Maximum Constant Heart Rate – A Heart Rate Based Method to Estimate Maximal Lactate Steady State in Running

Abstract

The aim of the present study was to investigate the accuracy of the maximal constant heart rate method for predicting anaerobic threshold (AnT) in running. This method only requires a common heart rate (HR) monitor and is based on the identification of the maximal constant HR maintainable for 30 min (HR\textsubscript{Mc}). HR\textsubscript{Mc}, 4-mmol threshold, and maximal lactate steady state (MLSS) were determined in 31 probands. 17 probands underwent an additional MLSS retest within 2 weeks. The correlation between HR at MLSS and at MLSS retest was very close (\(r = 0.807; \text{SEE} = 5.25\) beats · min\(^{-1}; p < 0.001). So were the correlations between HR at 4-mmol threshold and MLSS (\(r = 0.844; \text{SEE} = 6.43\) beats · min\(^{-1}\); \(p < 0.001\)) and between HR\textsubscript{Mc} and HR at MLSS (\(r = 0.820; \text{SEE} = 6.73\) beats · min\(^{-1}\); \(p < 0.001\)). Mean velocities at maximum constant HR trials and MLSS (\(r = 0.895; \text{SEE} = 0.185\) m · s\(^{-1}\); \(p < 0.001\)) as well as 4-mmol threshold and MLSS (\(r = 0.899; \text{SEE} = 0.186\) m · s\(^{-1}\); \(p < 0.001\)) were highly correlated. In conclusion, data presented in this study confirm that the determination of HR\textsubscript{Mc} is a manageable method giving a highly accurate estimation of both HR and velocity at MLSS in running.

Key words

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Introduction

It is commonly accepted that intensity is a decisive factor for determining the degree of adaption to endurance exercise training. Heart rate (HR) and velocity (V) at the anaerobic threshold (AnT) have been established as reference points for describing endurance training methods and adjusting endurance exercise intensities since AnT represents the characteristic shift from predominantly aerobic to anaerobic energy metabolism [7,11,25]. Determination of maximal lactate steady state (MLSS) is an excellent tool for assessing AnT by means of lactate diagnostics, whereas lactate threshold conceptions based on incremental exercise are not capable of predicting MLSS precisely [2,29]. In contrast to elite athletes the majority of the recreational and club level athletes do not have the opportunity to determine their individual MLSS since multiple prolonged exercise protocols and lactate diagnostics are required. In most cases recreational runners do not even have the alternative to identify their AnT by Incremental Exercise Protocols (IEP) and lactate diagnostics or respiratory parameters.

Therefore, techniques of AnT determination requiring minimal equipment are of general interest. HR based formulas, however, are regarded to be not highly accurate [11,25] and Conconi’s concept is still under discussion [8,9,18]. Interpretation of the HR variability is an interesting up-to-date approach, but its applicability to training practice still has to be demonstrated [20].

Recently our work group confirmed that the identification of the maximal constant HR (HR\textsubscript{Mc}), which is the highest HR maintainable for 30 min, is a workable and precise method to estimate HR and workload at MLSS in cycling [29]. The aim of the present
study was to verify if the HR_{MC} method, only requiring a common HR monitor, is also suitable in determining AnT in running.

**Material and Methods**

**Subjects**

Six female (31.8 ± 8.9 yrs, 165.3 ± 6.4 cm, 57.2 ± 4.3 kg) and 25 male subjects (26.5 ± 4.0 yrs, 181.6 ± 8.4 cm, 76.4 ± 9.7 kg) participated in this study. All participants met the following inclusion criteria: 1. free from serious diseases, 2. 20–50 yrs, 3. able to run for at least 60 min. Subjects were instructed to avoid exhausting exercise beyond those being a part of the study, to refrain from physical training for at least 48 h prior to testing and to retain their normal nutritional habits. All subjects acknowledged voluntary participation through written informed consent.

