The Traditional Maximal Lactate Steady State Test versus the 5×2000 m Test

Authors
A. Legaz-Arrese[1], L. E. Carranza-García[2], E. Serrano-Ostáriz[3], J. M. González-Ravé[4], N. Terrados[5]

Affiliations
[1] Section of Physical Education and Sports, University of Zaragoza, Spain
[2] Faculty of Sports Organization, Autonomous University of Nuevo Leon, San Nicolás de los Garza, Mexico
[3] Fisiatría y Enfermería, Universidad de Zaragoza, Spain
[4] Faculty of Sport Sciences, University of Castilla la Mancha, Toledo, Spain
[5] Unidad Regional de Medicina del deporte del Principado de Asturias, Fundación Deportiva Municipal de Avilés, Spain

Key words
- anaerobic threshold
- time limit
- lactate
- runners

Abstract

Here, we compared the maximal lactate steady state velocity (vMLSS) estimated from a single-visit protocol (v5×2000) to the traditional multi-day protocol (vMLSS). Furthermore, we determined whether there was a lactate steady state during the time limits (Tlim) at vMLSS or v5×2000. Eight runners completed a half marathon (HM), the traditional protocol to determine the vMLSS and the 5×2000 m test in a randomised order, and a Tlim at vMLSS and at v5×2000 in a randomised order. The vMLSS ($13.56 \pm 0.90\,km \cdot h^{-1}$) was higher than the v5×2000 ($12.93 \pm 0.90\,km \cdot h^{-1}$, $p = 0.001$) and comparable to the vHM ($13.34 \pm 0.75\,km \cdot h^{-1}$). The vMLSS ($r = 0.83$) and the v5×2000 ($r = 0.91$) were associated with the vHM but were not indicative of the competition pace. The Tlim at vMLSS (64±15 min) was lower than the Tlim at v5×2000 (94±21 min) and the HM time (95±5 min). In both Tlim, lactate was lower at 45 min than upon finishing the effort and was predictive of its duration ($p < 0.05$). Our results indicate that the 5×2000 m test can be equally useful to assess runners as the traditional MLSS protocol and that there is no lactate steady state during the Tlim at vMLSS or at v5×2000.

Introduction

The maximal lactate steady state (MLSS) corresponds to the highest workload (velocity of MLSS, vMLSS) that can be maintained over time without the continual accumulation of blood lactate [5,13]. The traditional 'gold standard' method used to determine vMLSS demands several subsequent, independent constant load tests that must be performed at different workloads on different days. Although there have been numerous MLSS definitions and determinations, it is now accepted that vMLSS is attained when the blood lactate concentration varies by no more than $1.0\,mmol \cdot l^{-1}$ between 10 and 30 min of exercise [2,4,5,7,17].

The various aspects associated with the concept and determination of the MLSS are seldom discussed in the scientific literature. Thus, few studies have tested whether there is truly an intensity at which the concentration of lactate remains stable over time and whether this intensity corresponds to the one established by the protocol traditionally used to determine the vMLSS [3,7]. In addition, it is not known if the vMLSS is useful to establish the pace of training and competition for long-distance endurance events [1]. Furthermore, there are no common criteria to establish the minimum increase in lactate concentration required in the last 20 min of a 30-min effort or the magnitude of a change in workload on different days. Consequently, the level of precision in determining the vMLSS is consistently low and differs between studies, with some runners having values ranging between $0.36\,km \cdot h^{-1}$ and $1\,km \cdot h^{-1}$ [11,17,19,26,28,30].

The traditional 'gold standard' method used to determine the MLSS is time-consuming and labour-intensive, and it introduces issues that relate to the inherent day-to-day variability of physiological measures. To address these limitations, several shorter methods to estimate the MLSS have been proposed [6,14,25]. For many years, the 5×2000 m test has been used to indirectly identify the MLSS (v5×2000) in elite marathoners, with the goal of establishing the effects of training and the pace of the competition [21,22]. There are no scientific studies on the practical use of the 5×2000 m test. This study sought to establish a comparison among runners between the vMLSS determined through the traditional protocol and the v5×2000, as well as the correspondence of both velocities to the half-marathon velocity (vHM). In addition, our objec-

accepted after revision
May 25, 2011

Bibliography
DOI http://dx.doi.org/10.1055/s-0031-1283178
Published online: 2011
Int J Sports Med

ISSN 0172-4622

Correspondence
Dr. Luis Enrique Carranza-García
Autonomous University of Nuevo Leon
Faculty of Sports Organization
Av. Universidad S/N
66455 San Nicolás de los Garza
Mexico
Tel.: +52/81/13 40 44 50
Fax: +52/81/13 40 44 51
kique_79@hotmail.com

Table 1 Plasma lactate values during the execution of the 5×2000 m test for each subject.

