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RELATIONSHIP BETWEEN THE ANAEROBIC THRESHOLD AND THE MAXIMAL LACTATE STEADY STATE IN MALE AND FEMALE ROWERS

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Abstract. The aim of the present study was to compare the anaerobic threshold and the maximal lactate steady state (MLSS) in rowers. The investigated athletes consisted of the elite Polish junior and senior male (n=14) and female (n=5) rowers. Each subject performed two tests on the Concept II rowing ergometer: one incremental exercise to determine the anaerobic threshold at 4 $\mathrm{mmol \cdot l^{-1}}$ lactate concentration (AT4) and one 30-min exercise at a constant, submaximal intensity to estimate MLSS. The latter parameter was defined as the highest blood lactate level that within the last 20 min of exercising at the constant intensity increased by no more than 1.0 $\mathrm{mmol \cdot l^{-1}}$. The estimated MLSS levels equalled to 3.66±0.93 $\mathrm{mmol \cdot l^{-1}}$ and to 2.72±0.54 $\mathrm{mmol \cdot l^{-1}}$ in the male and female rowers, respectively. In both groups of the athletes the obtained MLSS values markedly varied ranging from 1.83 to 5.93 $\mathrm{mmol \cdot l^{-1}}$. Significant differences between the power output at AT4 and the power output at MLSS were noted both in the male (307±41 vs. 278±35 W) and the female (219±15 vs. 192±14 W) rowers. The ratios of the power output at MLSS to the power output at AT4 equalled to 91±4% and 88±2% in the male and female athletes, respectively. The obtained results indicate that in order to optimally select the intensity of the aerobic capacity-shaping training of both male and female rowers the power output at AT4 should be lowered by approximately 10%. ***(Biol.Sport 22:171-180, 2005)***

Key words: Rowers - Anaerobic threshold – Maximal lactate steady state

Introduction

The anaerobic threshold indices are commonly used for estimation of the course of adaptation to exercising during training of rowers [14,15,16,19]. Intensity of the training is planned based on the threshold workload. It is commonly assumed that

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anaerobic threshold reflects the upper limit of the workload sustained by the aerobic metabolism. Recently, numerous studies have been aimed at verification of the above assumption [1,2,3,5]. A term of the maximal lactate steady state (MLSS) has been introduced as the highest value of the blood lactate level attainable during exercising with a constant intensity when production of lactate is balanced against its utilisation [7,8].

The aim of the present study was to compare the anaerobic threshold with the maximal lactate steady state determined in male and female rowers during exercising on a rowing ergometer.

Material and Methods

The elite Polish junior and senior rowers (14 males and 5 females) were recruited to participate in the study. Characteristics of the subjects is presented in Table 1. Approval from the Research Ethics Committee of the Institute of Sport had been granted prior to any testing and all the examinations were performed during the preparatory training period.

Table 1
Basic characteristics of the examined male (n=14) and female (n=5) rowers (means±SD)

	Age (years)	Body mass (kg)	Height (cm)	Training experience (years)
Male rowers	23.8±3.3	93.0±8.3	185.6±6.2	9.4±4.2
Female rowers	23.1±5.2	67.6±7.2	175.4±6.9	8.4±4.8

Each athlete was subjected to two exercise tests on the Concept II rowing ergometer. The anaerobic threshold test consisted of five 3-min submaximal exercises separated by the 30-s breaks. In the case of male rowers, the first workload equalled to 220 W and gradually increased by 50 W in subsequent workloads; in case of the females the respective values were 120 W and 40 W. The incremental workloads were carried out at the following rowing rates: 18, 20, 22, 24, and 26 pulls per min. The anaerobic threshold (AT4) was determined by interpolation of the values of the exercise indices registered at 4 $\text{mmol}\cdot\text{l}^{-1}$ blood lactate level [17].

To estimate the maximal lactate steady state (MLSS), a series of 30-min submaximal exercises at the constant power output and constant rowing rate separated by a one-day rest was employed. Each exercise was preceded by a 5-min warm up at the intensity corresponding to the heart rate (HR) of 130 bpm. Initial workload was set at the power output corresponding to 88-90% of AT4. If during a 30-min exercise at the given workload the blood lactate concentration did not change or decreased, the workloads would increase on the following days by 3-5%. In extreme cases, when the lactate concentration increased above 1 mmol·l^{-1} during the first exercise, it was necessary to lower the workloads in the subsequent tests by 3-5%. The applied changes of the workload were based on the results of our earlier studies [unpublished data]. MLSS was defined after Heck *et al.* [7] as the highest lactate concentration in the blood that does not exceed 1.0 mmol·l^{-1} during the last 20 min of exercising at a constant workload.

Blood for lactate assay was sampled from earlobes at rest, and immediately after every exercise bout and the blood lactate (LA) level was determined using the LP 400 photometer (Dr Lange, Germany). During the tests, HR was continuously recorded using the Polar Sport Tester (Polar Electro Oy, Finland).

