Artigo original

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PREDICTION OF MAXIMAL LACTATE STEADY STATE VELOCITY BASED ON PERFORMANCE IN A 5KM CYCLING TEST

PREDIÇÃO DA MÁXIMA FASE ESTÁVEL DE LACTATO NO CICLISMO A PARTIR DO DESEMPENHO EM TESTE DE 5KM

Abstract

Stationary cycling tests were used to analyze the validity of methods for estimating the Maximal Lactate Steady State (MLSS) and the velocity and heart rate (HR) that are sustainable during a 40-km time trial. Methods: 11 cyclists (23.9±4.1 years; 178±6.8 cm tall; 68.8±5.4 kg) performed the following tests on a cyclosimulator, using their own bicycles: 1) Determination of the mean velocity and HR achieved during a 5-km (5kmVel and HR5km) and a 40-km time trial (40kmVel and HR40km). 2) 2-3 endurance tests to determine MLSSV with blood lactate ([lac]) measurements. The relationship between MLSSV and 5kmVel in data from Harnish et al. (2001) was also used to calculate predicted MLSSV (km·h^{-1}): [MLSSVp = 0.8809 x 5kmVel + 1.6365]. The HR corresponding to MLSSV (MLSSHR) was estimated by taking 88% of HR5km (maximal-HR) (Swensen et al. 1999). Results: The 5kmVel, 40kmVel, MLSSV and MLSSVp were 50.07±2.03, 45.57±1.97, 45.64±2.0 and 45.77±1.77km·h^{-1} respectively. No differences were found between 40kmVel, MLSSV and MLSSVp. Neither did [lac] or HR corresponding to MLSSV/40kmVel exhibit differences (4.5±0.6/4.2±0.3mM and 175.1±3.0/176.8±3.1 bpm). The MLSSV was 90.9±0.5% of 5kmVel and MLSSHR was 93.6±0.5% of HR5km. Conclusion: The equation proposed is valid for estimating both MLSSV and 40kmVel on a stationary cyclosimulator.

Key words: Aerobic evaluation; Stationary cycling; Indirect assessment; Heart rate.

RESUMO

A validade de se estimar a velocidade e a frequência cardíaca (FC) correspondentes ao máximo estado estável de lactato sanguíneo (MEEL), bem como a velocidade e FC que poderiam ser mantidas durante uma prova simulada de 40-km foram estudados em ciclismo estacionário. Métodos: 11 ciclistas (23,9±4,1anos; 178±6,8cm altura; 68,8±5,4kg) realizaram os seguintes testes em ciclo-simulador, utilizando suas próprias bicicletas: 1) Determinação da velocidade média e a FC correspondentes aos testes de 5-km (5kmVel e FC5km) e 40-km (40kmVel e FC40km). 2) 2-3 testes de longa duração com dosagem de lactato sanguíneo [lac] para determinação do MEEL. O MEEL (km·h-1) foi estimado (MEELe) pela relação entre os resultados de MEEL e 5kmVel publicados por Harnish et al. (2001): [VSSMLp = 0,8809 x 5kmVel + 1,6365]. A FC correspondente ao MEEL (FCMEEL) foi estimada considerando 88% da FC5km (FCmáxima) (Swensen et al. 1999). Resultados: A 5kmVel, 40kmVel, MEEL and MEELe foram 50,07±2,03, 45,57±1,97, 45,64±2,0 and 45,77±1,77km·h^{-1} respectivamente. Não foram encontradas diferenças entre 40kmVel, MEEL e MEELe. A [lac] e a FC correspondentes ao MEEL/40kmVel (4,5±0,6/4,2±0,3mM e 175,1±3,0/176,8±3,1bpm) não foram diferentes entre si. O MEEL ocorreu a 90,9±0,5% de 5kmVel e a FCMEEL a 93,6±0,5% de FC5km. Conclusão: A equação proposta se mostrou válida para estimar tanto o MEEL quanto a velocidade em prova de 40km no ciclismo estacionário.

Palavras-chave: Avaliação aeróbia; Ciclismo estacionário; Medida indireta; Freqüência cardíaca.

