction for identification of the MLV. All tests were performed within a 2 weeks period. The tests were randomly applied, except for the 6 km performance, which was the first one to be applied. Unfavorable climate conditions such as rain and gusty winds were avoided. The mean velocity as well as the correct measurement of the velodrome were taken by a cyclecomputer (ASSIZE, CYCLOCOMPUTER).

All-out tests of 2, 4 and 6 km

After a 10-minute warm-up pedaling in their own bicycles between 90 and 100 rpm, the volunteers completed 2, 4 and 6 km all-out tests, always at different days and with an interval of at least 24 h. These tests were chosen as predictive series of CV since they were finished between approximately 1 to 10 minutes, as proposed by Poole⁽¹⁸⁾.

Determination of the critical velocity

The CV was determined in all participants from the distance-time linear model⁽¹²⁾. Linear regression between the completed distance (km) and the time used in order to complete this distance (h) was performed. The inclination of the distance-time regression line was defined as critical velocity (CV) (figure 1).

Having the 2, 4 and 6 km predictive series performance as starting point, combinations for the determination of four indices of different critical velocities were performed. The $CV_{2/4}$ (2 and 4 Km series), $CV_{2/6}$ (2 and 6 Km series), $CV_{4/6}$ (4 and 6 Km series) and $CV_{2/4/6}$ (2, 4 and 6 Km series) were determined through the distance-

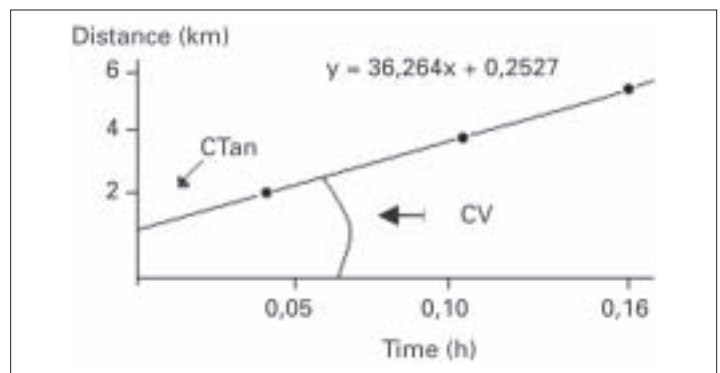


Figure 1 – Exemplification of the determination of critical velocity (CV) and anaerobic work capacity (WCan) through the distance-time linear model

time linear model. Such model also allows the identification of the anaerobic work capacity, despite not being object of this study as a parameter.

Identification of the equilibrium point between blood lactate production and removal

It consisted of the ML test application using a MacIntosh *et al.*⁽⁴⁾ modified protocol, being one 2 km all-out series used for blood lactate increase, followed by 8 minutes of recovery with a blood collection in the 7th minute. In the 8th minute an incremental bout consisting of 6 series of 2 km in progressive intensities, with 1 minute pause for capillary blood collection was applied. The intensity of the first series corresponded to 5 Km/h below the mean velocity obtained in 6 km bout previously performed, with increases of 1 km/h at each series of 2 km. The mean velocity of each series was controlled by a cyclecomputer (ASSIZE, CYCLOCOMPUTER) as well as by sound stimulus (whistle). The MLV identification was visually inspected (MLVv, figure 2-A), as well as by polynomial function of second degree for mathematical adjustment of the blood lactate response (MLVp, figure 2-B).