**Exercise protocols**

All tests were carried out in a laboratory (temperature 17 – 24°C, humidity 40 – 60%) on a motor driven treadmill (model Ergo ELG2, Woodway, Germany). The treadmill belt was set at 1% elevation to compensate for the absence of wind resistance. Each subject performed 1 Incremental Exercise Protocol (IEP 1) to determine the 4 mmol threshold (AnT-4), 2–5 Prolonged Exercise Protocols (PEP) with variable load in order to assess HR_{MC} (2–5 PEP with constant load to determine MLSS and another IEP (IEP 2). Seventeen of the 31 subjects performed an additional PEP at MLSS workload (MLSS retest) while the others were unable to perform the MLSS retest within 2 weeks due to organisational reasons. Because of the necessary extensive test protocol and the required regeneration, the test period lasted 2–3 months per subject.

IEP started at a running velocity of 2.0 m·s⁻¹ and increased by 0.4 m·s⁻¹ every 5 min until exhaustion. Before the test and at the end of 5 min of each work stage capillary blood samples were taken from the ear lobe to determine blood lactate concentration (BLC). Mean HR of 5 min of each work stage was analysed.

HR_{MC} was determined by variable load PEP lasting 45 min. Within the first 15 min of running velocity was gently increased in order to attain a certain HR. During the next 30 min speed was adjusted by the investigator in order to keep HR constant. The first trial was performed at a HR of 175 beats·min⁻¹. If the subjects were able to maintain the target HR for 30 min, then target HR was increased by 10 beats·min⁻¹ at the next test session. This procedure was conducted until they reached exhaustion before the test was completed. In order to specify HR_{MC} up to 5 beats·min⁻¹ another test was performed at a target HR 5 beats·min⁻¹ lower than the HR the subject was unable to withstand. If the subject was unable to maintain a HR of 175 beats·min⁻¹ in the first test, the procedure was executed alike, but with decreasing HR. Before testing, after warm-up (15 min) and in the 25th, 35th, and 45th min the subjects stopped running for circa 30 s to enable blood sampling for BLC quantification.

MLSS was determined by constant load PEP starting with a 3-min warm-up at 60% of the speed the subjects had to run for the next 30 min. The first test was carried out at the running velocity cor-

responding to AnT-4 deduced from the first IEP. The load of the following bouts was altered in 0.1 m·s⁻¹ steps. The tests were interrupted for blood sampling for circa 30 s after 8, 13, 18, 23, 28, and 33 minutes.

**Assays**

Capillary blood samples (20 µl) for quantification of BLC were taken from the ear lobe and analysed by an enzymatic–amperometric method (Super GL, Dr. Müller Gerätebau, Germany). HR was measured continuously every 10 s by a Fitwatch HR monitor (Polar Electro, Germany).

**Data analysis**

Velocity and HR at AnT-4 (V_{AnT-4} HR_{AnT-4}) were determined graphically according to the Mader concept [22, 23]. The results of the lactate analysis were communicated neither to the investigator nor the probands until HR_{MC} was determined. The mean velocity at HR_{MC} trial (V_{HRMC}) was calculated from the values of the 20th to 45th min except for the 2 min after each sample drawing. According to Heck [13] MLSS was attained when BLC increase was less than 1.0 mmol·l⁻¹ during the final 20 min. Mean BLC at MLSS was the average of the 13th, 18th, 23rd, 28th, and 33rd min. HR at the end of MLSS (HR_{MLSS} and MLSS retest (HR_{MLSS-re}) was the mean HR of the 33rd min. MLSS retest was accomplished within 2 weeks (8.5 ± 5.1 days) after determination of MLSS. Since 1 proband was unable to maintain MLSS workload at MLSS retest, interrelationship between HR_{MLSS} and HR_{MLSS-re} was computed from 16 data records. Data of IEP 2 was taken to compare HR_{AnT-4} to HR_{MLSS}. Due to organisational reasons IEP 2 could not be conducted on 2 subjects so that the correlation between HR_{MC} and HR_{MLSS} was based on 29 data records. All 31 data records were applied in calculating the correlation between HR_{MC} and HR_{MLSS}. HR_{MC} was determined 31.1 (± 15.7) days prior to MLSS identification while IEP 2 was carried out 21.8 (± 10.9) days thereafter.