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INTRODUCTION

The maximal lactate steady state (MLSS) is useful for aerobic evaluation and training prescription[1-5] and has been considered the most reliable parameter for measuring endurance performance.[2,3,5-12] Identification of the velocity at which MLSS is achieved (MLSSV) while running, cycling or swimming usually requires 2 to 5 long-term exercise sessions (e.g. 30 to 50min) with blood lactate ([lac]) being measured periodically. These procedures call for technicians with expertise in dealing with blood collection in addition to laboratory equipment for [lac] measurements which, in turn, makes them less accessible to coaches and athletes[8,13,14].

In recent years some researchers have presented methods for estimating MLSSV of cyclists. Van Handel[15] suggested that the velocity that cyclists can sustain during a 40-km time trial was a good estimate of MLSSV. Swensen et al.[14] proposed that 5km performance could be used to predict cycling MLSSV. They observed that the MLSSV of 10 competitive cyclists corresponded to approximately 90% of the mean velocity reached during a 5-km time trial (5kmVel) and that 88% of maximal heart rate would be useful to identify an exercise intensity at which cyclists would perform at their MLSS.

More recently Harnish et al.[13] confirmed that the MLSSV of competitive cyclists could be accurately estimated from 5-km performance as proposed by Swensen et al.[14] The MLSSV observed by Harnish et al.[13] corresponded to 92.1 ±1.2% of 5kmVel and was not statistically different from, and was highly correlated with the velocity corresponding to 90% of 5kmVel (R=0.85). This group of researchers has presented evidence for the estimation of MLSSV from 5kmVel and 88% of maximal heart rate. However, the validity of methods to predict the MLSSV needs to be investigated. We hypothesized that both MLSSV and the heart rate associated with MLSSV would be accurately predicted in a group of competitive Brazilian cyclists by using the methods proposed previously. Therefore, in addition to analyzing the methods proposed by Swensen et al.[14] and Harnish et al.[13], the aim of this study was to suggest a predictive equation for estimating the velocity corresponding to cycling MLSS and to investigate its validity. Specifically, we analyzed the validity of the linear regression equation [MLSSVp (km·h^{-1}) = 0.8809 x 5kmVel + 1.6365] derived from the relationship between 5-km performance and MLSSV in the study by Harnish et al.[13]. Additionally, the estimates of the velocity and heart rate that correspond to MLSS were compared to the actual velocity and HR obtained during a 40-km time trial.

METHODS

Subjects

The local Ethics Committee for Human Research approved the methods used in this study. After completing the written informed consent form and once all testing equipment and procedures had been demonstrated, 11 trained, male, state level mountain bikers volunteered to participate in this investigation (23.9±4.1 years old; 178±6.8 cm tall; 68.8±5.4 kg body weight; 21.2±1.1 kg·m^{-2} body mass index; 8.9±2.8% body fat and with a mean velocity of 50.1±6.7 km·h^{-1} in a 5-km time trial). The volunteers had been training for ~ 8 years and were accustomed to stationary cycling training. Body density was estimated by the skinfold technique (Cescorf scientific, Brazil) from which body composition was then determined using the Siri formula for estimation of percent body fat and fat free mass[16].

Procedures

All tests were performed in the Exercise Physiology Laboratory at Mogi das Cruzes University. Subjects took part in 4 to 5 testing sessions within a 10-day period using their own racing road bikes attached to a stationary cycle cylinder (Blackburn Trakstand Defender), on different days and at least 48 hours apart. Tire pressures were kept constant for all tests. Temperature (22ºC) and humidity (50%) were controlled and tests were performed at the same time of day (between 9 and 11 am) to avoid circadian effects.

The subjects were instructed to rest and to avoid strenuous exercise during the previous 24 hours and to have their last meal at least 3 hours before testing. Volunteers went through their routine warm-up for each testing session. Heart rate (Polar Pro-Trainer NV, Finland) and blood lactate concentration [lac] (YSI 2300S) were measured at intervals during tests. For [lac] analysis 25μl of capillary blood was collected from the ear lobe using heparinized and calibrated microcapillaries. The 25μl blood samples were transferred into Eppendorf tubes containing 50μl of Sodium Fluoride (NaF) 1% and then analyzed in duplicate. The [lac] results were corrected for the volume of the blood sample contained in the Eppendorf tubes and are presented in mM.

