Original article (short paper)

Maximal power output estimates the MLSS before and after aerobic training

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Abstract—The purpose of this study is to present an equation to predict the maximal lactate steady state (MLSS) through a VO_{2peak} incremental protocol. Twenty-six physically active men were divided in two groups (G1 and G2). They performed one maximal incremental test to determine their VO_{2peak} and maximal power output (W_{peak}), and also several constant intensity tests to determine MLSS intensity (MLSSw) on a cycle ergometer. Group G2 underwent six weeks of aerobic training at MLSSw. A regression equation was created using G1 subjects W_{peak} and MLSSw to estimate the MLSS intensity ($MLSSw_{eq}$) before and after training for G2 ($MLSSw_{eq}$ = 0.866 x W_{peak}-41.734). The mean values were not different (150±27W vs 148±27W, before training / 171±26W vs 177±24W, after training) and significant correlations were found between the measured and the estimated MLSSw before (r^2=0.49) and after training (r^2=0.62) in G2. The proposed equation was effective to estimate the MLSS intensity before and after aerobic training.

Keywords: predictive equation, lactate threshold, aerobic training

Resumo—"Potência máxima estima a MFEL antes e após o treinamento aeróbio." Este estudo propõe uma equação para predição da máxima fase estável de lactato (MFEL) através de um teste para medida do VO_{2pico}. Vinte e seis homens fisicamente ativos foram divididos em dois grupos (G1 e G2). Eles realizaram um teste máximo para medida do VO_{2pico} e potência máxima (P_{pico}) e testes submáximos para determinar a intensidade da MFEL (MFELw) em cicloergômetro. O grupo G2 treinou por seis semanas na MFELw. Uma equação de regressão linear foi desenvolvida utilizando os resultados do G1 (P_{pico} e MFELw) para estimativa da MFEL ($MFELw_{eq}$) antes e após o treinamento no G2 ($MFELw_{eq}$=0,866 x P_{pico}-41,734). Os valores médios não foram diferentes (150±27W vs 148±27W, pré-treino / 171±26W vs 177±24W, pós-treino) e encontrou-se uma correlação significativa entre a MFELw medida e estimada antes (r^2=0,49) e após o treinamento (r^2=0,62) no grupo G2. A equação proposta foi efetiva para estimar a MFEL antes e após o treinamento.

Palavras-chave: equação de predição, limiar de lactato, treinamento aeróbio

Resumen—"Potencia máxima estima el MLSS antes y después del entrenamiento aerobio." Este estudio propone una ecuación para la predicción del máximo estado estable de lactato (MLSS) a través de un test para medir VO_{2pico}. Veintiséis hombres físicamente activos se dividieron en dos grupos (G1 y G2). Ellos realizaron un test máximo para medir el VO_{2pico} y potencia máxima (P_{pico}) y testes submáximas para determinar la intensidad de la MLSS (MLSSw) en cicloergómetro. El grupo G2 entrenó por seis semanas en la MLSSw. Una ecuación de regresión lineal fue desarrollada utilizando los resultados del G1 (P_{pico} y MLSSw) para estimar la MLSS ($MLSSw_{eq}$) antes y después del entrenamiento en el G2 ($MFELw_{eq}$=0,866 x P_{pico}-41,734). Los valores medios no fueron distintos (150±27W vs 148±27W, pre-entrenamiento / 171±26W vs 177±24W, después del entrenamiento) y se encontró una correlación significativa entre la MFELw medida y estimada antes (r^2=0,49) y después del entrenamiento (r^2=0,62) en el G2. La ecuación propuesta fue eficaz para estimar la MLSS antes y después del entrenamiento.