**Statistical analysis**

SPSS version 10.0.7 was used to analyse the data. Kolmogorov-Smirnov test was applied to prove normal distribution. Significant differences were identified using one-way analysis of variance (ANOVA). When only two means were compared a two-sided t-test, both for dependent or independent variables, was employed. Linear regression analysis was applied to describe the relationship between two independent variables. Data is presented as mean ± standard deviation unless otherwise indicated.

In order to determine the relationship between V_{MLSS} and V_{HRMC} as well as V_{AnT-4} and V_{MLSS} the period elapsed between determination of the two compared parameters was limited to 30 days reducing sample size to 21 and 25 cases, respectively. For ANOVA analysis of the differences between V_{HRMC}, V_{MLSS}, and V_{AnT-4} both the time interval from V_{HRMC} to V_{MLSS} plus the interval from V_{AnT-4} to V_{MLSS} did not exceed 30 days. Therefore, sample size was reduced to 17 cases.
Results

$V_{\text{AIt-4}}$ increased slightly from $3.40 \pm 0.51$ m·s$^{-1}$ at IEP 1 to 3.53 \( \pm 0.42 \) m·s$^{-1}$ at IEP 2 (p < 0.01). On the other hand, $HR_{\text{AIt-4}}$ decreased from 179.8 \( \pm 10.2 \) beats·min$^{-1}$ at IEP 1 to 177.2 \( \pm 11.3 \) beats·min$^{-1}$ at IEP 2 (p < 0.05).

$HR_{\text{BMC}}$ and $V_{\text{BMC}}$ were 177.9 \( \pm 9.0 \) beats·min$^{-1}$ and 3.09 \( \pm 0.45 \) m·s$^{-1}$ on average. In order to reach the aspired HR running velocity had to be increased during warm-up. From then on velocity had to be continuously reduced to maintain a constant HR. This decrease was even more defined from the 15th to 25th than from the 25th to 45th min. On the other hand, BLC reached its maximum in the 25th min followed by a continuous decrease (Fig. 1).

Velocity at MLSS ($V_{\text{MLSS}}$) was $3.39 \pm 0.40$ m·s$^{-1}$. Mean BLC was $3.77 \pm 1.12$ mmol·l$^{-1}$ accompanied by an increase of BLC (0.61 \( \pm 0.27 \) mmol·l$^{-1}$) during the final 20 min. During that time HR increased from 169.7 \( \pm 10.4 \) beats·min$^{-1}$ in the 13th min to 179.0 \( \pm 11.9 \) beats·min$^{-1}$ in the 33rd min. Mean BLC and BLC increase at MLSS retest were 3.66 \( \pm 1.30 \) and 0.45 \( \pm 0.54 \) mmol·l$^{-1}$. HR increased from 167.8 \( \pm 8.4 \) to 176.6 \( \pm 9.1 \) beats·min$^{-1}$.

In contrast to the differences between $V_{\text{BMC}}$ (3.07 \( \pm 0.48 \) m·s$^{-1}$) and $V_{\text{MLSS}}$ (3.35 \( \pm 0.42 \) m·s$^{-1}$) and between $V_{\text{AIt-4}}$ (3.49 \( \pm 0.44 \) m·s$^{-1}$) and $V_{\text{MLSS}}$ the discrepancy between $V_{\text{BMC}}$ and $V_{\text{AIt-4}}$ was significant (p < 0.05). The correlations between $V_{\text{BMC}}$ and $V_{\text{MLSS}}$ ($r = 0.895$; SE = 0.185 m·s$^{-1}$; p < 0.001) as well as $V_{\text{AIt-4}}$ and $V_{\text{MLSS}}$ ($r = 0.899$; SE = 0.186 m·s$^{-1}$; p < 0.001) were very close. The slope (0.823) and intercept (0.493) of the regression equation predicting $V_{\text{MLSS}}$ from $V_{\text{AIt-4}}$ indicate a regression line being somewhat closer to the line of identity than that of $V_{\text{MLSS}}$ and $V_{\text{BMC}}$ (slope = 0.809; intercept = 0.850).