5-km and 40-km time trials

The volunteers first performed a 5-km cycling time trial to determine their mean velocity (5kmVel) and the heart rate reached at the end of the test (maximal heart rate - 5kmHR). A 40-km time trial was also performed on a different day to determine mean velocity (40kmVel) and HR (40kmHR) at the end of 40km. Both HR and [lac] were measured at the 7th, 14th, 21st, 28th, 35th and 40th kilometers of the test. It has been suggested that the 40kmVel on cycling reflects the highest intensity exercise during which cyclists can reach a blood lactate steady state. Therefore, comparisons were made between 40kmVel, maximal lactate steady state velocity (MLSSV), maximal lactate steady state velocity prediction (MLSSVp) and 90% of 5kmVel, in addition to their respective HR related variables.

30 minute endurance trials to identify MLSSV

Subjects performed 2 to 3 30 minute sessions at constant velocity on separate days. These endurance tests were done at random and the velocity of each session was between 86 and 94% of 5kmVel. Then,

for the next session, velocity was either increased or decreased by more or less 2% until MLSS had been identified. Velocity was kept constant throughout the sessions using speed recorder equipment (Cateye MITY2). Capillary blood samples were collected from the ear lobe at the 10th, 20th and 30th minutes during each MLSS trial without interrupting the exercise.

The criterion for MLSS was a variation in blood lactate of less than 1.0mM or 0.05 mM between the 10th and 30th minutes as proposed previously[3-5,14,17-21].

Indirect assessment of MLSSV

The following linear regression equation, derived from the relationship between MLSSV and 5-km velocity in a study by Harnish et al.[15], was used to predict the MLSSV (MLSSVp) in our study: MLSSVp $(km \cdot h^{-1})$ = 0.8809 x 5kmVel + 1.6365

Additionally, the velocity corresponding to 90% of 5kmVel was used to estimate MLSSV, as proposed by Swensen et al.[14].

Identification of the HR corresponding to MLSS and for the 40-km time trial

The HR averaged from the 10th, 20th and 30th min at MLSSV (MLSSHR) as well as for the 40-km time trial (40kmHR) were determined. The HR corresponding to MLSSV was also predicted (MLSSHRp) by considering 88% of maximal HR as proposed previously[14]. These HR related parameters (MLSSHR, 40kmHR and MLSSHRp) were then compared with each other.

Statistical Analysis

All results are presented as mean ± standard error of mean (SE). A repeated measures ANOVA was used to establish comparisons between the 5kmVel, 40kmVel, MLSSV and MLSSVp as well as between the MLSSHR, 40kmHR and MLSSHRp. Linear regression and Pearson's Moment Correlation were used to establish relationships between the parameters studied and thus to analyze the validity of the proposed methods for estimating MLSSV. Student's t test was applied to compare the [lac] corresponding to MLSSV and 40kmVel. The level of significance was set at P<0.05 and Graph Pad Instat (GraphPad software INC) was used for calculations.

RESULTS

The mean (±SE) velocities for the 5-km and 40-km time trials together with MLSSV, MLSSVp and 90% of 5kmVel are presented in Table I. The actual MLSSV, as determined in the 30 minute endurance tests, was 45.64±2.0km·h⁻¹, which is the equivalent of 90.9±0.5% of 5kmVel and which is not significantly different from MLSSVp (45.77±1.77 km·h⁻¹), 90% of 5kmVel (45.09±1.81 km·h⁻¹) or 40kmVel (45.57±1.97km·h⁻¹).

The mean [lac] reached during the 30 min at MLSSV (4.5±0.6mM) and during 40-km time trial (4.2±0.3 mM) did not differ significantly from each other. Figure 1 represents individual and mean [lac] responses during cycling at the velocity that elicited a [lac] variation of less than 0.05mM·min⁻¹ during the last 20min of the test, thus identifying MLSSV. The relationships between the variables studied are represented in Figure 2(a-f). High levels of correlation were observed between the 5km and MLSSV (r=0.9947), MLSSV and MLSSVp (r=0.9948) and between 90%5kmVel and MLSSV (r=0.9952). Furthermore, 40kmVel was highly correlated with MLSSV, MLSSVp and 90%5kmVel, (r=0.9928; r=0.9955 and r=0.9954, respectively).