Palabras clave: ecuación de predicción, umbral de lactato, entrenamiento aeróbico

Introduction

The power output or velocity at the maximal lactate steady state (MLSSw) is considered the gold standard to determine the lactate threshold (LT) (Svedahl & Macintosh, 2003), and have been widely used for training prescription and to predict aerobic capacity (Billat, Sirvent, Py, Koralsztein, & Mercier, 2003). The method used for the determination of the MLSSw requires two or more 30min constant intensity exercise tests in different days and several blood sample collections. These procedures are quite expensive, time consuming and are not considered very practical for use with athletes and other physically active subjects (Sotero, Pardono, Campbell, & Simões, 2009).

Several authors have proposed simplify the methods for LT identification from a single test, which may include blood collection and analysis (individual anaerobic threshold - IAT (Stegmann, Kindermann, & Schnabel, 1981), onset of blood lactate accumulation - OBLA (Heck et al., 1985), lactate minimum - LM (Tegtbur, Busse, & Braumann, 1993) or, respiratory variables (ventilatory threshold - VT (Wasserman & McIlroy, 1964). However, these methods also require highly specialized technicians to collect and analyze the blood and also expensive equipments and chemical reagents, which may not be available for most athletes at any time. Moreover, some of these methods depend on data interpretation and different testers can produce different results.

Other existing protocols that do not require blood or ventilatory analyses such as time trials (Swensen, Harnish, Beitman, & Keller, 1999) and linear regression equations (Matsunami, Taguchi, Taimura, Suga, & Taba, 1999; Sotero et al., 2009) can be used by fitness coaches as alternative tools for exercise prescription. However these regression equations protocols were originated from MLSS estimates such as LM and OBLA and this may compromise the reliability of the results obtained using such calculations.

The peak power output (W_{peak}) achieved during an incremental protocol, has been found to be strongly correlated to MLSSw (Schuylenbergh, Vanden Eynde, & Hespel, 2004). Endurance training provides several aerobic adaptations which lead to increases in W_{peak} (Carter, Jones, & Doust, 1999) and MLSSw (Ferreira et al., 2007; Gobatto et al., 2001). Therefore, any method used to estimate the MLSS intensity should be sensitive to the effects of training, thereby ensuring the reliability of all tests results over a training period. In our literature review we found only one study proposing a single test method (LM) to estimate the MLSSw after a training period (Carter et al., 1999). However the LM did not accurately identify MLSSw after training.

Therefore, the aim of the present study was to propose a noninvasive, inexpensive and objective protocol to identify the MLSSw, and to test this method's validity for physically active subjects before and after a training period.

Methods

Participants

Twenty six physically active men, divided into two groups (G1; *n*=13 [24 ± 2 years; 73.8 ± 7.3 kg; 15.9 ± 6.0 %fat; 48.86 ± 7.75 $ml.kg^{-1}.min^{-1}$] and G2; *n*=13 [23 ± 2 years; 72.9 ± 6.3 kg; 14.9 ± 5.5 %fat; 44.88 ± 4.77 $ml.kg^{-1}.min^{-1}$]) volunteered for this study after having signed an informed consent form stating both the risks and benefits of their participation**.** The study was approved by the local Ethics Committee for Human Research (no.153/2008).

All participants were asked to refrain from any physical exercise and to abstain from ingesting alcohol or caffeine containing beverages or food during the 24-hour period preceding the experiments. The physical tests as well as the aerobic training sessions were performed on a mechanically braked cycle ergometer (Monark Ergomedic E-824E) previously adjusted and calibrated before each situation in a room with temperature between 21-24ºC and 50-70% relative humidity. The volunteers ingested 500ml of water two hours before the experiments to ensure that they would begin the tests euhydrated (American College of Sports Medicine, 1996).

Overview of experimental design

The research was divided into two parts. The first part of the study was designed to create a prediction equation to identify the MLSSw using the W_{peak} measured during an incremental exercise test performed by a group of 13 participants (G1). In the second part of the study, we tested the accuracy of the prediction equation, prior and immediately after six weeks of aerobic training on another group of 13 participants (G2). The overview of the procedures is presented in Figure 1.