Blood collections and analyses

After local asepsis, a small incision on the earlobe was done with disposable material for collection of 25 μ L of capillary blood

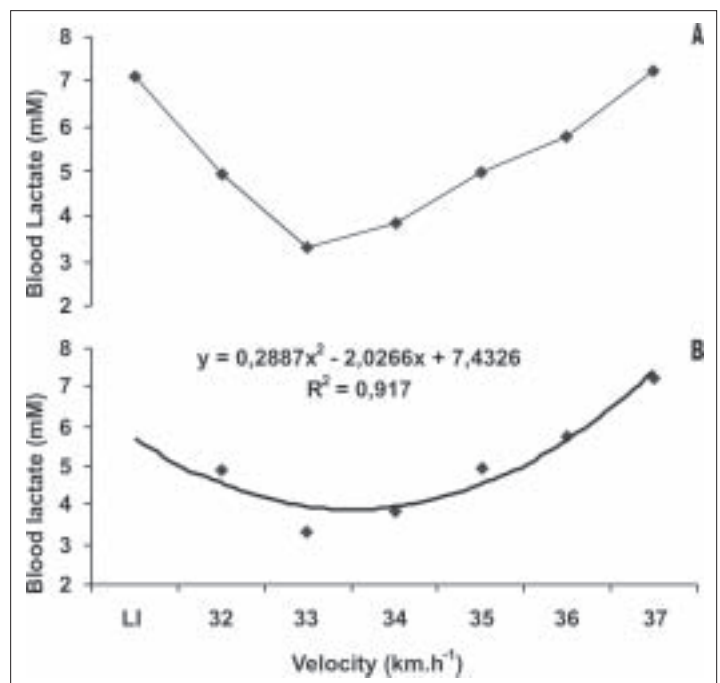


Figure 2 – Exemplification of the MLV identified by visual inspection (MLVv – A) and polynomial function (MLVp – B). LI – Blood lactate increase through 2 km bouts at all-out intensities.

using heparinized and calibrated capillary tubes. The collections occurred in the intervals between exercise series during the minimum lactate test and stored in Eppendorfs tubes containing 50 µL of sodium fluoride 1%. During the collection procedures, all materials were disposable in order to avoid any kind of contamination. Besides that, the first blood drop was discarded in order to avoid blood and sweat mixture. The samples were analyzed through electroenzymatic method, using a lactate analyzer (Yellow Springs instruments 2.700 STAT).

Statistical analyses

The data were expressed in mean ± standard deviation (SD). The results of MLVv, MLVp and CV determined by different combinations of predictive series were compared using variance analysis for repeated measures and Tukey test as well as *post hoc* and the correlations between CV and MLV were determined using the Pearson correlation coefficient. The significance level accepted was $p < 0,05$. Moreover, the agreement level between LMV and CV determined by different methods was analyzed through the Bland-Altman technique⁽¹⁹⁾.

RESULTS

No statistically significant differences were verified between MLVp and MLVv (table 2) nor between their respective lactate concentrations (table 3) ($p > 0,05$). The intensities (Km/h^{-1}) corresponding to $\text{CV}_{2/4}$, $\text{CV}_{2/6}$ and $\text{CV}_{2/4/6}$ were statistically different from the MLV identified both visually and by polynomial function ($p < 0,001$). However, the $\text{CV}_{4/6}$ did not differ from the MLVp and MLVv (table 2).

TABLE 2
Results (km/h^{-1}) concerning the MLVv, MLVp, $\text{CV}_{2/4}$, $\text{CV}_{2/6}$, $\text{CV}_{4/6}$, $\text{CV}_{2/4/6}$

	MLVv (km/h^{-1})	MLVp (km/h^{-1})	$\text{CV}_{2/4}$ (km/h^{-1})	$\text{CV}_{2/6}$ (km/h^{-1})	$\text{CV}_{4/6}$ (km/h^{-1})	$\text{CV}_{2/4/6}$ (km/h^{-1})
1	30,5	29,9	34,0	32,8	31,7	32,8
2	30,5	28,3	36,0	35,0	34,0	34,9
3	34,0	34,8	40,2	37,5	35,1	37,4
4	33,0	32,9	37,1	36,0	35,0	36,0
5	34,0	31,3	40,4	38,0	35,8	37,9
6	36,0	35,9	36,9	38,0	39,1	38,0
7	36,5	36,4	42,1	38,8	36,0	38,7
8	33,0	33,2	35,1	34,9	34,6	34,9
9	36,0	35,0	39,1	39,0	38,9	39,0
10	31,0	31,9	40,2	34,0	29,5	33,8
11	27,5	28,8	36,4	31,0	27,1	30,8
12	33,5	33,4	36,9	34,0	31,6	34,0
13	34,5	34,5	37,9	38,0	38,1	38,0
14	34,0	34,4	38,5	36,2	34,1	36,1
15	36,0	36,2	38,7	38,4	38,1	38,4
Mean	33,3	33,1	38,0*	36,1*	34,6	36,1*
± SD	2,5	2,6	2,2	2,4	3,5	2,5

* $P < 0,001$ in relation to MLVp and MLVv.