Table 1. Individual and mean results as related to the parameters studied (n=11).

Subject	5kmVel (km·h⁻¹)	MLSSVp (km·h⁻¹)	90% 5kmVel (km·h⁻¹)	MLSSV (km·h⁻¹)	40kmVel (km·h⁻¹)	Mean [Lac] at MLSSV (mM)	Mean [Lac] 40km (mM)	MLSSV as % of 5kmVel (%)	40kmVel as % of 5kmvel (%)
1	59.8	54.3	53.8	56.0	55.5	3.7	4.0	93.6	92.8
2	58.3	53.0	52.5	53.0	54.0	5.7	5.9	90.9	92.6
3	55.5	50.5	50.0	52.0	50.0	6.6	4.7	93.7	90.1
4	56.6	51.5	50.9	51.0	51.0	3.1	3.5	90.1	90.1
5	50.8	46.4	45.7	46.0	46.0	4.4	3.7	90.6	90.6
6	48.9	44.7	44.0	45.2	45.4	3.3	4.2	92.4	92.8
7	48.0	43.9	43.2	43.5	44.3	2.4	3.3	90.6	92.3
8	46.6	42.7	41.9	41.6	42.0	2.9	3.9	89.3	90.1
9	44.4	40.7	40.0	40.0	39.6	5.4	4.2	90.1	89.2
10	41.7	38.4	37.5	37.3	37.4	3.2	3.0	89.4	89.7
11	40.2	37.4	36.5	36.4	36.1	8.9	6.3	89.7	89.8
Mean	50.07*	45.77	45.09	45.64	45.57	4.5	4.2	90.9	90.9
SE	2.03	1.77	1.81	2.00	1.97	0.6	0.3	0.5	0.4

Mean velocity on the 5km test (5kmVel); predicted maximal lactate steady state (MLSSVp); velocity corresponding to 90% of 5kmVel; maximal lactate steady state velocity (MLSSV); 40km velocity (40kmVel); mean blood lactate concentration ([lac]) over 30min at MLSSV and for 40km time trial; relative intensity (%) of MLSSV and 40kmVel related to 5kmVel; * P<0.05 in relation to all velocities.
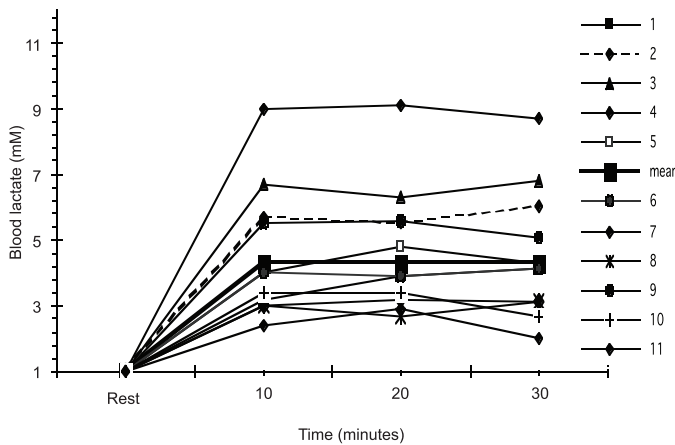
Figure 1. Individual and mean blood lactate results over 30 minutes at MLSSV.

Maximal HR (5kmHR) was 187±2.5 bpm. Mean MLSSHR (175.1±3.0 bpm) corresponded to 93.6±0.5 % of 5kmHR (Table II) and was not statistically different from the mean HR during the 40km time trial (40kmHR – 176.8±3.1 bpm; 94.5±1.0% 5kmHR). Predicted MLSSHR (MLSSHRp), calculated as 88% of maximal heart rate, differed significantly both from MLSSHR and 40kmHR. A moderate-high correlation was found between MLSSHR and 40kmHR in spite of there being no significant difference between MLSSV and 40kmVel. (Table 1, Table 2 and Figure 3).