		Plasma lactate concentration (mmol·l^{-1})					
	vHM (km·h^{-1})	1ª repetition (vHM−0.9 km·h^{-1})	2ª repetition (vHM−0.6 km·h^{-1})	3ª repetition vHM−0.3 km·h^{-1})	4ª repetition (vHM)	5ª repetition (vHM+0.3 km·h^{-1})	v5×2000 (km·h^{-1})
subject 1	13.9	1.58	1.56	1.66	1.92*	2.45	13.9
subject 2	13.2	2.23	2.58*	3.29	4.61	6.67	12.6
subject 3	13.3	2.36	2.54*	3.06	3.87	4.74	12.7
subject 4	12.3	3.54	3.68*	4.15	4.20	6.02	11.7
subject 5	12.8	2.71	2.75*	3.81	5.01	6.60	12.2
subject 6	14.4	2.07	2.17*	2.75	3.07	4.06	13.8
subject 7	13.3	2.91	2.97	3.23*	3.88	4.42	13.0
subject 8	14.4	2.19	2.27	2.54*	3.38	4.45	14.1

vHM = half marathon velocity; *Intensity corresponding to the v5×2000 of each athlete

tive was to determine the differences in the time limits (Tlim) of both velocities and the evolution of lactate concentration during their execution, with the goal of determining if a lactate steady state really exists.

Materials and Methods

Subjects

8 male endurance-trained runners (age: 42±8 years; height: 1.75±0.08 m; body mass: 73.1±6.8 kg; VO_{2max}: 55.3±4.8 ml·kg^{-1}·min^{-1}; training volume: 61±19 km·week^{-1}) who had competed in a HM (95±5 min) and were accustomed to treadmill running participated in the study. Before participation, each athlete completed a medical questionnaire and provided written informed consent. Ethical approval was granted by the Research Ethics Committee of the Government of Aragón (Spain), and the study was conducted according to the most recent standards of the International Journal of Sports Medicine [15].

Design and procedures

Participants visited the laboratory for physiological testing on 7 to 10 separate occasions within a 20-d period after the HM competition. Initially, the runners performed a protocol for the traditional determination of the MLSS and a protocol for the 5×2000 m test in a randomised order. Subsequently, each runner was randomly subjected to a Tlim at vMLSS and a Tlim at v5×2000.

All tests were completed in an air-conditioned room (20 °C) on a motor-driven treadmill (Laufergotest, Jaeger, Germany) with the gradient set at 1% to simulate the oxygen cost of outdoor running [16]. Each athlete completed all tests at the same time of day. Throughout the testing period, the participants were requested to maintain their usual dietary intake and to abstain from training sessions. In all tests, blood samples (3.0 ml) were drawn from an antecubital vein and collected in tubes. The samples were promptly centrifuged, and the plasma was stored below −25 °C. The plasma lactate concentration was analysed with the Cobas modular system C-711 (Roche Diagnostics). Heart rate (HR) was measured at 5-s intervals by short-range telemetry (Polar S410, Polar Electro Oy, Kempele, Finland). The rate of perceived exertion (RPE) was measured using Borg's category-ratio scale [8], which consists of 12 statements scored from 0 to 10 (from 'nothing' to 'maximal').

The 5×2000 m test

The subjects performed an incremental load test of 5 repetitions of 2000 m. The subjects began running at an initial speed of 0.9 km·h^{-1} less than their vHM, and their speed was progressively increased by 0.3 km·h^{-1} every 2000 m. The initial velocity was selected so that each athlete reached the vHM in the fourth repetition. The exercise was interrupted for 1 min for blood sampling after the completion of each 2000 m interval. The v5×2000 was defined as the highest velocity during which the increase in lactate with respect to the concentration observed at the end of the first repetition of 2000 m was no higher than 0.4 mmol·l^{-1} (**Table 1**). This maximum increase in lactate has been suggested as the most appropriate to set the pace of competition in elite marathoners [22]. After 48 h, each participant ran 7200 m at v5×2000. The exercise was interrupted for 1 min at the 3200-m mark to collect a blood sample. The v5×2000 was confirmed if the increase in lactate from 3200 to 7200 m was not higher than 0.4 mmol·l^{-1}. Otherwise, the v5×2000 was established as the lowest velocity (−0.3 km·h^{-1}) reached in the 5×2000 m test. RPE and HR were recorded at the end of each repetition of the 5×2000 m test, at 3200 m and at the end of the 7200-m test.