Relative intensities concerning the CV identified by different methods expressed in % of the MLVv and MLVp, are presented in table 3. The blood lactate concentrations [Lac] corresponding to the MLVv and MLVp are also represented in table 3.

TABLE 3
Relative indices (%) in which the CV was identified and lactate concentration corresponding to MLVv and MLVp

	$\text{CV}_{2/4}$	$\text{CV}_{2/6}$	$\text{CV}_{4/6}$	$\text{CV}_{2/4/6}$	[Lac] (mM)
MLVv	114,1	108,4	103,9	108,4	3,5
MLVp	114,8	109,1	104,5	109,1	3,1

The Pearson correlations between the minimum lactate velocities (MLVp and MLVv) and the variables $\text{CV}_{2/4}$, $\text{CV}_{2/6}$, $\text{CV}_{4/6}$, $\text{CV}_{2/4/6}$ are presented in table 4.

TABLE 4
Pearson bi-varied correlation between CV and MLV values

	MLVv	$\text{CV}_{2/6}$	$\text{CV}_{2/4}$	$\text{CV}_{4/6}$	$\text{CV}_{2/4/6}$
MLVv	–	0,52*	0,92**	0,87**	0,93**
MLVp	0,91**	0,51	0,77**	0,70**	0,78**

* $P < 0,05$ ** $P < 0,01$.

The application of the technique proposed by Bland-Altman showed high level of agreement between MLV and CV determined by different methods (figure 3 A-E), with the mean of the differences (and 95% of the reliability interval) of 2,8 (0,8 to 4,8); 4,6 (–0,2 to 9,4) and 2,7 (0,7 to 4,7) km^*h^{-1} respectively between MLV and $\text{CV}_{2/6}$, MLVv and $\text{CV}_{2/4}$, and MLVv and $\text{CV}_{2/4/6}$. However, the best agreement occurred between MLVv and MLVp –0,2 (–2,4 to 2) km^*h^{-1} , as well as between MLVp and $\text{CV}_{4/6}$ 1,2 (–2,4 to 4,8) km^*h^{-1} .

DISCUSSION

The present study investigated the effects of different combinations of predictive series in the identification of the CV on cycling as well as analyzed the CV validity on estimating the equilibrium point between blood lactate production and removal (identified by the ML test). The main results of the present study were that the majority of the CV indices identified with different combinations of predictive series overestimated the MLV identified both visually and by application of polynomial function. Nevertheless, it was observed that the combination of longer predictive series (4 and 6 km) may produce CV values that do not differ from the MLV (table 2), with high correlation and agreement between these variables when Pearson correlation and Bland-Altman technique were applied (table 4 and figure 3 A-E).

Moreover, the present study showed that the minimum lactate velocities identified by visual inspection and by polynomial function were not statistically different (table 2), and the blood lactate concentrations corresponding to the MLVv and MLVp were respectively of $3,5 \pm 2,3$ and $3,1 \pm 2,1$ (table 3).

Polynomial function is a new method used for the MLCV identification from a response adjustment of the blood lactate during the test. The polynomial function of second order originates an equation which may be derived to mathematically identify the equilibrium point between blood lactate production and removal. Although differences between the MLVv and MLVp were not observed, the utilization of the MLVp should be stimulated since this new methodology avoids misinterpretation which may occur when only visual inspection is used. The Bland-Altman technique showed that the mean of the residual scores between MLVv and MLVp was close to zero (figure 3A) and that the MLV values either visually determined or by polynomial adjustment were within the agreement limits, suggesting that the MLVp is an interesting option. Besides that, further studies have been conducted in our laboratories in which a considerable decrease in the incremental bouts during the test for determination of the MLV has been possible through the application of polynomial function.

