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ESTIMATION OF THE MAXIMAL LACTATE STEADY STATE IN JUNIOR SOCCER PLAYERS

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ABSTRACT

This study aimed to predict the velocity corresponding to the maximal lactate steady state ($MLSS_V$) from non-invasive variables obtained during an incremental maximal running test (University of Montreal Track Test, UMTT); and to determine whether a single constant velocity test (CVT), performed several days after the UMTT, could estimate the $MLSS_V$. Within 3 wk, twenty male junior soccer players performed: 1) a UMTT, and 2) several 20 min CVT to determine $MLSS_V$ to a precision of 0.35 $km \cdot h^{-1}$. Maximal aerobic velocity (MAV) and velocity at 80% of maximum heart rate ($V_{80\%HRmax}$) were strong predictors of $MLSS_V$. A regression equation was obtained: $MLSS_V = (1.106 \cdot MAV) - (0.309 \cdot V_{80\%HRmax}) - 3.024$; $R^2 = 0.60$. Running velocity during CVT (V_{CVT}) and blood lactate at 10 (La_{10}) and 20 (La_{20}) minutes further improved the $MLSS_V$ prediction: $MLSS_V = V_{CVT} + 0.26 – (0.812 \cdot \Delta La_{20-10})$; $R^2 = 0.66$. $MLSS_V$ can be estimated from MAV and $V_{80\%HRmax}$ during a single incremental maximal running test among a homogeneous group of soccer players. This estimation can be improved by performing an additional CVT. In terms of accuracy, simplicity and cost-effectiveness, the reported regression equations can be used for the assessment and training prescription of endurance in team sport players.

Key Words: physical fitness, endurance training, anaerobic threshold, lactate threshold, team sports

INTRODUCTION

The exercise intensity corresponding to the maximal lactate steady state (MLSS), defined as the highest constant velocity or power output that can be maintained over time without a continual blood lactate accumulation, is considered the gold standard for the assessment of endurance capacity [6, 19, 20, 27, 28]. Determination of the MLSS is, however, a time consuming procedure since it requires to perform several (3-5) constant workload tests, on separate days within a 1-2 week period [17]. To avoid such an extensive procedure, simpler methods have been proposed which try to determine the MLSS from the response to a single incremental test, involving the use of either blood lactate [6, 19, 23, 31] or respiratory exchange measurements [10, 19]. Several studies have shown that the workload corresponding to the maximal oxygen uptake (VO_{2max}) or the maximal workload attained at the end of an incremental test to exhaustion (a simple and bloodless procedure) predicts the MLSS with a wide range of correlations (r = 0.67-0.95) [2, 3, 5-7, 10, 19, 23, 31]. These reported correlations obtained from a single, non-invasive, incremental maximal exercise test are equal to or superior to those found with other invasive, more expensive, or difficult-to-measure lactate or ventilatory-related methods, such as the onset of blood lactate accumulation [6, 19, 31], individual anaerobic threshold [6], Dmax [31], lactate minimum test [19], lactate turn-point [19], lactate threshold [23], or the first and second ventilatory thresholds [10, 19].

One of the reasons explaining the wide range of correlations reported in the literature is that participants in the aforementioned studies were not very homogeneous in terms of performance. Thus, the coefficient of variation (CV) for the MLSS intensity in these studies varied between 7% and 17%. This observation may skew the correlation coefficient (r) because, if the range of values is wide, r tends to be high and vice versa [24]. We were interested in determining whether the relationship between MLSS and some variables measured during an incremental running test to exhaustion are consistent when a very homogeneous sample of subjects is used. Therefore, the primary purpose of this cross-sectional descriptive study was to determine the relationship between the running velocity at MLSS ($MLSS_V$) and some simple and non-invasive variables measured during an incremental, multistage, maximal running test, such as maximal aerobic velocity (MAV) and heart rate (HR), in a highly homogeneous group of soccer players (CV < 5% for $MLSS_V$). We aimed to obtain a multiple regression equation developed from running velocity and HR data, together with other simple anthropometric variables, that could significantly improve the prediction of the MLSS. In addition, to the best of our knowledge, no previous studies have investigated if MLSS can be predicted from a single constant workload test performed after an incremental test to exhaustion. Accordingly, a secondary purpose of the present study was to determine the extent to which a single constant velocity running test, performed several days after an incremental maximal test, could estimate the $MLSS_V$.

MATERIALS & METHODS

Subjects

Twenty junior soccer players (age 17.3 ± 0.9 years, height 177.3 ± 5.5 cm, body mass 72.4 ± 4.5 kg, body fat 7.2 ± 2.0%) took part in this study. Players were members of a club in the Spanish First Division of professional soccer. All had a regular training and competitive background in soccer. The subjects and their coaches were informed about the experimental procedures and the possible risks and benefits of their participation. Written informed consent was obtained from players or their parents (for minors). The study met the ethical standards of this journal [16] and was conducted in agreement with the guidelines of the Institutional Review Committee of the *Sports and Youth Institute of Navarre*. Subjects were not taking any medications or other substances that would have an impact on the results of the study. Testing sessions were carried out in the spring, right after the end of the competitive season.