Maximal heart rate (5kmHR); maximal lactate steady state heart rate estimated as 88% of 5kmHR (MLSSHRp); heart rate at the 10th , 20th and 30th minutes at maximal lactate steady state velocity (HR10th min MLSSV, HR20th min MLSSV, HR30th min MLSSV); mean HR over 30min at MLSSV (MLSSHR); mean HR during 40-km time trial (40kmHR); heart rate at maximal lactate steady state (HRMLSS) and heart rate during 40km tests as percentages of 5kmHR; * P<0.05 in relation to MLSSHR, 40kmHR and HR at the 10th, 20th and 30th minutes of the MLSSV test.
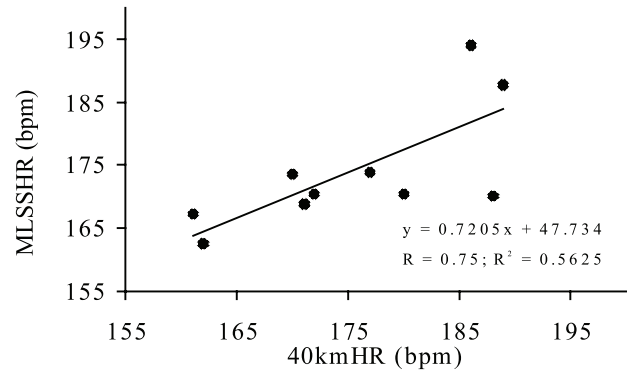

Figure 3. Relationship between mean heart rates corresponding to MLSSV (MLSSHR) and during 40-km time trial (40kmHR).

DISCUSSION

The present study investigated the validity of methods for estimating the MLSSV in cycling. The main finding was that MLSSV can be accurately estimated using either the predictive equation proposed, the 40kmVel or the velocity corresponding to 90% of 5kmVel. However, predictions of the heart rate corresponding to MLSSV (MLSSHRp) were not entirely consistent.

We first hypothesized that the linear regression equation derived from the relationship between 5kmVel and MLSSV as presented by Harnish et al.[13] could be used to estimate the MLSSV of cycling. However, during the course of the present study it was perceived that the relationship as published seemed to be erroneous[15] (page 1053, Figure 1-A). Based on the data as presented in a table in that paper, the y-axis of the relationship actually refers to 5kmVel and not to MLSSV as stated by the authors. Even if a typographical error had taken place, the linear regression still does not represent the relationship between the parameters. So, after re-

Table 2. Individual and mean heart rate as related to the parameters studied (n=11).