The MLSS test

The subjects performed an incremental load test and 3–5 constant load tests. The incremental load test started at 10 km·h^{-1} and was increased by 1.5 km·h^{-1} every 3 min until exhaustion. The constant load tests lasted 30 min. The exercise was interrupted for 1 min for blood sampling after the completion of each 3-min workout (incremental load test) and at 10 min (constant load test). The workload of the first constant load test corresponded to a plasma lactate concentration of 3.0 mmol·l^{-1} measured during the incremental load test. Constant load tests with higher or lower workloads were applied with a break of 48 h until the vMLSS was determined and verified. The MLSS was defined as the highest plasma lactate concentration that increased by no more than 1.0 mmol·l^{-1} during the final 20 min of constant workload, considering a minimal increase of 0.7 mmol·l^{-1}. RPE and HR were recorded at 10 and 30 min of each constant load test. Additionally, during the incremental load test, VO_2 was measured by means of a Jaeger EOS-Sprint spiroergometer. VO_{2max} was chosen as the highest VO_2 value in the series of 30 s-by-30 s VO_2 values.

The time limit at v5×2000 and the time limit at vMLSS

All subjects were randomly asked to perform 2 tests at the intensities corresponding to the previously determined vMLSS and v5×2000 until exhaustion. There was a 96-h interval between tests. In each test, the concentration of lactate was determined every 45 min (1 min break) and at the end of the test. RPE and the HR were recorded every 15 min and at the end of the test.

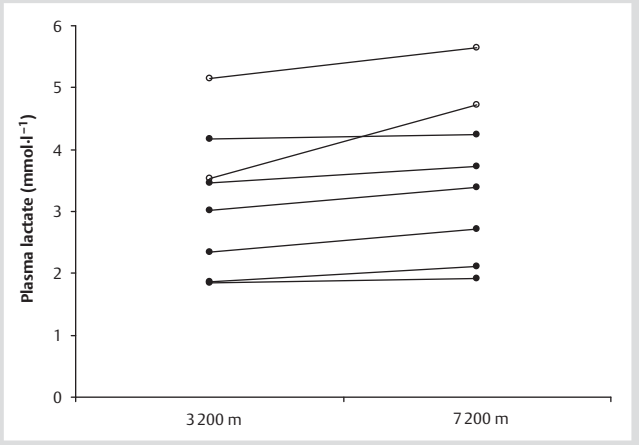

Fig. 1 Changes in each subject in the plasma lactate concentration in the final 4 000 m of the 7 200-m test at the v5 × 2000.

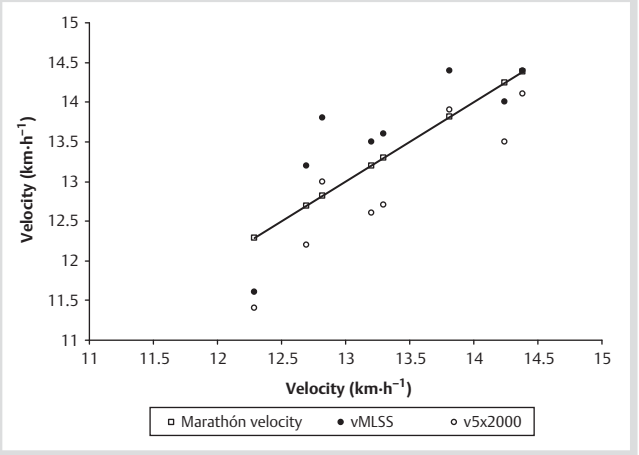

Fig. 2 Individual differences in the vHM, vMLSS and v5 × 2000.

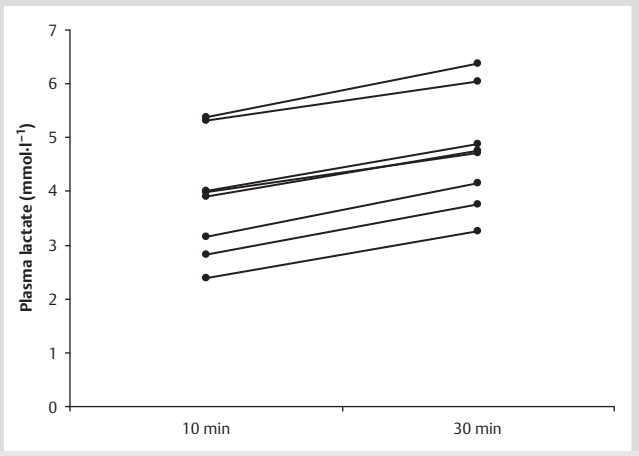

Fig. 3 Changes in the plasma lactate concentration of each subject during the last 20 min of a 30-min effort, in which the vMLSS was identified.