Study Design

A predictive study was conducted to determine the $MLSS_V$ from an incremental maximal running test. Testing was conducted over 4-5 sessions, separated by at least two resting days. During the first session, each subject was subjected to the following tests: 1) anthropometric measurements, 2) countermovement vertical jumps (CMJ), 3) 15 m maximal running sprints, and 4) an incremental maximal running field test. In the remaining sessions, several 20 min constant velocity tests were performed to determine the $MLSS_V$. Jumping and sprinting abilities were assessed in order to determine whether they could contribute to the prediction of the MLSS in the multiple regression analyses.

Anthropometric Measurements

Height and body mass were determined using a medical stadiometer and scale (Año Sayol, Barcelona, Spain) to a precision of 0.001 m and 0.01 kg, respectively. Percent body fat was estimated using a skinfold calliper (Holtain Ltd., Dyfed, Wales) and the Jackson & Pollock formula [18].

Vertical Jumps

Following a standardized 15 min warm-up that incorporated jogging and several running accelerations and jumps, subjects performed 3 maximal CMJ, interspersed by 10 s rests, on a contact mat (Newtest OY, Oulu, Finland). CMJ height was registered from flight time [9] and the resulting average kept for analysis. From the standing position, a rapid eccentric action down to ~90° knee flexion, immediately followed by an explosive concentric action, was required. Subjects kept their hands at their waist during each jump and were instructed to land on the contact mat in a similar position to that of take-off.

Running Sprints

Three maximal 15 m running sprints, separated by a 90 s rest, were performed in an indoor court. Photocell timing gates (Newtest OY, Oulu, Finland) measuring time to a precision of 0.001 s were placed 0.4 m above the ground at 0, 5 and 15 m. Subjects started the sprint when ready from a standing start, with the leadoff foot placed 0.5 m behind the first timing gate. An all-out maximal effort was required, and the best of the three trials was kept for analysis.

Incremental Maximal Running Test

The original protocol of the *University of Montreal Track Test* (UMTT) [21], an incremental and maximal multistage running field test, was used. This test provides an indirect estimation of VO_{2max}, based on the energy cost of walking and running. The UMTT was conducted around an outdoor artificial grass soccer court (100 x 50 m) where red pylons were placed at every 50 m. To ensure constant velocity for each stage, subjects were instructed to match their running pace to the audio beeps emitted from a pre-programmed computer. Subjects were encouraged to give a maximal effort. Maximal aerobic velocity (MAV) was estimated according to the formula:

$$\text{MAV} = \text{Velocity of last stage } (\text{km}\cdot\text{h}^{-1}) + [\text{t (s)} / 120 \cdot \text{stage increment } (\text{km}\cdot\text{h}^{-1})]$$

where ‘t’ is the time sustained during the incomplete stage.

VO_{2max} was estimated multiplying MAV by 3.5 [21]. HR was registered at 5 s intervals using a heart rate monitor (Sportester, Polar, Kempele, Finland) and maximal HR (HR_{max}) considered as the highest recorded value. Capillary whole blood samples were taken from the earlobe at the 3rd minute of the post-exercise recovery to measure peak lactate. HR was plotted against running velocity, and a second-degree polynomial regression fit was calculated. The resulting formula was used to determine the running velocities corresponding to 70%, 80% and 90% of HR_{max}.

Constant Velocity Tests for the determination of MLSS

Subjects completed three to four 20 min constant velocity tests (CVT) in the same soccer court used for the UMTT. Total duration for each CVT was 22.5 min. Rest periods of 30 s after the 5th minute, and 2 min after the 10th minute of exercise, were introduced. Blood samples were taken at rest and at the 5th, 10th and 20th minute of exercise. Running velocity of the first CVT corresponded to ~75% of the MAV reached during the UMTT. If during this first CVT a steady state or a decrease in blood lactate concentration was found, velocity was increased by 0.25 to 0.50 $\text{km}\cdot\text{h}^{-1}$, and subsequent CVT performed on separate days until no steady state of blood lactate concentration ($[\text{La}^-]$) was observed. Conversely, if the first CVT resulted in a clearly identifiable increase in $[\text{La}^-]$, subsequent CVT were performed at 0.25 to 0.50 $\text{km}\cdot\text{h}^{-1}$ lower velocities until a steady state $[\text{La}^-]$ was reached. HR was averaged every minute of exercise. Running pace was set using a pre-programmed audio protocol. An increase $\leq 0.5\ \text{mmol}\cdot\text{L}^{-1}$ in $[\text{La}^-]$ during the final 10 min of exercise ($0.05\ \text{mmol}\cdot\text{L}^{-1}\cdot\text{min}^{-1}$) was defined as the criterion for lactate to be considered at a steady state. The $MLSS_V$ was defined as the highest running velocity meeting this stability criterion. The average value of $[\text{La}^-]$ measured at 10 and 20 minutes of exercise was considered the mean lactate value at the MLSS. $MLSS_V$ was determined to an average precision of 0.35 $\text{km}\cdot\text{h}^{-1}$.

Blood Sampling

A 5 µL sample of whole blood was aspirated from a hyperemized earlobe into an enzyme-coated electrode test strip. $[\text{La}^-]$ was determined via amperometric measurement using a portable analyzer (Lactate Pro LT-1710; Arkray, Japan) calibrated before every test. Manufacturers report a CV of 3.2% and 2.6% for lactate standards of 2 and 11 $\text{mmol}\cdot\text{L}^{-1}$, respectively.