The 26 participants were initially tested for VO_{2peak} and MLSSw. Then, the 13 participants of G2 underwent 6 weeks of aerobic training at MLSS intensity. One week before they finished training all participants of G2 were tested again on VO_{2peak} and MLSSw.

Determination of VO_{2peak} and W_{peak}

A maximal incremental exercise test was performed on a braked cycle ergometer starting at 50W and with increments of 25W at every other two minutes of exercise (Balke & Ware, 1959). Pedal frequency was maintained at 50rpm. Heart rate (HR) was recorded every 1 min during the tests using a HR monitor (Polar S810i®, Finland). Blood samples (30μL) were collected from the earlobe before and at the end of each stage of exercise. Respiratory variables were measured using a gas analyzer ($K4b^2$, Cosmed®, Italy) calibrated before every test. The highest VO_2 of the last minute of exercise was considered the VO_{2peak}. At least two of the following criteria had to be met for determination of the VO_{2peak}: 1) no increase in VO_2 or HR despite increased exercise intensity; 2) respiratory exchange ratio greater than 1.10; 3) maximal heart rate within 5 b.min-1 of age predicted HR (220-age) (American College of Sports Medicine, 2009).

W_{peak} was considered as the highest power output at which the last stage of the test was completed. If the stage was not completed, W_{peak} was calculated using Kuipers, Verstappen, Keizer, Geurten and Van Kranenburg (1985) equation:

$$W_{peak} = W1 + (W2 \cdot t / 120)$$

Where W1 is the power output of the last completed stage, W2 the power output that was incremented in each stage and t is the duration time (in seconds) of the incomplete stage.

Determination of MLSSw

Following the described W_{peak} exercise tests, the participants performed two to five 30-min exercise tests at constant pre-set intensities for the determination of MLSSw. The first intensity was that corresponding to 60% W_{peak} obtained during the maximal incremental exercise. If during the first trial the $[La^-]$ remained stable or decreased towards the end of the 30 min of exercise, the intensity of the following trial was increased until a steady $[La^-]$ could no longer be maintained. On the other hand, if during the first trial $[La^-]$ increased continuously over the 30 min or exercise was interrupted due to participant's fatigue, the intensity of the following trials was reduced. The MLSSw was determined with a precision of 15W. During the tests to determine the MLSSw, blood samples were collected for $[La^-]$ analysis prior to the beginning of the exercise and at 5-min intervals until the end of the test. The highest intensity at which $[La^-]$ increased less than 1mM during the last 20min of exercise was defined as the MLSSw (Heck et al., 1985).

Blood analyses

All blood samples were stored at -20ºC in tubes containing 60µL NaF (1%) and later analyzed in triplicates for lactate on (YSI 1500 STAT®, Yellow Springs, Ohio, USA). The YSI 1500 STAT was calibrated with standard solutions of 5mM and 30mM lactate, according to the manufacturer's recommendations.

Part 1 – Generation of the predictive equation

From the results of the W_{peak} and MLSS tests obtained for the participants of G1, a predictive equation of MLSSw was generated (Figure 2).

Part 2 – Validation of the predictive equation before and after aerobic training

The W_{peak} of G2 participants before training was used in the predictive equation to estimate MLSS intensity ($MLSSw_{eq}$). The $MLSSw_{eq}$ was then compared to the actually measured values (MLSSw) to analyze its validity. The same calculations were repeated with G2 data after the 6-week training period.

Aerobic training program

The aerobic training protocol was adapted from Philp, Macdonald, and Watt (2005). The G2 participants accomplished three constant exercise training sessions per week during six weeks. The initial training session duration was 24 min and it was increased continuously by 3 min per week, reaching 39 min over the six-week period. The G2 participants were instructed to maintain their normal daily activities and not undertake any kind of additional physical training during the study period.