Statistical analysis

All analyses were performed using SPSS (v15.0, SPSS, Chicago, IL). Data are expressed as means with the corresponding standard deviations. Paired t-tests were used to compare physiological measures. The Pearson and Spearman correlation coefficients were used to quantify the relationships between variables. Statistical significance was set at $p < 0.05$.

Results

The 5 × 2 000 m test

In all subjects, the v5 × 2000 was determined in a single day (**Table 1**) (13.0 ± 0.87 km·h^{-1}) (lactate: 2.7 ± 0.6 mmol·l^{-1}; HR: 152 ± 7 beats·min^{-1}; RPE: 2.9 ± 0.8). In 6 out of 8 subjects, the v5x2000 was confirmed during the 7200-m test (Δ lactate: 0.23 ± 0.14 mmol·l^{-1}) (**Fig. 1**). 2 subjects had increases greater than 0.4 mmol·l^{-1} (0.51 and 1.18 mmol·l^{-1}) during the final 4 000 m of the 7 200-m test, establishing the lower intensity (−0.3 km·h^{-1}) as its corresponding v5 × 2000. Thus, the v5 × 2000 was established at 12.93 ± 0.90 km·h^{-1}. During the final 4 000 m of the 7 200-m test, we observed an increase in HR (7 ± 3 beats·min^{-1}, $p < 0.001$) and in the RPE (0.9 ± 0.6, $p = 0.020$). The v5 × 2000 was significantly lower than the vHM (12.93 ± 0.90 vs. 13.34 ± 0.75 km·h^{-1}, respectively, $p = 0.002$) (**Fig. 2**). The v5 × 2000 was highly correlated with the vHM ($r = 0.91$, $p = 0.001$) and lactate concentration at v5 × 2000 ($r = -0.76$, $p = 0.030$).

The MLSS test

We needed 3.6 ± 0.7 days (range: 3–5 days) to identify the vMLSS (13.56 ± 0.90 km·h^{-1}) with a lactate increase of 0.87 ± 0.10 mmol·l^{-1} (range: 0.72–1.0 mmol·l^{-1}) between 10 (3.87 ± 1.08 mmol·l^{-1}) and 30 min (4.74 ± 1.06 mmol·l^{-1}) ($p < 0.001$) (**Fig. 3**). We also found evidence of increases in HR (11 ± 4 beats · min^{-1}, $p < 0.001$) and RPE (0.9 ± 0.6, $p = 0.020$). Although there were no significant differences between the average vMLSS and the average vHM ($p = 0.498$), both velocities were clearly different for each subject (**Fig. 2**). The vMLSS was significantly higher than the v5 × 2000 ($p = 0.001$). The vMLSS was highly correlated with the vHM ($r = 0.83$, $p = 0.010$), the v5 × 2000 ($r = 0.94$, $p < 0.001$) and the lactate concentration at 10 ($r = -0.72$, $p = 0.044$) and 30 min ($r = -0.72$, $p = 0.045$) of the MLSS test.

The time limit at v5 × 2000 and the time limit at vMLSS

The Tlim at v5 × 2000 (94 ± 21 min) was significantly higher than the Tlim at vMLSS (64 ± 15 min) ($p = 0.001$). There were no significant differences between the HM time and the Tlim at v5 × 2000 ($p = 0.902$); however, there were differences with respect to the Tlim at vMLSS ($p < 0.001$). We observed increases associated with the duration of the effort in the lactate concentration, HR and RPE in both tests. For the Tlim at v5 × 2000, the lactate concentration at 45 min (4.07 ± 0.86 mmol·l^{-1}) was not significantly higher than that observed at 3 200 m (average 15 min, $p = 0.110$) or at 7 200 m (average 33 min, $p = 0.385$) during the 7 200-m test, but it was significantly lower than that observed at the end of the effort (5.44 ± 1.31 mmol·l^{-1}, $p = 0.006$). For the Tlim at vMLSS, the lactate concentration at 45 min (6 subjects: 5.86 ± 1.17 mmol·l^{-1}) was significantly higher than that observed during the MLSS test at 10 min ($p = 0.002$) and 30 min ($p = 0.027$) and significantly lower than that observed at the end of the effort (7.07 ± 1.18 mmol·l^{-1}) ($p < 0.001$). Regarding the Tlim at v5 × 2000, the RPE increased from 3.9 ± 0.8 at 45 min to 8.8 ± 1.0 at the end of the effort ($p < 0.001$), and HR increased from 164 ± 10 to 173 ± 10 beats·min^{-1} ($p = 0.003$) for the same measurement times. Similar results were observed for the Tlim at vMLSS between 45 min and the end of the effort: the RPE