Statistical Analyses

Standard statistics were used for the calculation of means and standard deviations (SD). Normal data distribution was confirmed with the *Shapiro-Wilk* test. A repeated measures ANOVA with *Bonferroni* post-hoc tests was used to compare $[\text{La}^-]$ and HR at different time points during the CVT. *Pearson* product-moment correlation coefficients

(r) were used to determine associations between variables. The adjusted R^2 was used to assess the proportion of variance explained by the independent variables. Validity of the $MLSS_V$ predictions was investigated by the standard error of the estimate (SEE) and by the 95% limits of agreement method (mean difference ±1.96 SD) originally reported by Bland and Altman [8]. A regression analysis between mean $MLSS_V$ and $MLSS_V$ difference was applied to explore whether the degree of systematic error is uniform over the range of $MLSS_V$ studied [1]. A stepwise regression analysis to predict $MLSS_V$ (dependent variable) from variables derived from the UMTT (independent variables) was performed. [La^-] at minutes 5, 10 and 20 of each CVT, as well as the difference of [La^-] and HR between the 20th and 10th minute of exercise during the CVT, were used as independent variables to predict $MLSS_V$ from the CVT. The difference between the running velocity of the CVT (V_{CVT}) and $MLSS_V$ was employed as a dependent variable. Statistical significance was set at $P \leq 0.05$. Statistical analyses were performed using SPSS 17.0 (SPSS Inc., Chicago, USA).

RESULTS

Vertical Jumps and Running Sprints

CMJ height was 43.9 ± 3.9 cm and times for 5 m and 15 m sprints were 1.04 ± 0.05 s and 2.36 ± 0.06 s, respectively.

UMTT and CVT

Results are presented in **Table 1**. **Figure 1A** shows the [La^-] at the $MLSS_V$ and at a 0.35 $km \cdot h^{-1}$ faster velocity than $MLSS_V$ ($MLSS_{V+0.35}$). At $MLSS_{V+0.35}$, [La^-] during the last 10 min of the corresponding CVT increased more than 0.5 $mmol \cdot L^{-1}$ (1.0 ± 0.6 $mmol \cdot L^{-1}$). [La^-] at the end of the CVT was higher at $MLSS_{V+0.35}$ than at $MLSS_V$ ($P < 0.05$). HR at $MLSS_V$ and at $MLSS_{V+0.35}$ is shown in **Fig. 1B**. When expressed as a percentage of the HR_{max} attained during the UMTT, HR at the $MLSS_V$ corresponded to 83 ± 4 % HR_{max} after 5 min of exercise, increased to 86 ± 3 % HR_{max} at 10 min, and reached 89 ± 4 % HR_{max} at the end (20 min) of the CVT (**Fig. 2**).

Prediction of the MLSS from the UMTT

$MLSS_V$ correlated significantly with MAV (**Fig. 3A**), explaining 52% of the variance, and yielding the equation:

$$MLSS_V = -0.75 + (0.784 \times MAV) \quad \text{[Equation 1]}$$

$MLSS_V$ also correlated with $MLSS_V$ expressed as a percentage of MAV (**Fig. 3B**):

$$MLSS(\%MAV) = 37.616 + 2.966 \times MLSS_V \quad \text{[Equation 2]}$$

Stepwise linear regressions identified the following key determinants of $MLSS_V$:

MAV and the running velocity corresponding to 80% HR_{max} ($V_{80\%HRmax}$), accounted for 60% of the variance ($P = 0.04$; SEE = 0.39 $km \cdot h^{-1}$):

$$MLSS_V = -3.024 + (1.106 \times MAV) - (0.309 \times V_{80\%HR_{max}}) \quad \text{[Equation 3]}$$

Figure 4 shows the difference between the predicted and the actual $MLSS_V$ against their mean for equations 1 (**Fig. 4A**) and 3 (**Fig. 4B**). These plots indicate a good agreement between the predicted and actual $MLSS_V$ based on the low bias and relatively narrow limits of agreement [Bias (±95 % confidence interval)] for equation 1 [0.002 (0.82) $km \cdot h^{-1}$] and for equation 3 [0.01 (0.72) $km \cdot h^{-1}$]. Gradients of the regression lines in **Fig. 4A** and **Fig. 4B** are not different from zero (P= 0.07 and 0.13, respectively).

Prediction of the MLSS from a single CVT

Stepwise linear regression identified the following key determinants for the prediction of the $MLSS_V$ from the running velocity of the first CVT (V_{CVT}):

$\Delta[La^-]_{20\text{-}10}$, accounted for 66% of the variance ($P < 0.001$; SEE = 0.26 $km \cdot h^{-1}$):

$$MLSS_V = V_{CVT} + 0.26 - (0.812 \times \Delta[La^-]_{20\text{-}10}) \qquad \text{[Equation 4]}$$

where $\Delta[La^-]_{20\text{-}10}$ is the difference in $[La^-]$ measured between the 20th and 10th minute of the CVT.

Bland-Altman plot for equation 4 (**Fig. 5**) showed good agreement between the predicted and actual $MLSS_V$ based on the low bias and relatively narrow limits of agreement [Bias (±95 % confidence interval): -0.014 (0.462) $km \cdot h^{-1}$]. Gradient of the regression line in **Fig. 5** is not different from zero (P = 0.721).