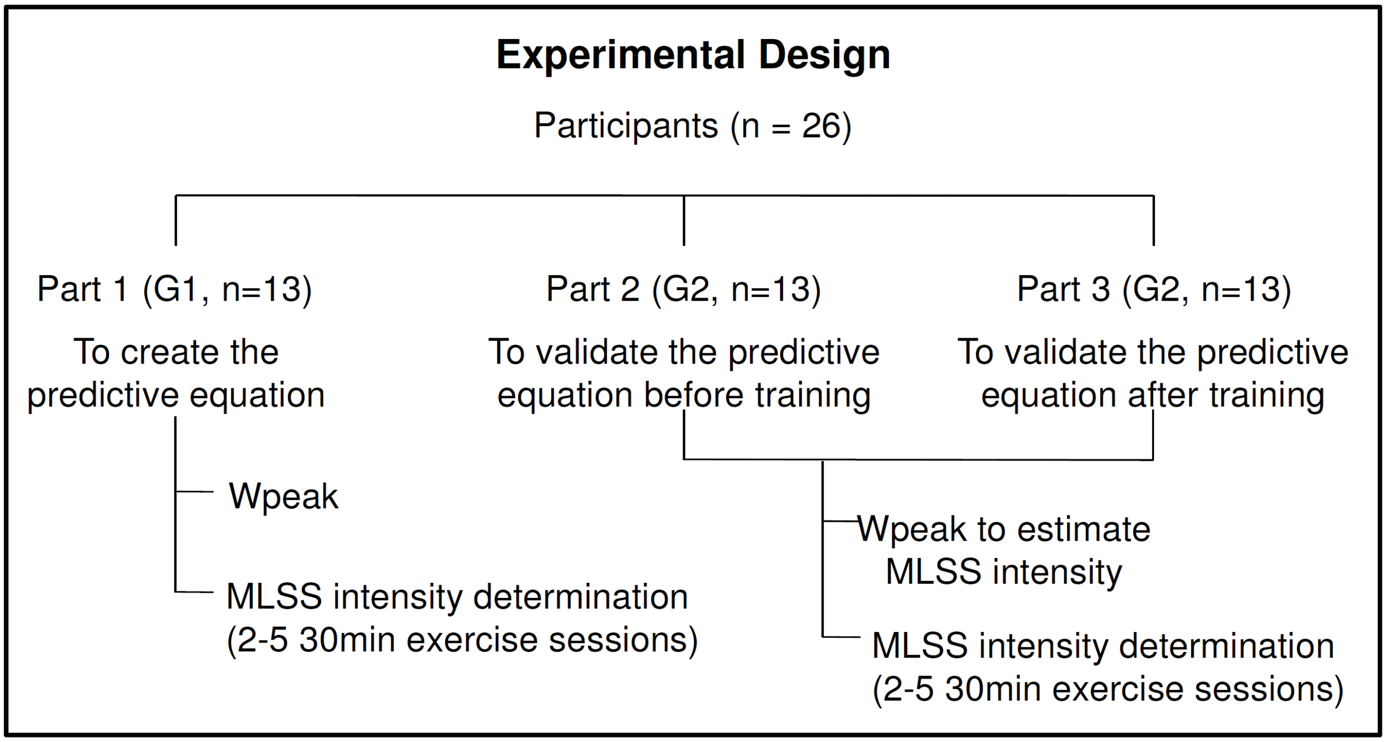

Figure 1. Overview of the experimental procedures.