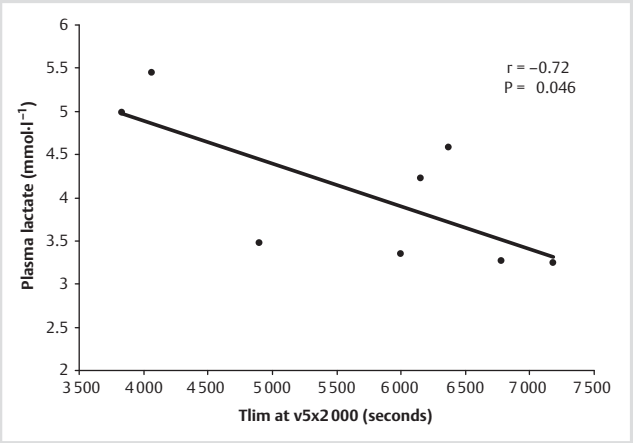

Fig. 4 The relationship between the Tlim at v5 × 2000 and the plasma lactate concentration at 45 min.

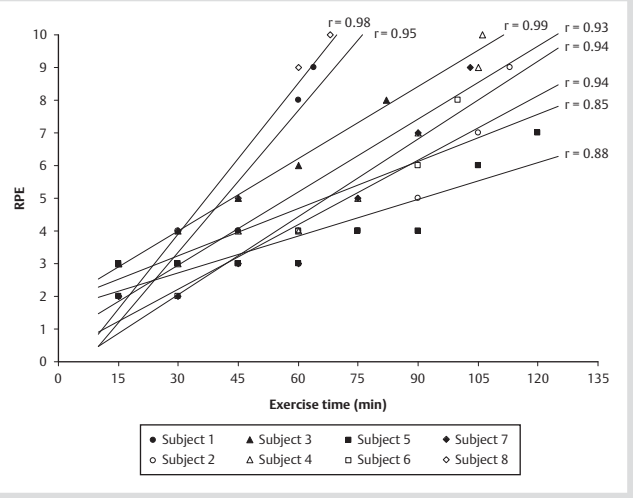

Fig. 5 The rating of the perceived exertion (RPE) for each subject against exercise duration during the Tlim at v5 × 2000.

increased from 4.8 ± 1.3 to 8.6 ± 1.4 ($p < 0.001$), and the HR increased from 169 ± 6 to 175 ± 10 beats·min^{-1} ($p = 0.011$).

The Tlim at v5 × 2000 was significantly associated with the lactate concentration at 45 min ($r = -0.72$, $p = 0.046$) (**Fig. 4**) and with the v5 × 2000 ($r = -0.74$, $p = 0.037$), indicating a non-significant relationship with the vHM ($r = -0.66$, $p = 0.074$). The Tlim at vMLSS was significantly associated with the lactate concentration at 45 min (6 subjects) ($r = -0.83$, $p = 0.042$). The RPE rose linearly in each subject throughout both Tlim trials (**Fig. 5**). For Tlim at v5 × 2000, there were inverse linear relationships between the trial duration and the rate of increase in RPE ($r = -0.92$, $p = 0.001$) and the RPE at 60 min ($r = -82$, $p = 0.012$), but not with the RPE at 15 ($r = 0.56$, $p = 0.153$), 30 ($r = -0.28$, $p = 0.497$) or 45 min ($r = -0.65$, $p = 0.084$). The Tlim at vMLSS was significantly associated with the RPE at 30 min ($r = -0.77$, $p = 0.026$), but not with the rate of increase in RPE ($r = -0.51$, $p = 0.456$) or with the RPE at 15 min ($r = -0.13$, $p = 0.766$).