DISCUSSION

One of the main findings of this study was that the MAV attained during a UMTT was the single most powerful predictor of the $MLSS_V$ in a homogeneous group of young soccer players, accounting for 52% of the variance. This finding agrees with previous research showing that maximal workload or the workload/velocity at VO_{2max} obtained during an incremental maximal test in cycling [2, 3, 5, 7, 10, 31], rowing [3, 5, 6], running [19, 23] and speed-skating [5] are significant determinants of the MLSS. The accounted variance for MAV is, however, among the lowest values reported (44-90%). Differences such as homogeneity of the sample, test protocol characteristics and specificity, precision and stability criterion in the MLSS determination, as well as the exact variables derived from the incremental maximal test chosen for each study might explain these differences. For instance, soccer players in the present study were very homogeneous in terms of $MLSS_V$ (CV 4.9%) and the determination of the $MLSS_V$ was fairly accurate (±0.35 $km \cdot h^{-1}$; ±2.9% of mean $MLSS_V$). In contrast, most of the above-mentioned studies used more heterogeneous samples (CV 7-17%) and lower precision (3-10%) in their MLSS determinations, which are factors that can bias the comparison of the explained variance between studies. The present findings confirm that the running velocity attained during an incremental maximal test is a good predictor of the $MLSS_V$ in a homogeneous group of soccer players. Previous studies have shown that the maximal workload attained during an incremental test to exhaustion is as good or better predictor of the MLSS than other invasive, more expensive or difficult-to-measure lactate or ventilatory-related methods [6, 10, 19, 23, 31]. Therefore, in terms of accuracy, simplicity and cost-effectiveness, the maximal workload or velocity attained during an incremental maximal test can be considered the best single predictor of the MLSS.

A statistically significant contribution to the prediction of $MLSS_V$ was made when adding $V_{80\%HRmax}$ to the prediction model. Thus, MAV and $V_{80\%HRmax}$ accounted for 60% of the explained variance in $MLSS_V$. No other anthropometric or physical fitness variable was identified as a primary contributing factor to the prediction of $MLSS_V$. The prediction of $MLSS_V$ from MAV and $V_{80\%HRmax}$ resulted in a SEE of 0.39 $km \cdot h^{-1}$, which is only 3.2% of the mean $MLSS_V$. This compares favorably with other studies predicting $MLSS_V$ from the velocity corresponding to a 4 $mmol \cdot L^{-1}$ $[La^-]$ and velocity at the maximal constant HR maintainable for 30 min, where SEE values of 0.67 $km \cdot h^{-1}$ (5.5% of the mean $MLSS_V$) have been reported [33]. The *Bland-Altman* limits of agreement (-0.7 to 0.7 $km \cdot h^{-1}$ or ±5.9% of mean $MLSS_V$) of equation 3 are narrower or similar to those of other studies predicting MLSS from a 1600 m time trial (-0.8 to 0.7 $km \cdot h^{-1}$ or ±6.0% of the mean) [25], lactate minimum test (-0.9 to 0.7 $km \cdot h^{-1}$ or ±6.6% of the mean) [19, 28], power output at a fixed blood lactate concentration (±10.3% of the mean) [14], power output from the minimum equivalent of the blood lactate-power relationship plus 1.5 $mmol \cdot L^{-1}$ (±9.5% of the mean) [14], velocity associated with a respiratory exchange ratio equal to 1.00 (-1.2 to 1.6 $km \cdot h^{-1}$ or ±9.0% of the mean) [22] or ventilatory threshold (2.5 to -1.3 $km \cdot h^{-1}$ or ±12.0% of the mean) [22], in cyclists [14], runners [19, 22] and physically active men [27, 28]. This evidence adds support to the finding that MAV, together with $V_{80\%HRmax}$, provide a likely better estimation of the MLSS intensity than other lactate or ventilatory-related thresholds. $V_{80\%HRmax}$ is therefore proposed as a novel physiological variable related to the estimation of the MLSS.

During exercise at $MLSS_V$, absolute HR differed significantly between subjects but relative HR was very similar. Thus, at 20 min of running, HR was 89 ± 4% of HR_{max}. This is in agreement with previous research showing that relative HR at 20 min, or between 10 and 30 min of running at the MLSS, ranged from 88% to 94% of HR_{max} [11, 12, 22, 26, 29, 30, 32]. This finding has led some authors to suggest that MLSS can be estimated non-invasively during constant velocity running based solely on a percentage of HR_{max} [26]. However, the individual values varied considerably (84-97% HR_{max}), which indicates that the HR zone corresponding to MLSS should be estimated on an individual basis [15]. An interesting finding of the present study was that when HR values at 20 min of a CVT were lower than 85% of HR_{max}, none of the subjects was exercising above their $MLSS_V$. This indicates that, at least in this sample, when the individual assessment of MLSS is not possible, exercising below 85% HR_{max} may prevent individuals from exceeding their MLSS. This has practical relevance since it has been suggested that training at or below the MLSS intensity may optimize training adaptations [25], and may constitute the most time-efficient tradeoff between the volume and intensity of endurance training [26].