Although several studies have demonstrated that the MLV represents the intensity of $\text{MLSP}^{(2,4,7,9)}$, the determination of the MLV and the MLSP involves invasive procedures as well as costly equipment. The utilization of the CV in order to estimate the MLV and consequently the MLSP would largely facilitate the procedure. Nonetheless, in the present study the CV overestimated the MLV between 3 to 15% (table 3). Such difference found between the

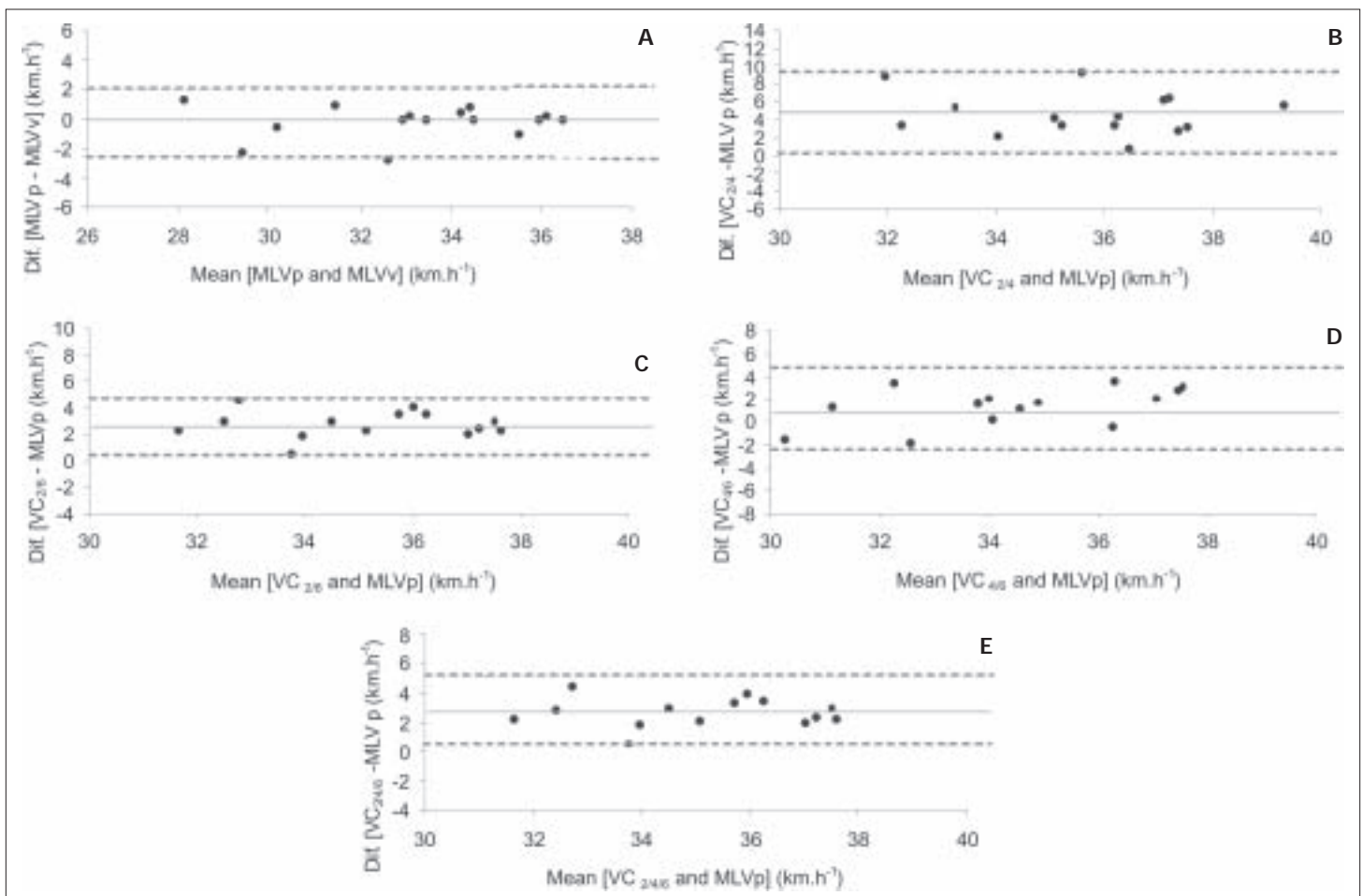


Figure 3 – Result of the agreement analysis by Bland-Altman. The continuous lines show the mean of differences and the traced lines show 95% of the reliability limit between the two variables.

CV and MLV indices may be explained by the influence of the exercise time of the predictive series which originated the CV indices. The CV identification is dependent on the duration of the predictive series, being the CV indices inversely proportional to their duration, which was confirmed in the present study. The CV identified from the combination of the 4 and 6 km series produced indices which were close to each other and did not statistically differ from the MLV, suggesting that longer distances produce critical velocities which would theoretically represent the equilibrium point between blood lactate production and removal. Moreover, the Bland-Altman technique showed that the mean of the residual scores between MLVv and $CV_{4/6}$ was close to zero suggesting that the agreement level between MLVv and $CV_{4/6}$ (longer series) is higher than between MLVv and $CV_{2/4/6}$, $CV_{2/4}$ and $CV_{4/6}$ (figure 3, B-E), whose combinations of predictive series include the 2 km bout (shortest duration).

Bishop *et al.*⁽¹⁶⁾ verified that the combination of loads that allow exhaustion time between 68 and 193 seconds determines higher indices of critical power (201 W) if compared with the loads that allow exhaustion time between 193 and 485 seconds (164 W). Jenkins *et al.*⁽²⁰⁾ verified that the critical power presented different values when the 3 lowest (268 W) and the 3 highest (321 W) loads were selected, the latter resulting in higher values of critical power.