The differences between $HR_{\text{BMC}}$ (177.9 \( \pm 9.0 \) beats·min$^{-1}$), $HR_{\text{AIt-4}}$ (177.2 \( \pm 11.3 \) beats·min$^{-1}$), $HR_{\text{MLSS-Re}}$ (176.1 \( \pm 8.9 \) beats·min$^{-1}$), and $HR_{\text{MLSS}}$ (178.5 \( \pm 11.6 \) beats·min$^{-1}$) were minimal and insignificant (Fig. 2). The regression line predicting $HR_{\text{MLSS}}$ from $HR_{\text{BMC}}$ almost equals the line of identity (Fig. 3), whereas the regression lines for $HR_{\text{AIt-4}}$/HRMLSS and $HR_{\text{MLSS-Re}}$/HRMLSS diverge slightly from the bisecting line (Figs. 4, 5).

Discussion

HR is the parameter most frequently used to control endurance exercise intensity in the field [11,26], because on the one hand it is easily accessible and on the other hand transferring absolute data like running velocity or power output from the laboratory to the field is rather problematic. Moreover, for many athletes HR deduced from formulas or the Conconi method is the only parameter available. Therefore, the objective of this study was to verify the accuracy of the $HR_{\text{BMC}}$ method to determine HR at MLSS in running since this method requires only minimal technical equipment and can be easily integrated into training practice. Yet, determination of $HR_{\text{BMC}}$ calls for several exhausting exercise bouts so that high motivation as well as medium aerobic capacity are obligatory. For this reason, this method is unsuitable for untrained or unmotivated persons.
Determination of \( V_{\text{Ant}} \) by means of incremental exercise protocols is somewhat imprecise with respect to the parameters of threshold conceptions applied \([2, 12, 14, 19, 24, 29]\). In order to obtain a closer relationship between \( V_{\text{Ant}} \) and \( \text{MLSS} \) (HR\(_{\text{MLSS}}\)) than what is observed by comparing it to MLSS which is regarded to be an excellent tool for assessing \( V_{\text{Ant}} \) \([2]\). In addition, the widely used 4-mmol lactate threshold was determined because comparison of data from different studies is rather difficult. The coefficients of correlation most frequently used to describe the goodness-of-fit \([10, 16, 29]\) vary extremely mainly depending on the heterogeneity of the random samples \([15]\) and, thus, not being very meaningful.