As far as we know, this is the first study to investigate whether the MLSS can be predicted from a single CVT after having performed an incremental maximal test several days before. The present results show that $[La^-]$ values observed at 10 and 20 min of a single CVT can be considered good predictors of the $MLSS_V$, accounting for 66% of the variance, in a homogeneous group of soccer players. Prediction of $MLSS_V$ using equation 4 resulted in a SEE of 0.26 $km \cdot h^{-1}$, which is only 2.1% of the mean $MLSS_V$, whereas the *Bland-Altman* limits of agreement clearly demonstrated a good precision (0.46 $km \cdot h^{-1}$ or ±3.8% of the mean). These values compare favorably with the prediction obtained for $MLSS_V$ from the MAS and $V_{80\%HRmax}$ variables (equation 3) and, as already mentioned, with those of other studies estimating MLSS from blood lactate or ventilatory-related measurements obtained during an incremental maximal test [6, 10, 19, 23, 31]. The better precision in the $MLSS_V$ prediction from the CVT compared to that of other studies could result in a better estimation of MLSS for individual subjects. It is therefore suggested that, when direct blood lactate assessment is available, and only two testing sessions are allowed (one incremental maximal test and one CVT), $[La^-]$ at the 10th and 20th min of a single CVT (at a suggested velocity of ~75% MAV) could be considered the best predictors of $MLSS_V$.

The present investigation is limited in some aspects. First, the extent to which testing in other types of indoor or outdoor surfaces might alter the relationship between the variables obtained from an incremental maximal test and a constant velocity running test, together with its impact on $MLSS_V$ determination, is uncertain. Second, different test protocols and stability criteria for the determination of MLSS have been used in the literature. In most studies, MLSS was determined during a CVT lasting 30 min, and a $[La^-]$ increase $\leq 1.0\ mmol \cdot L^{-1}$ ($0.05\ mmol \cdot L^{-1} \cdot min^{-1}$) between the 10th and the 30th min of exercise set as the stability criteria [5, 7]. In the present study, however, because of time limitations and in order to maximize compliance, MLSS was determined by analyzing the change in $[La^-]$ between the 10th and the 20th min of CVT, and MLSS was also defined as an increase $\leq 0.05\ mmol \cdot L^{-1} \cdot min^{-1}$ in the ten last minutes of exercise. CVT lasting only 20 min can be adequate for MLSS determination [4] since no difference in the MLSS intensity was found when 20 min or 30 min constant intensity exercise tests were used [7]. Finally, the applicability of the results is limited to homogeneous groups of subjects with $MLSS_V$ values ranging from 11.0 to 13.5 $km \cdot h^{-1}$. Caution should be taken when generalizing these results to other populations, especially to those with significantly different $MLSS_V$ values. Despite these limitations, the results of the present study provide important and novel information about the prediction of the MLSS, which is considered the gold standard for the assessment of endurance capacity.

In conclusion, the results of this study indicate that when direct blood lactate assessment is undesirable or unfeasible, and only one testing session can be carried out, MAV and $V_{80\%HRmax}$, attained during an incremental test to exhaustion, are the two most powerful predictors of the $MLSS_V$, accounting for 60% of the variance. If direct blood lactate measurement is available and only two testing sessions can be arranged: one incremental maximal test and, several days later, one CVT, the prediction of $MLSS_V$ is improved when taking into account the $[La^-]$ at the 10th and 20th min of the CVT, since they account for 66% of the variance and show a good limit of agreement ($\pm 0.46\ km \cdot h^{-}$). A practical guideline consisting in exercising below 85% HR_{max} can be established to prevent individuals from exceeding their MLSS. The prediction equations reported in this study can be used for the physiological assessment and training prescription of endurance capacity in soccer players, and, very likely, by other team sport athletes showing similar lactate/velocity characteristics, such as futsal, basketball or handball [13]. Being able to estimate the MLSS with acceptable precision from one or two, relatively simple, field tests, is a reasonable alternative to reduce the time and financial costs, as well as the psychological burden on the athletes, derived from the classical determination of MLSS.

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FIGURE CAPTIONS

Figure 1 Blood lactate (A), and heart rate (B) responses during the CVT at the running velocity corresponding to the maximal lactate steady state ($MLSS_V$) and at a 0.35 km·h^{-1} faster velocity ($MLSS_{V+0.35}$).

* Significantly different than $MLSS_V$ ($P < 0.05$) at the corresponding time point.

Figure 2 Relative heart rate at minutes 5, 10, 15 and 20 of the CVT performed at the $MLSS_V$.

Statistically significant differences between time points: ** $P < 0.01$; *** $P < 0.001$.

Figure 3 Relationships and correlations between the velocity corresponding to the maximal lactate steady state ($MLSS_V$) and: (A) Maximal Aerobic Velocity (MAV) attained during the UMTT; and (B) $MLSS_V$ expressed relative to MAV.

Figure 4 *Bland-Altman* plots comparing the difference between the predicted and actual MLSS running velocity ($MLSS_V$ difference) and the mean of those velocities for the obtained regression equations: (A) equation 1; and (B) equation 3. See text for details. The dotted horizontal lines represent the bias between the two measures. The dashed horizontal lines represent the 95% limits of agreement between the two variables. The solid lines correspond to the regression lines.