According to Poole⁽¹⁸⁾, predictive bouts that are able to be completed between 1 and 10 minutes should be chosen in order to determine the critical power/critical velocity. In the present study these recommendations were followed; however, only when the 4 and 6 km bouts were used (which had duration between 6 and 10 minutes) it was possible to identify CV indices which were similar to the MLV. Despite not being statistically different from the

MLV as well as the Bland and Altman technique has confirmed the acceptable level of agreement between the variables, the $CV_{4/6}$ corresponded approximately to 104% of the MLV. It would be necessary to perform rectangular tests in intensities below, above and at the CV, analyzing the blood lactate response in these intensities in order to really assert that the CV identifies an exercise intensity similar to the MLSP, which was not done in the present study. Therefore, further studies should be conducted in order to affirm whether the MLSP and CV intensities are really similar (and not different from each other) when predictive series with performance times higher than 6 minutes are applied, as in the present study.

It would be interesting to standardize a protocol of CV determination which could estimate the MLSP. The results of the Bland and Altman technique application showed agreement level acceptable between MLVv and the remaining studied parameters (figure 3). Nevertheless, the $CV_{4/6}$ was the only predictive bout which did not differ in relation to the minimum lactate velocities (table 2) besides presenting the best agreement (figure 3A-E). Thus, the utilization of the CV by coaches and athletes should be cautiously conducted. Despite being a non-invasive method of easy application, low cost and suitability for evaluation of a large number of individuals, the selection of the predictive series should be careful in order to determine values of CV which are close to the intensity corresponding to the equilibrium point between lac production and removal, or MLSp.

CONCLUSION

We concluded that despite being 1 km/h above the MLV, the CV identified from the predictive bouts of longest duration (4 and 6km approximately 6 and 10 min) does not statistically differ from the

MLV. Nevertheless, it is necessary to investigate whether the CV represents a balance between lac production and removal during long duration exercises.

All the authors declared there is not any potential conflict of interests regarding this article.

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