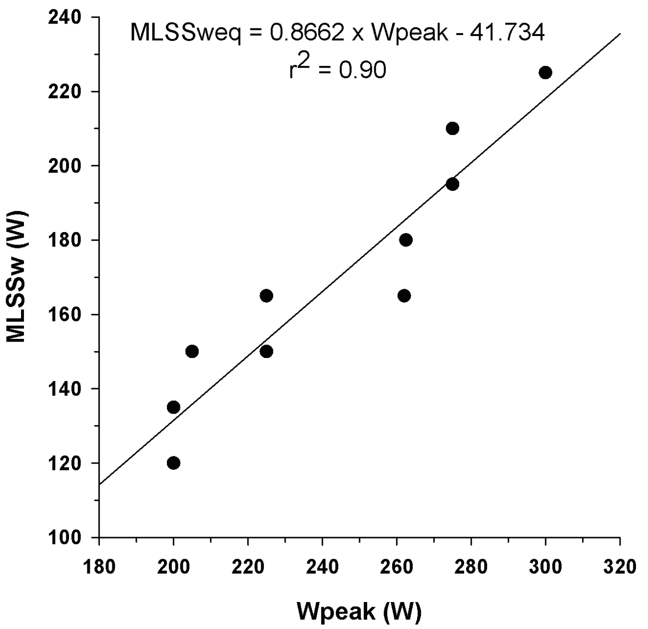

Figure 2. Linear regression between maximal power output (W_{peak}) and power output at MLSS (MLSSw) for participants in group 1.

Statistical analysis

A linear regression between W_{peak} and MLSSw was applied to the G1 results (Figure 2) to yield a predictive equation for $MLSSw_{eq}$. The equation generated by G1 ($MLSSw_{eq}$= 0.8622 x W_{peak} – 41.734) was applied to G2 to predict MLSSw before and after training. To compare MLSSw and $MLSSw_{eq}$ a paired Student's *t* test was used. Correlations between MLSSw and $MLSSw_{eq}$, both before and after aerobic training were calculated using the Pearson product-moment correlation. The agreement between the studied variables was analyzed by the method of Bland and Altman. The level of significance adopted was $p < 0.05$ and all data were analyzed and expressed as mean ± standard deviation.

Results

The results of W_{peak}, MLSSw e $MLSSw_{eq}$ are presented in Table 1.

Table 1. Maximal power output (W_{peak}), power output corresponding to MLSS (MLSSw) and power output corresponding to MLSS estimated by the regression equation ($MLSSw_{eq}$) (Watts) of G1 and G2 before (pre) and after (post) six weeks of aerobic training.

	G1	G2	
	Pre	Pre	Post
W_{peak}	242 ± 34	222 ± 27	252 ± 28*
MLSSw	169 ± 31	150 ± 27	171 ± 26*
$MLSSw_{eq}$	-	148 ± 27	177 ± 24*

* Different from pre-training (p<0.05).

A strong correlation was found between W_{peak} and MLSSw of G1 ($r^2 = 0.89$; $p<0.001$) and the linear regression yielded the following predictive equation for MLSSw: MLSSweq = 0.8662 x W_{peak} – 41.734.

When the predictive equation was applied to data obtained from participants of G2 no differences were observed ($p > 0.05$; Table 1) and there was a strong correlation between MLSSw and $MLSSw_{eq}$ before training ($r^2 = 0.49$; $p < 0.01$). After the training period G2 W_{peak} and MLSSw were higher than before ($p < 0.05$; Table 1) and there were no differences between the MLSS power output measured and that estimated using the predictive equation (Table 1). Moreover, a strong correlation ($r^2 = 0.62$; $p < 0.05$) between MLSSw and $MLSSw_{eq}$ was found.

The Bland-Altman technique revealed a good agreement between MLSSw and $MLSSw_{eq}$ before and after the six weeks of training (Figure 3). The difference between the measured and the estimated MLSSw was lower than 25W for 85% of the participants before and after training, and only for two participants the variations was close to 40-60W.

Discussion

The main finding of this study was that the equation ($MLSSw_{eq}$ = 0.8662 x W_{peak} – 41.734) provided a good estimate of the MLSSw using the maximal power output reached on a single incremental test of physically active man before and after six weeks of aerobic training.

The traditional method used to determine the MLSS requires 3 to 5 days of testing, making its use burdensome for athletes. Furthermore, the excessive number of testing sessions increases the cost of the evaluation, which can be too expensive for recreational athletes and physically active participants. Given that the MLSSw is considered the gold standard to predict aerobic capacity (Denadai, Gomide, & Greco, 2005) and performance in exercises lasting from 30 to 60 minutes (Billat et al., 2003), the development of alternative methods for the simplification of its measurement becomes important (Sotero et al., 2009; Swensen et al., 1999).