Figure 5 *Bland-Altman* plot comparing the difference between the predicted and actual MLSS running velocity ($MLSS_V$ difference) and the mean of those velocities for regression equation 4. See text for details. The dotted horizontal lines represent the bias between the two measures. The dashed horizontal lines represent the 95% limits of agreement between the two variables. The solid lines correspond to the regression lines.

Table 1 Variables obtained from the UMTT and CVT tests (N = 20)

Test	**Variable**	**Mean ± SD**
UMTT	MAV ($km \cdot h^{-1}$)	16.5 ± 0.6
	HR_{max} ($beats \cdot min^{-1}$)	199 ± 9
	Peak [La^-] ($mmol \cdot L^{-1}$)	8.0 ± 2.1
	Estimated VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	57.8 ± 2.0
	Running velocity at 70% HR_{max} ($km \cdot h^{-1}$)	8.1 ± 0.4
	Running velocity at 80% HR_{max} ($km \cdot h^{-1}$)	9.8 ± 0.9
	Running velocity at 90% HR_{max} ($km \cdot h^{-1}$)	12.6 ± 1.0
CVT	$MLSS_V$ ($km \cdot h^{-1}$)	12.2 ± 0.6
	$MLSS_V$ (% MAV)	73.8 ± 2.5
	[La^-] at $MLSS_V$ ($mmol \cdot L^{-1}$)	3.2 ± 0.7
	HR at $MLSS_V$ during UMTT ($beats \cdot min^{-1}$)	177 ± 9
	HR at $MLSS_V$ during UMTT (% HR_{max})	88.6 ± 3.0

UMTT: *University of Montreal* track test; MAV: maximal aerobic velocity; HR: heart rate; HR_{max}: maximum heart rate; [La^-]: blood lactate concentration; VO_{2max}: maximal oxygen uptake; CVT: 20 min constant velocity test; $MLSS_V$: running velocity at the maximal lactate steady state.

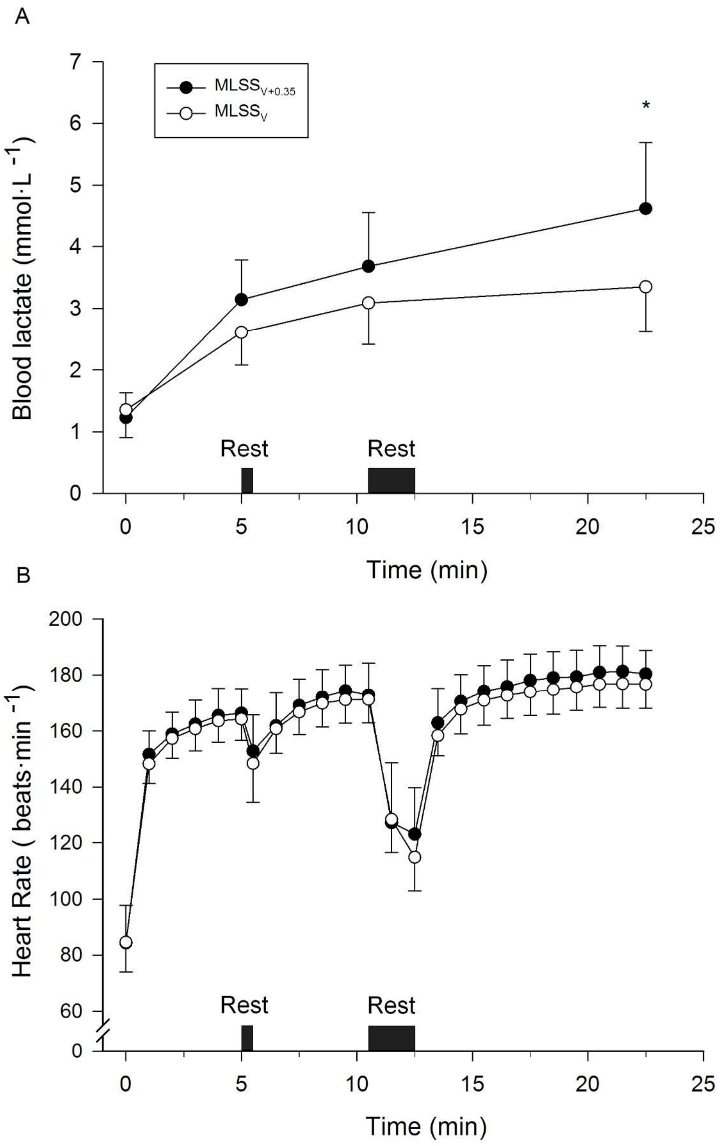

Figure 1 Blood lactate (A), and heart rate (B) responses during the CVT at the running velocity corresponding to the maximal lactate steady state (MLSS$_V$) and at a 0.35 km·h^{-1} faster velocity (MLSS$_{V+0.35}$). * Significantly different than MLSS$_V$ ($P < 0.05$) at the corresponding time point.