| Sub-ject	Maximal HR (5kmHR) (bpm)	MLSSHRp (88% 5kmHR) (bpm)	HR10th min MLSSV (bpm)	HR20th min MLSSV (bpm)	HR30th min MLSSV (bpm)	MLSS HR (bpm)	40km HR (bpm)	HR MLSS (as % of 5kmHR)	HR 40km (as % of 5km HR)
1	182	160.2	169	163	179	170.3	180	93.6	98.9
2	196	172.5	181	189	193	187.7	189	95.8	96.4
3	181	159.3	166	171	174	170.3	172	94.1	95.0
4	180	158.4	160	168	174	167.3	161	92.9	89.4
5	198	174.2	185	190	188	187.7	189	94.8	95.5
6	184	161.9	172	174	175	173.7	170	94.4	92.4
7	188	165.4	169	170	171	170.0	188	90.4	100.0
8	203	178.6	191	192	199	194.0	186	95.6	91.6
9	180	158.4	166	166	174	168.7	171	93.7	95.0
10	179	157.5	160	165	163	162.7	162	90.9	90.5
11	186	163.7	173	174	175	174.0	177	93.5	95.2
$\overline{X}$	187.0	164.6*	172.0	174.7	178.6	175.1	176.8	93.6	94.5
±SE	2.5	2.2	3.0	3.2	3.2	3.0	3.1	0.5	1.0
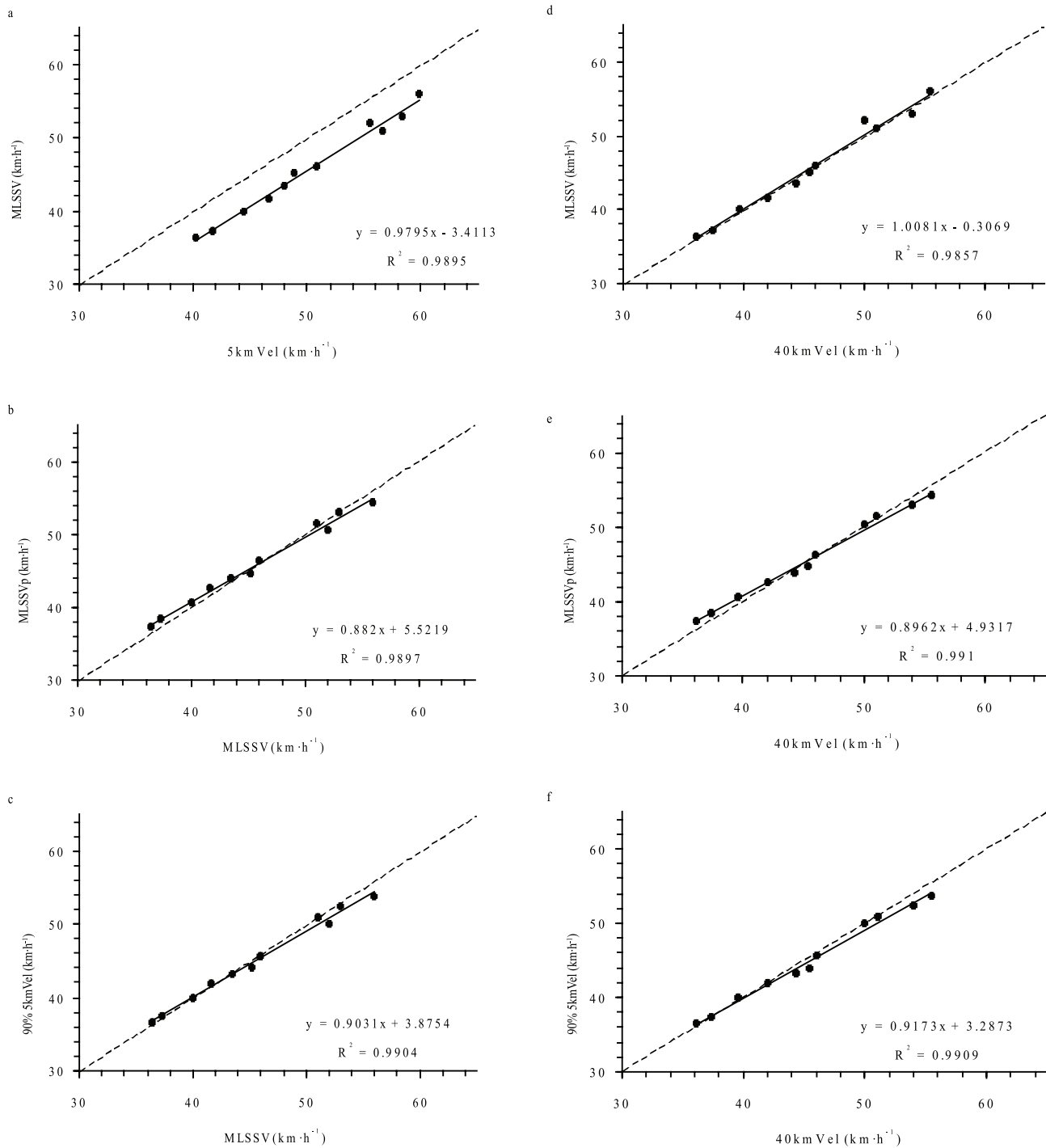
Figure 2. Relationships between parameters studied. High correlations were found between 5KmVel and MLSSV (a), MLSSVp calculated with linear regression equation and MLSSV (b), 90% 5KmVel as an estimate of MLSSV and actual MLSSV (c), 40KmVel and MLSSV (d), MLSSVp and 40KmVel (e) and between 90%5kmVel and 40kmVel (f).

analyzing the individual results for MLSSV and 5kmVel as published in that paper, a different relationship was produced and a predictive equation (the validity of which was investigated in the present study) was derived: [MLSSVp (km·h⁻¹) = 0.8809 x 5kmVel + 1.6365]. In general, our results provide evidence that this proposed equation is valid for estimating both the MLSSV and the velocity that can be sustained during

a 40-km time trial.