Discussion

This study establishes, for the first time in long-distance runners, a comparison between the 5 × 2000 m test and the traditional test to determine the MLSS, as well as the Tlim at v5 × 2000 and the Tlim at vMLSS. The results obtained here deserve discussion from several different perspectives.

Importantly, our results indicate that the 5 × 2000 m test can be useful, in a single day and with an elevated level of precision, to establish the maximal velocity that induces an increase in lactate no higher than 0.4 mmol·l^{-1} during the last 4000 m (average of 18 min and 28 s in our study) of a 7200-m test. Specifically, this was achieved in 6 out of the 8 subjects analysed. The 2 subjects in whom this criterion was not satisfied had increases in lactate comparable to the criteria established in the traditional protocol to determine the MLSS. Future studies with a larger sample size should be performed to confirm these results. In contrast, for an equivalent level of precision, 3–5 days (not including the initial incremental test) were required to identify the vMLSS. In addition, the level of correlation with the vHM was higher for the v5 × 2000 than for the vMLSS. This suggests that the 5 × 2000 m test can be especially useful to determine the effects of training in long-distance runners. Although other tests that require only 1 day (e.g., the incremental test) have also proven to be useful in differentiating homogenous groups that compete in long-distance events [20], we can speculate that the sensitivity may be higher in the 5 × 2000 m test due to the higher level of precision and the use of velocities that are similar to those used in competition. This issue will be addressed in future investigations. In addition, the 5 × 2000 m test can be adjusted better than other tests to the characteristics of the training sessions used by runners who compete in long-distance events, which facilitates the use of the test to regularly control the effects of training. The adaptation of the 5 × 2000 m test to other sports (e.g., rowing, cycling and swimming) may be of interest to future investigations.

In this study, we observed that the concentration of lactate at the v5 × 2000 and at the vMLSS was lower in the best runners. This analysis deserves further investigation and could lead to interesting practical applications for models that establish the anaerobic threshold for a fixed lactate concentration. The average increase of the vMLSS to 0.64 km·h^{-1} higher than the v5 × 2000 is reasonable, considering the differences between the protocols in the maximal increase of lactate permitted for identification during constant exercise (1.0 and 0.4 mmol·l^{-1}, respectively). Determining the differences between vMLSS and v5 × 2000 matching the maximally accepted increase in lactate concentration may be of interest for future studies. Importantly, these results demonstrated the elevated sensitivity of the lactate concentration to small changes in intensity, which highlights the importance of identifying the MLSS with a high level of precision. On the other hand, the differences that we observed for each subject between the vHM with the vMLSS and the v5 × 2000 lead us to believe that for the sample analysed, the runners cannot use the vMLSS and the v5 × 2000 as the race pace for a long-distance event. Future studies should confirm these results by determining the vMLSS and the v5 × 2000 through field tests and by evaluating elite runners.

Our results also support previous studies that have suggested important differences in running performance on treadmills, asphalt and synthetic track surfaces [9,18,24,27]. Specifically, we observed that although the average vHM (13.34 km·h^{-1}) was

only slightly less than that for the vMLSS (13.56 km·h^{-1}), the average Tlim at vMLSS (64 min) was much lower than the average time that the athletes took to accomplish the HM (95 min). Along these lines, although the v5 × 2000 (12.93 km·h^{-1}) was significantly lower than the vHM (13.34 km·h^{-1}), the average of Tlim at v5 × 2000 (94 min) was equivalent to the average time of the HM (95 min). At the expense of future studies that determine the differences in the vMLSS and the v5 × 2000 as well as in their respective Tlim between laboratory and field protocols, this analysis is predicted to achieve, at least on a practical level, the evaluation of runners through field tests. Nevertheless, it is possible that these results may partially be a result of the different conditions associated with the implementation of a Tlim, with respect to the context of long distance competitions. On this issue it should be specified that the best runners achieved a lower Tlim at v5 × 2000, which suggests that this test does not provide useful information for evaluating runners.