Many researchers have published papers proposing the use of single-day test protocols to estimate MLSS in order to make these methods of training evaluation and prescription more affordable for the people in general (De Barros et al., 2011; Knoepfli-Lenzin & Boutellier, 2011; Schuylenbergh et al., 2004). Some of these methods are widely used (Amann, Subudhi, & Foster, 2004; Heck et al., 1985; Stegmann et al., 1981). However most studies are focused on the relationships among direct blood lactate measurements (Grossl, De Lucas, Souza, & Guglielmo, 2012) or indirect methods using gas exchange (Bentley & McNaughton, 2003). Additionally, few studies tested alternative methods that require less technology and lower cost (Sotero et al., 2009; Swensen et al., 1999) and none of them checked their validity after a training period.

The W_{peak} has been shown to be highly correlated to time trial performance ranging from 21 to 40km (Balmer, Davison, & Bird, 2000; Hawley & Noakes, 1992) and lasting for 90 min (Bentley, Lars, Dylan, Veronica, & Alan, 2001). In our study, the W_{peak} was also highly correlated to MLSSw (G1 - $r^2 = 0.89$;

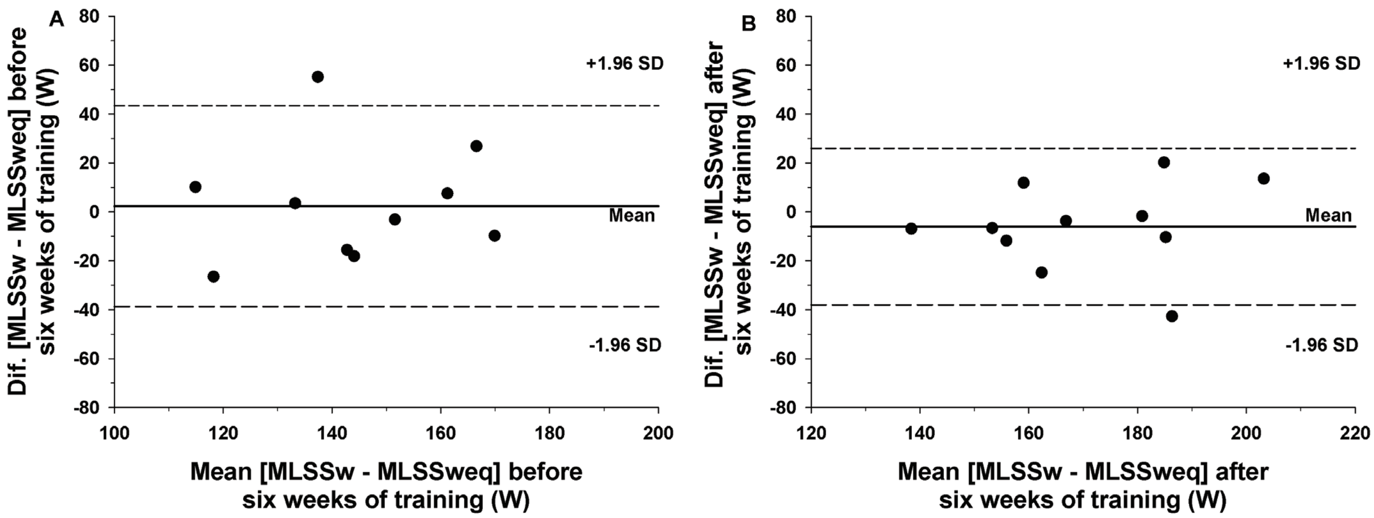

Figure 3. Limits of agreement between power output at maximal lactate steady (MLSSw) - power output at MLSS estimated by the regression equation ($MLSSw_{eq}$) of G2 before (A) and after (B) six weeks of aerobic training.