The mean (±SE) result for MLSSV in the present study (45.6±2 km·h⁻¹) was similar to that of Swensen et al.[14] who reported results for MLSSV of 43.7±1.1 and 41.5±1.0 km·h⁻¹ for laboratory and track tests, respectively. In contrast, MacIntosh et al.[5] and Harnish et al.[13] reported lower MLSSV results than achieved by our participants (33.5±3.1 and 36.7±0.9 km·h⁻¹,

respectively). These differences may be because the participants in those studies were male and female cyclists and triathletes. Not with standing, the relative intensity at which MLSSV was observed (90.9±0.01% of 5kmVel) is in agreement with the results of both Swensen et al.[14] and Harnish et al.[13] (~90% and 92.1±1.2% of 5kmVel). These authors found evidence that MLSSV in cycling would be reached at intensities of between 85 and 92% of 5kmVel.

A similar relationship between middle-distance events and the MLSSV has been documented in other sports than cycling. It has been demonstrated that ~ 92% of 3-km velocity for male endurance runners and ~ 91% of 700-m velocity for young (male and female) swimmers are good estimates of MLSSV.[22,23] The r^2 of the relationship between MLSSV and 5kmVel (r^2=0.9895) confirms the accuracy of 5-km time trial for predicting MLSSV (Fig 2a). For our participants both the predictive equation and 90% of 5kmVel were considered valid for estimating MLSSV (Table I and Figures 2b-c). Furthermore, in confirmation of data presented previously[13], 40kmVel seemed to be the best method for predicting MLSSV because the regression line between the 40kmVel and MLSSV was exactly the same as the line of identity (Figure 2-d). The present study's limitations are that it was based on indoor cycling and that our sample could have been more homogeneous that it actually was in terms of regarding performance (Table I). Nevertheless, our sample does appear to be more homogeneous than that of the original study from which the predictive equation was generated.[13] Our participants were male, whereas in the study by Harnish et al.[13] the sample was composed of men and women and therefore performance variation was more pronounced.

Although able to identify MLSSV, the 40-km time trial is time consuming and more stressful than the 5-km test. Predicting MLSSV from the 5-km time trial is practical and accurate and can be easily carried out by coaches, cyclists and exercise physiologists on exercise evaluation. Moreover, the results in Figure 2-a and 2-b suggest that MLSSVp would better predict the MLSSV for cyclists able to perform between 44 and 56 km·h⁻¹ on a 5-km time trial. For cyclists who are faster or slower than these velocities the regression line shows a tendency to underestimate or overestimate the actual MLSSV (Figure 2-b), probably because their performance levels are different from the majority of the cyclists studied by Harnish et al.[13], whose data was used to elaborate our predictive equation. Therefore, the predictive equation should be used mainly for cyclists with similar characteristics to the participants of present study. As can be observed in Table I, about two cyclists were slightly below and above the recommended 5-km performance range. However, the BIAS (which can be calculated from the mean of differences between MLSSV and MLSSVp) was close to zero (-0.13 ± 0.98) suggesting that the proposed equation was valid for estimating the MLSSV of the group studied despite the individual variations in performance. Even so, we emphasize the recommendation that this equation

would be more accurate for cyclists performing at between 44 and 56 km·h⁻¹ in the 5-km time trial.

The relationships between the 90%5kmVel and MLSSV and between 90%5kmVel and 40kmVel indicate a tendency to underestimate both the MLSSV and 40kmVel for faster participants. As can be observed in Figures 2-c and 2-f, the regression lines for those relationships diverge from the line of identity at higher velocities. Once again, this could be explained because the 90%5km as an estimate of MLSSV[14] was based on cyclists slower than the participants of the present study in the 5-km time trial (43.3±2.0 vs. 50.07±2.03 km·h⁻¹).

The methods for predicting MLSSV presented here are of interest for several reasons. They are practical and inexpensive, no blood samples are required and they produce the same results as the direct identification of MLSSV from [lac] measurement. However, in spite of the accuracy of the methods presented for predicting the velocity corresponding to MLSS in this study, the predictions of the HR at which MLSS is observed should be used with caution due the inconsistency of our results when compared to other studies.