The rate of increase in RPE predicts the VO_{2max} in the first few stages of an incremental exercise test [12] and the exercise duration at a fixed power output in the first minutes of exercise [10]. Our results confirmed that the RPE is sensitive to the intensity and duration of exercise. Our results also confirmed the results of Crewe et al. [10] that the increase in RPE is a linear function of exercise duration and that the time to volitional exhaustion is inversely related to the absolute rate of RPE increase. These findings indicate that the brain, in response to afferent feedback from multiple systems in the body, perceives that exercise is becoming progressively more demanding, even though the work rate remains constant, supporting the theory of the central governor model in the regulation of fatigue from exercise [23]. In this way, an important application is that the time to fatigue could be predicted by RPE values within the first moments of exercise. Our results show, however, that when all athletes perform at the same relative intensity (e. g., vMLSS or v5 × 2000), the exercise duration can only be predicted in advanced stages of exercise when some runners are close to exhaustion: 60 min for the Tlim at v5 × 2000 (range of Tlim: 64–120 min), 30 min for the Tlim at vMLSS (range of Tlim: 41–80 min). In this regard, several factors must be considered to compare results from different studies: the size and homogeneity of the sample, the methods used to determine the intensity of exercise, the Borg RPE scale used and the time interval of RPE data recording.

Interestingly, during a 2-h effort, swimmers have been shown to select a strategy that allows them to develop the highest possible velocity and keep their serum lactate concentration stable [1]. In contrast, our results show that, probably due to the impossibility of regulating effort during the implementation of a Tlim at v5 × 2000 and a Tlim at vMLSS, there is no true lactate steady state. In fact, the lactate concentration during the effort was an important predictor of the Tlim. A progressive increase in the lactate concentration during the Tlim at v5 × 2000, and especially during the implementation of the Tlim at vMLSS, is not surprising if we consider that the protocols established to determine both velocities were developed for an unstable physiological situation (significant increases in lactate, HR and RPE). Other factors may also significantly contribute to the increases in these parameters with the duration of the effort. In this regard, as the duration of exercise at constant intensity increases, the running economy [29] and the regulation of body temperature [10] worsen. Although an increase in the lactate concentration associated with the duration of exercise during the implementation of the Tlim at vMLSS (using the Billat test) has been observed [7], in a recent study by Baron et al. [3], during the implementation of the Tlim at vMLSS in a cycle ergometer, the arterial lactate concentration decreased upon finishing the exercise, accompanied by significant increases in HR and RPE. Future studies should clarify these contradictory results. We analyzed the concentration of lactate every 45 min during the execution of Tlim at vMLSS and at v5 × 2000. This schedule allowed only 1 or 2 periods of rest (for blood collection), which ensured accuracy in the determination of lactate concentration and Tlim. A greater number of blood samples might be useful in future studies so that lactate kinetics during exercise can be analysed in more detail.

In conclusion, our results suggest that (i) in middle-aged amateur runners, the 5 × 2 000 m test can, in a single day, be equally useful in the assessment of runners as the traditional protocol to determine the MLSS; (ii) the vMLSS and the v5 × 2000 are strongly correlated with the vHM but are not useful for establishing competition pace; (iii) the vMLSS and the v5 × 2000 are not associated with a steady lactate level over time; and (iv) the implementation of a Tlim at vMLSS and at v5 × 2000 on a treadmill does not provide useful information. Further exploratory research in athletes competing in other sports and in athletes with greater sports performance is suggested.

References

1 *Baron B*, *Dekerle J*, *Depretz S*, *Lefevre T*, *Pelayo P*. Self selected speed and maximal lactate steady state speed in swimming. J Sports Med Phys Fitness 2005; 45: 1–6
2 *Baron B*, *Dekerle J*, *Robin S*, *Neviere R*, *Dupont L*, *Matran R*, *Vanvelcenaher J*, *Robin H*, *Pelayo P*. Maximal lactate steady state does not correspond to a complete physiological steady state. Int J Sports Med 2003; 24: 582–587
3 *Baron B*, *Noakes TD*, *Dekerle J*, *Moullan F*, *Robin S*, *Matran R*, *Pelayo P*. Why does exercise terminate at the maximal lactate steady state intensity? Br J Sports Med 2008; 42: 828–33 Erratum in: Br J Sports Med 2009; 43: 310-311
4 *Beneke R*. Methodological aspects of maximal lactate steady state-implications for performance testing. Eur J Appl Physiol 2003; 89: 95–99
5 *Beneke R*, *von Duvillard SP*. Determination of maximal lactate steady state response in selected sports events. Med Sci Sports Exerc 1996; 28: 241–246
6 *Billat V*, *Dalmay F*, *Antonini MT*, *Chassain AP*. A method for determining the maximal steady state of blood lactate concentration from two levels of submaximal exercise. Eur J Appl Physiol 1994; 69: 196–202
7 *Billat VL*, *Sirvent P*, *Py G*, *Koralsztein JP*, *Mercier J*. The concept of maximal lactate steady state: a bridge between biochemistry, physiology and sport science. Sports Med 2003; 33: 407–426
8 *Borg GA*. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 1982; 14: 377–381
9 *Ceci R*, *Hassmén P*. Self-monitored exercise at three different RPE intensities in treadmill vs. field running. Med Sci Sports Exerc 1991; 23: 732–738
10 *Crewe H*, *Tucker R*, *Noakes TD*. The rate of increase in rating of perceived exertion predicts the duration of exercise to fatigue at a fixed power output in different environmental conditions. Eur J Appl Physiol 2008; 103: 569–577
11 *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: 364–368
12 *Eston RG*, *Faulkner JA*, *Mason EA*, *Parfitt G*. The validity of predicting maximal oxygen uptake from perceptually regulated graded exercise tests of different durations. Eur J Appl Physiol 2006; 97: 535–541
13 *Farrell PA*, *Wilmore JH*, *Coyle EF*, *Billing JE*, *Costill DL*. Plasma lactate accumulation and distance running performance. Med Sci Sports 1979; 11: 338–344
14 *Harnish CR*, *Swensen TC*, *Pate RR*. Methods for estimating the maximal lactate steady state in trained cyclists. Med Sci Sports Exerc 2001; 33: 1052–1055