169x249mm (300 x 300 DPI)

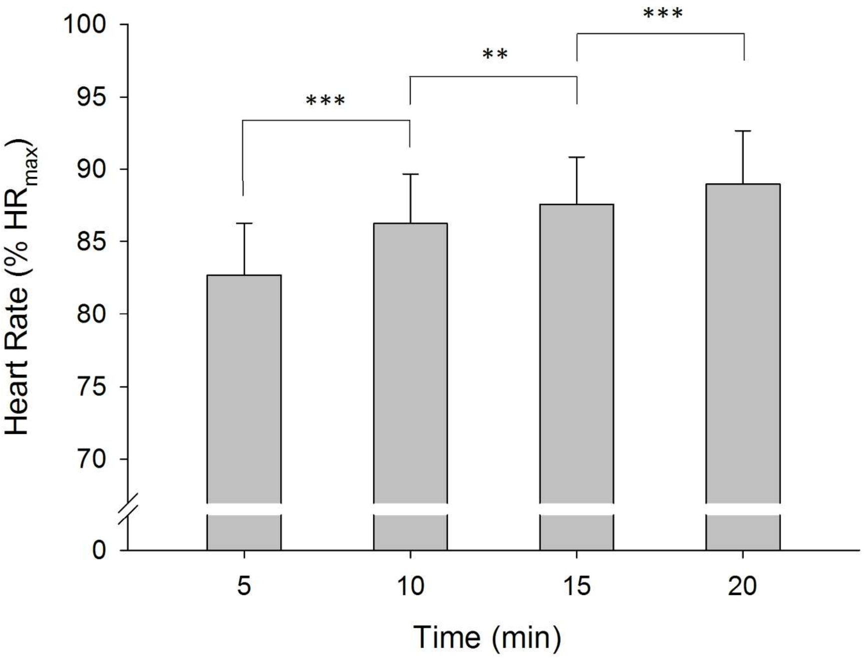

Figure 2 Relative heart rate at minutes 5, 10, 15 and 20 of the CVT performed at the MLSS$_V$. Statistically significant differences between time points: ** $P < 0.01$; *** $P < 0.001$.
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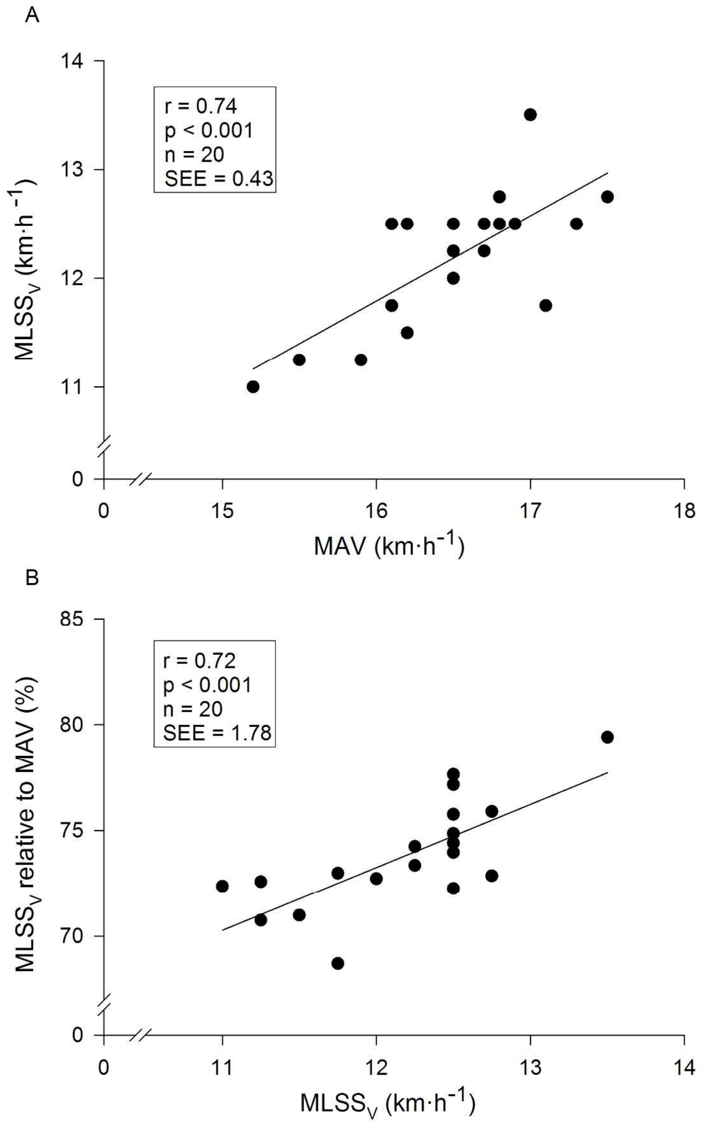