While the mean MLSSHR in the present study (175.1±3.0 bpm) was similar to that observed by Harnish et al.[13] (174.7±2.6 bpm), Swensen et al.[14] reported lower HR results (167.0±9.5 bpm) in relation to MLSS. These authors first stated that MLSSHR could be estimated by taking 88% of maximal heart rate and that the blood lactate steady state would be attained if cyclists perform intermittent "on-road" cycling at HR within 88 ± 2% of the maximal heart rate.[14] However, the mean MLSSHR of our participants (whose 5kmVel results were in a range from 40.8 to 59.8 km·h⁻¹) actually corresponded to 93.6% of maximal HR and was not significantly different from the mean HR reached during the 40-km time trial (94.5% of maximal HR). These differences in relation to the 88% of maximal HR as described by Swensen et al.[14] may be due to the differences in performance level between the participants of the two studies. Our participants reached 50.07±2.03 km·h⁻¹ over 5-km while in the study by Swensen et al.[14] the cyclists performed the 5-km time trial at 43.3±2.0 km·h⁻¹ It is well established that highly trained individuals may reach the MLSS at VO_2 and HR closer to VO_2max and maximal HR, and therefore closer to 5kmVel than less trained athletes.

In spite of there being no significant differences between MLSSHR and 40kmHR (Table II), the correlation between them (0.75) was much lower than the correlations between predicted and actual MLSSV (Figure 2). Also, even though there were no differences between mean HR during the 40-km and the MLSSV tests, there was a clear increase in HR from the 10th to 30th minute of exercise at MLSSV. This drift in HR in spite of blood lactate steady state condition has been shown by other authors[24,25] and suggests that an HR zone, rather than a fixed HR or a % of maximal HR, should be considered during training sessions when the goal is to reach an exercise intensity related to MLSS. For our participants, whose mean maximal HR was 187.0±2.5 bpm, this mean HR zone was from 172.0±3.0

to 178.6±3.2 bpm between the 10th and 30th minute of exercise (Table II), which corresponded to 92.0±1.8 and 95.5±2.6% of maximal HR respectively. Therefore, when training is being controlled in response to HR (as with cycling), the HR zone corresponding to MLSS (MLSSHR zone) should be estimated on an individual basis. Considering that the consistency of the methods presented for predicting MLSSV was better than those for estimating MLSSHR, one of these methods could be used to estimate a cyclist's MLSSV on a cycle simulator using their own bike and then, on a different day, the HR zone observed during a long term cycling session at predicted MLSSV (on the same cycle simulator), should be considered the MLSSHR zone. Thus both the velocity and HR corresponding to MLSS could be used during outdoor training (on-road) if desirable.

The mean blood lactate concentration at which MLSSV was observed in the present study was around 4mM (4.5±0.6; ranging from 2.4 to 8.9mM). These results are similar to those of Foster et al.[12], Weltman[26] and Beneke[27]. Foster et al.[3] demonstrated that MLSS intensity occurred between 2.5 and 4.0mM for cyclists and between 4.0 and 6.5mM for speed skaters. Beneke[27] verified that the MLSSV occurred at 3.1±0.5; 5.4±1.0 and 6.6±0.9mM for rowers, cyclists and skaters respectively. On the other hand, MacIntosh et al.[5] found blood lactate concentration to be 7.06±2.5 and 6.7±2.0mM at the 10th and 30th minutes of cycling at MLSSV. Some athletes have a higher [lac] due the specificity of training adaptations. So, some groups of athletes may have both a higher glycolysis rate and buffering capacity while others may have a faster [lac] removal rate and therefore a lower [lac] at MLSSV[28,29]. Also, some athletes have higher type I muscle fibers distribution and thus a lower blood lactate concentration at MLSSV[30].

CONCLUSION

It was concluded that the velocity corresponding to the maximal lactate steady state may be accurately predicted using the equation proposed [(MLSSVp (km·h^{-1}) = 0.8809 x 5kmVel + 1.6365)] and also as by considering mean velocity over the 40-km time trial or 90% of 5kmVel. Additionally, the results suggest that training control by means of HR responses should be approached with caution and on an individual basis. Future studies should address the validity and application of predictive methods in outdoor cycling.

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