\( V_{\text{Ant}} \) increased only marginally from IEP 1 to IEP 2 (0.13 m\( \cdot \)s\(^{-1}\); \( p < 0.01 \)). Also, the time intervals between determination of \( V_{\text{HRMC}} \) and \( \text{MLSS} \) as well as \( V_{\text{Ant}} \) and \( \text{MLSS} \) did not exceed 30 days, so that the influence of changing aerobic capacities which might be potentially induced by the testing procedure or alterations in the subjects’ regular training regime was negligible. These interrelationships were very close and almost identical. At first sight, the coefficient of correlation between \( V_{\text{Ant}} \) and \( \text{MLSS} \) presented by Heck et al. \([13]\) indicated a somewhat closer interrelationship. However, \( \text{SEE} = 0.199 \text{ m} \cdot \text{s}^{-1} \) calculated on the basis of the raw data presented in the aforementioned study indicated that the goodness-of-fit for the prediction of \( V_{\text{MLSS}} \) from \( V_{\text{HRMC}} \) \( (\text{SEE} = 0.185 \text{ m} \cdot \text{s}^{-1}) \) and from \( V_{\text{Ant}} \) \( (\text{SEE} = 0.186 \text{ m} \cdot \text{s}^{-1}) \) was even somewhat closer in the present study. Thus, the data presented in this paper demonstrate that \( V_{\text{HRMC}} \), although not representing metabolic steady state conditions, provides a close estimate of \( V_{\text{MLSS}} \). In our investigation on evaluating the HR\(_{\text{MC}}\) method in cycling \([29]\) we also found a very close correlation between the power output at HR\(_{\text{MC}}\) trials and at MLSS. The correlation between the power output at the 4-mmol threshold and at MLSS in comparison was somewhat weaker. So were the interrelationships between HR\(_{\text{MC}}\) and HR\(_{\text{MLSS}}\) and between HR\(_{\text{Ant}}\) and HR\(_{\text{MLSS}}\). The weaker correlation between \( V_{\text{Ant}} \) and MLSS might be due to the fact that the variation of BLC at MLSS was more pronounced in our cycling than in the present running study. The 4-mmol threshold per definition calls for a BLC of 4 mmol\( \cdot \)l\(^{-1}\) at MLSS and so will be more faulty the more BLC at MLSS differs from 4 mmol\( \cdot \)l\(^{-1}\). In general, mean BLC and variation of BLC at MLSS seems to be somewhat higher in cycling than in running \([1, 3 – 6, 10, 14, 16, 17, 19, 21, 29]\).

Nevertheless, the primary purpose of this study was to verify the suitability of the HR\(_{\text{MC}}\) method estimating the HR at the end of MLSS. But, despite the fact that HR is commonly used to record and control endurance exercise intensities in the field, studies comparing the HR calculated from threshold conceptions or HR formulas to the HR at MLSS are very seldom. Foster et al. \([11]\) attempted to develop a model based on the maximum HR, but prediction of steady state conditions was correct only in 68\%. Dekker et al. \([10]\) found that the HR at the second ventilatory threshold and at MLSS was not significantly correlated. In the present study both coefficients of correlation and SEE indicated very close interrelationships between HR\(_{\text{MC}}\) and HR\(_{\text{MLSS}}\) as well as HR\(_{\text{Ant}}\) and HR\(_{\text{MLSS}}\) with the latter being marginally closer.

Residual variance for the interaction between HR\(_{\text{Ant}}\) and HR\(_{\text{MLSS}}\) can be explained by the aforementioned variations of BLC at MLSS to a certain degree. Correlation between HR\(_{\text{MC}}\) and HR\(_{\text{MLSS}}\), on the other hand, might be affected by the probands unequal anaerobic capacities in that BLC rose clearly above 4 mmol\( \cdot \)l\(^{-1}\) at the beginning of the HR\(_{\text{MC}}\) trials. In this study the initial increase occurred although running speed and, therefore, HR was increased slowly during the 15-min warm-up. Furthermore, HR\(_{\text{MC}}\) was determined in 5 beats\( \cdot \)min\(^{-1}\) steps implying both, a certain inaccuracy and potential for improvement.

It has to be pointed out that the interrelationship between HR\(_{\text{MLSS-Re}}\) and HR\(_{\text{MLSS}}\) was only slightly stronger when indicated by SEE and even somewhat weaker when indicated by the coefficient of correlation. One proband even had to discontinue the MLSS retest. Regrettably, studies investigating the reproducibility of MLSS determination are missing. It is implausible that these variations are caused by changes in aerobic capacity throughout the study. As mentioned before, \( V_{\text{Ant}} \) increased only...
marginally from IEP 1 to IEP 2. Furthermore, training does not affect the HR at a given percentage of maximal oxygen uptake [27]. More likely these variations are caused by the normal daily changes in performance capacity. This has to be taken into account when evaluating the accuracy of the HRMC method.

In summary, data presented in this study demonstrates that determining the ANT by means of the HRMC method is a workable alternative for those athletes not having access to laboratory diagnostics. It only requires a commercially available heart rate monitor and the estimation of HR and velocity at MLSS in running is as precise as the lactate-based ANT-4 method.

References