Figure 3 Relationships and correlations between the velocity corresponding to the maximal lactate steady state (MLSS$_V$) and: (A) Maximal Aerobic Velocity (MAV) attained during the UMTT; and (B) MLSS$_V$ expressed relative to MAV.
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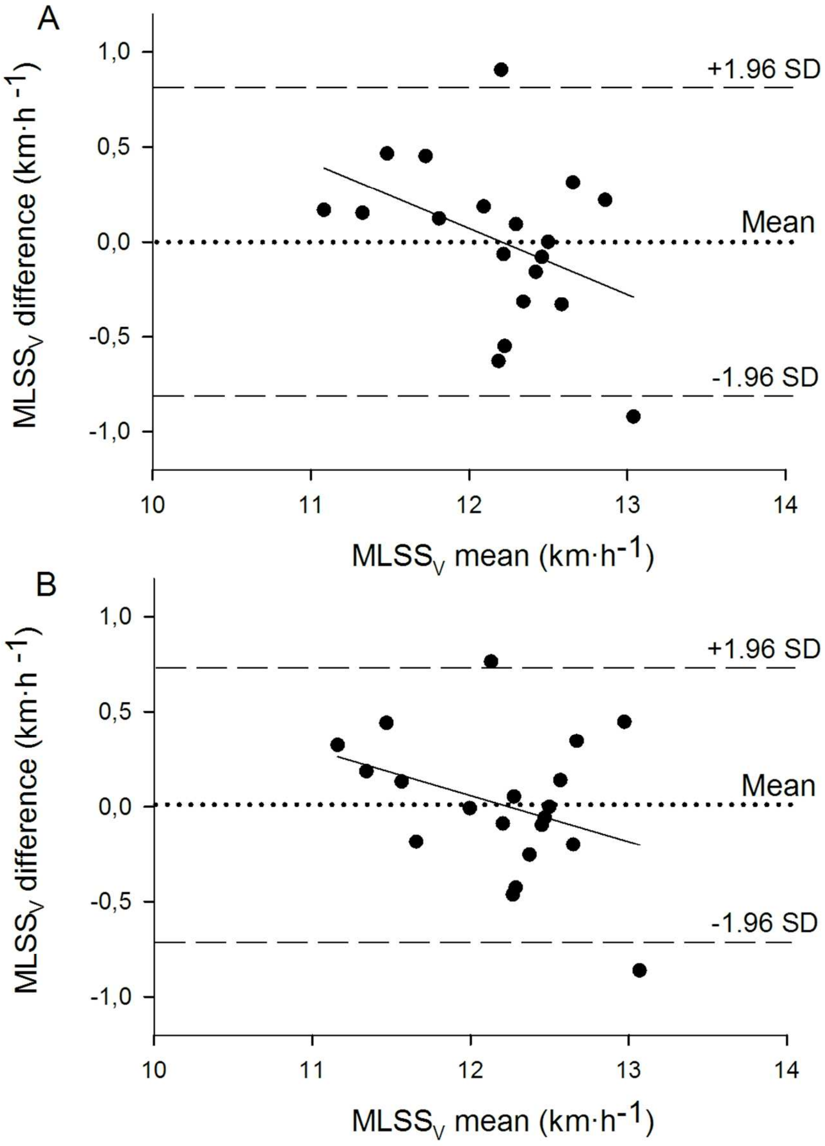

Figure 4 *Bland-Altman* plots comparing the difference between the predicted and actual MLSS running velocity (MLSS$_V$ difference) and the mean of those velocities for the obtained regression equations: (A) equation 1; and (B) equation 3. See text for details. The dotted horizontal lines represent the bias between the two measures. The dashed horizontal lines represent the 95% limits of agreement between the two variables. The solid lines correspond to the regression lines.
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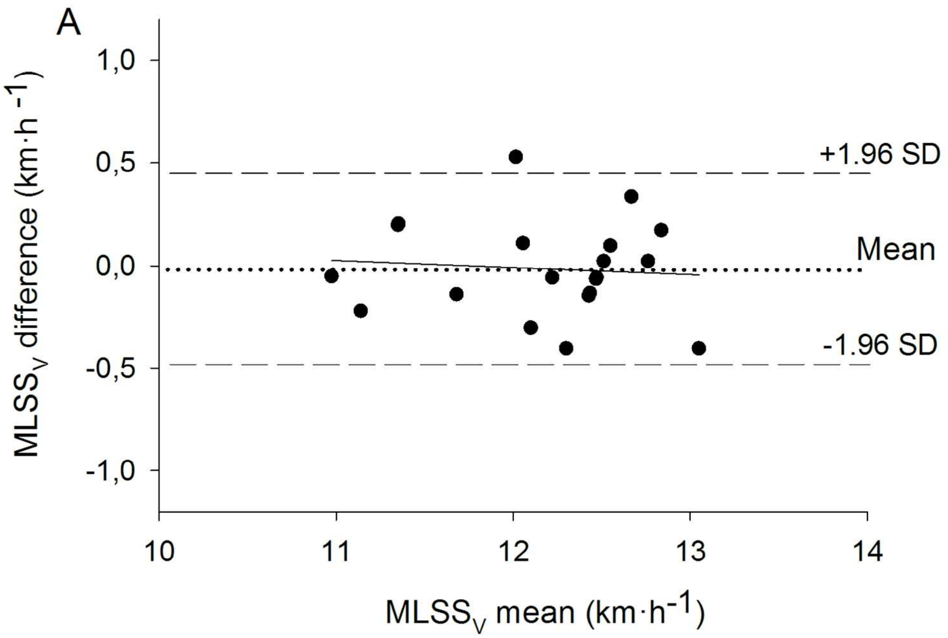

Figure 5 *Bland-Altman* plot comparing the difference between the predicted and actual MLSS running velocity (MLSS$_V$ difference) and the mean of those velocities for regression equation 4. See text for details. The dotted horizontal lines represent the bias between the two measures. The dashed horizontal lines represent the 95% limits of agreement between the two variables. The solid lines correspond to the regression lines.
132x89mm (300 x 300 DPI)