15 *Harriss DJ*, *Atkinson G*. Update – Ethical Standards in Sport and Exercise Science Research. Int J Sports Med 2011; 32: 819–821
16 *Jones AM*, *Doust JHA*. 1 % treadmill grade most accurately reflects the energetic cost of outdoor running. J Sports Sci 1996; 14: 321–327
17 *Kilding AE*, *Jones AM*. Validity of a single-visit protocol to estimate the maximum lactate steady state. Med Sci Sports Exerc 2005; 37: 1734–1740
18 *Kong PW*, *Candelaria NG*, *Tomaka J*. Perception of self-selected running speed is influenced by the treadmill but not footwear. Sports Biomech 2009; 8: 52–59
19 *Kuphal KE*, *Potteiger JA*, *Frey BB*, *Hise MP*. Validation of a single-day maximal lactate steady state assessment protocol. J Sports Med Phys Fitness 2004; 44: 132–140
20 *Legaz Arrese A*, *Munguía Izquierdo D*, *Serveto Galindo JR*. Physiological measures associated with marathon running performance in high-level male and female homogeneous groups. Int J Sports Med 2006; 27: 289–295
21 *Leibar X*, *Terrados N*. Un approccio biomedico alla corsa di maratona. Revista di Cultura Sportiva/SdS 1996; 35: 43–51
22 *Navarro F*, *Legaz Arrese A*. Características fisiológicas de los maratonianos de elite (II): Umbral anaeróbico. Revista de Entrenamiento Deportivo 1998; 12: 25–28
23 *Noakes TD*, *St Clair Gibson A*, *Lambert EV*. From catastrophe to complexity: a novel model of integrative central neural regulation of effort and fatigue during exercise in humans: summary and conclusions. Br J Sports Med 2005; 39: 120–124
24 *Nummela A*, *Hämäläinen I*, *Rusko H*. Comparison of maximal anaerobic running tests on a treadmill and track. J Sports Sci 2007; 25: 87–96
25 *Palmer AS*, *Potteiger JA*, *Nau KL*, *Tong RJA*. 1-day maximal lactate steady-state assessment protocol for trained runners. Med Sci Sports Exerc 1999; 31: 1336–1341
26 *Philp A*, *Macdonald AL*, *Carter H*, *Watt PW*, *Pringle JS*. Maximal lactate steady state as a training stimulus. Int J Sports Med 2008; 29: 475–479
27 *Riley PO*, *Dicharry J*, *Franz J*, *Della Croce U*, *Wilder RP*, *Kerrigan DC*. A kinematics and kinetic comparison of overground and treadmill running. Med Sci Sports Exerc 2008; 40: 1093–1100
28 *Smith CG*, *Jones AM*. The relationship between critical velocity, maximal lactate steady-state velocity and lactate turnpoint velocity in runners. Eur J Appl Physiol 2001; 85: 19–26
29 *Sproule J*. Running economy deteriorates following 60 min of exercise at 80 % VO2max. Eur J Appl Physiol 1998; 77: 366–371
30 *Vobejda C*, *Fromme K*, *Samson W*, *Zimmermann E*. Maximal constant heart rate–a heart rate based method to estimate maximal lactate steady state in running. Int J Sports Med 2006; 27: 368–372