$p < 0.01$), a similar value to the one reported by Schuylenbergh et al. (2004), who studied trained cyclists. Based on this relationship we created a predictive equation to estimate power output at MLSS using W_{peak}.

The MLSS in G2 estimated by the equation created in this study was very similar to the MLSSw determined by traditional method (148 ± 27 W *vs* 150 ± 27 W, respectively, $p > 0.05$). Furthermore they presented strong correlation ($r = 0.70$; $p<0.01$) and the technique of Bland and Altman showed an agreement between MLSSw and MLSSweq. These results were supported by the fact that for 85% of the participants the estimated MLSSw showed an error of up to 15% or 25W. However estimated MLSSw of two participants showed variation between 30-60W from the original measure, which may have a significant impact on training prescription and therefore shows a limitation of the use of the equation proposed on this study.

Prediction of the MLSS using different methods has already been shown to have limitations for individual analysis and differences between the measured and the estimated MLSS between 15 and 70W were already found (Faude, Kindermann, & Meyer, 2009). Nevertheless based on the lack of difference between the measured and the estimated MLSSw and the high correlation between them before and after training, the use of proposed equation can contribute to training prescription of athletes and physically active people that do not have access to the gold standard measure procedures.

Another way of predicting MLSS is through time trials. Cycling time trials of 5 and 40km has been proposed to estimate the MLSS velocity (Harnish, Swensen, & Pate, 2001; Swensen et al., 1999). However it would be necessary more than one day of testing to determine MLSS velocity through 5km TT, while the 40km TT can be limited only to highly trained participants.

Sotero et al. (2009) proposed an equation to predict LM running velocity trough a 1600 meters TT that was found to be valid for physically active men. Although there were no differences between the measured MLSS and the estimated LM velocity the predictive equation was created using an estimation method for MLSS determination, and that could decrease the results reliability.

More studies with the aim to predict MLSS intensity through regression equation used protocols that already estimate MLSSw - OBLA or LM - (Almeida et al., 2010; Matsunami et al., 1999) to design their methods. Moreover, they did not compare the estimated MLSSw to the traditional method, therefore making the results even less reliable. In addition, those studies were conducted in swimming and running, while we used cycling exercise.

Aerobic training performed at or near the intensity corresponding to MLSS has been related to an increase in MLSSw (Carter et al., 1999). Corroborating these data, in the present study the period of aerobic training increased the MLSSw (150 ± 27 W before and 171 ± 26 W after training), showing that adaptations occurred. Even with increased MLSSw no differences and a strong correlation were found between the measured and estimated MLSS intensity after the training period (MLSSw = 171 ± 26 W and $MLSSw_{eq}$ = 177 ± 24 W; $r = 0.79$).

The LM is not sensitive enough to detect changes in aerobic capacity over an endurance training period of 6 weeks (Carter et al., 1999). Recently Knoepfli-Lenzin and Boutellier (2011) suggested using LM as an accurate estimative of MLSS for physically active and trained participants, however LM intensity was different from the one observed at MLSS.

Our results showed that the use of the equation is reproducible since it can be used for physically active individuals over a training period. Another advantage provided by this test protocol is that it was first designed to assess VO_{2peak} (American College of Sports Medicine, 1996). Thus a single test can be used to assess both the MLSSw and VO_{2peak}.

However, since the participants in the present study were young and physically active men, caution should be taken when extrapolating the use of the proposed equation to women, older people and aerobic trained individuals. Also, the reduced number of participants used to test the predictive equation (13 participants) is a limitation of this study. Therefore, more studies should be encouraged to test the validity of proposed equation in a larger sample of participants, and in different groups.

In conclusion, the proposed linear regression equation ($MLSSw_{eq}$ = 0.8662 x W_{peak} – 41.734) may be applied to estimate MLSS intensity on a cycle ergometer of physically active individuals before and after a period of aerobic training in a practical, non-invasive and inexpensive procedure.

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