For statistical analysis of the results mean values and standard deviations were calculated. Significance of the differences for independent trials and conformity of the distribution of the tested variables to the normal distribution were analysed using the Student t ($p<0.05$) and Shapiro-Wilk tests, respectively.

Results

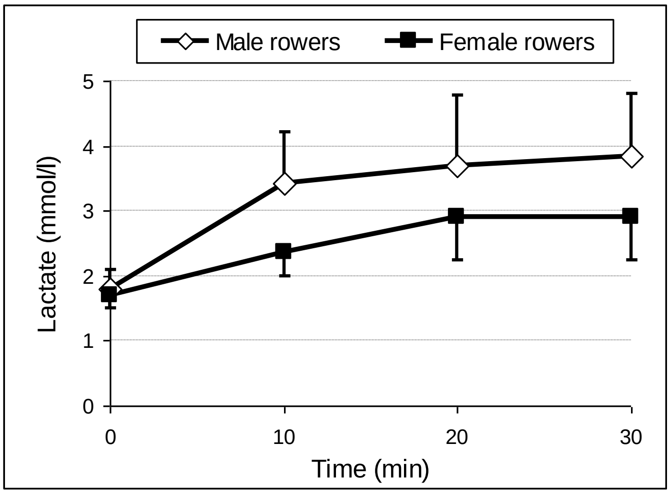

Fig. 1
Lactate concentration in the blood of male (n=14) and female (n=5) rowers during 30 min of rowing with the workload at the maximal lactate steady state

Changes in the blood lactate concentration at MLSS in the male and female rowers are shown in Fig. 1.

As indicated, MLSS in the male and female rowers corresponded to the blood lactate level of 3.66±0.93 and 2.72±0.54 $mmol \cdot l^{-1}$ (expressed as mean from the samples collected at the 10th, 20th, and 30th min of the exercise), respectively (Table 2). The power output at AT4 (equal to 307±41 W in the male and to 219±15 W in the female rowers) was significantly higher than the power output at MLSS (278±35 W and 192±14 W for the males and females, respectively). The results demonstrated high individual variation of the MLSS values (1.83-5.93 $mmol \cdot l^{-1}$) in both groups of the athletes.

Table 2

Comparison of the blood lactate level, power output and heart rate measured at the maximal lactate steady state (MLSS) and the anaerobic threshold level (AT4) in male (n=14) and female (n=5) rowers

		MLSS			AT4	
		Lactate ($mmol \cdot l^{-1}$)	Power output (W)	HR_{30min} (bpm)	Power output (W)	HR (bpm)
Male rowers	x±SD	3.66±0.93	278±35	168±12	307±41*	164±9*
	Min	2.17	205	144	229	143
	Max	5.93	332	194	374	181
Female rowers	x±SD	2.72±0.54	192±14	177±8	219±15*	175±11
	Min	1.83	176	168	201	160
	Max	3.20	210	190	234	184

*-$p<0.05$

No significant differences in the MLSS values were observed between the male and female rowers (Fig. 2). The ratio of the power output at MLSS to that at AT4 equalled to 91±4% in the male and to 88±2% in the female rowers; the obtained ranges did not significantly differentiate the two examined groups.

In the male rowers, the values of HR corresponding to MLSS at the 30th min of the exercise (HR_{MLSS30}) were significantly higher (by 4.3±7.0 bpm) than the values of HR_{AT4}, whereas in the females the difference equalled to 2.2±5.7 bpm and was statistically insignificant (Fig. 3, Table 2). In the former group of the athletes HR_{MLSS30} constituted 90±3% and HR_{AT4} 88±3% of the maximal heart rate (HR_{max}) whereas in the latter group the respective values equalled to 92±3% and 91±2%.

Discussion

In the training practice the threshold workload is supposed to correspond to the balance between production and utilisation of lactate. However, the present results demonstrate that application to all the athletes of a similar training workload corresponding to 4 $mmol \cdot l^{-1}$steady blood lactate level (anaerobic threshold – AT4) may result in the lactate concentration inconsistent with the one expected during the aerobic capacity-shaping training. MLSS determined in the group of Polish rowers corresponded to the blood lactate level of 3.66±0.93 $mmol \cdot l^{-1}$ and was close to 4 $mmol \cdot l^{-1}$ - the level used for estimations of the anaerobic threshold with the method of Mader [17]. As shown by Beneke [1], lower values of MLSS (3.0±0.6 $mmol \cdot l^{-1}$) were recorded in the highly fit German rowers but in that study the estimations were performed on the Gjessing rowing ergometer. It was also demonstrated that MLSS in rowers was significantly lower (3.1±0.5 $mmol \cdot l^{-1}$) than in cyclists (5.4±1.0 $mmol \cdot l^{-1}$) and speed skaters (6.6±0.9 $mmol \cdot l^{-1}$) [2]. It was suggested that this parameter can be inversely proportional to the mass of muscles engaged in the given exercise [2]. Result of some of the recent studies indicate that MLSS is independent from the physical capacity level although subjects exhibiting enhanced capacity sustain higher workloads at the balance between production and utilisation of lactate [3]. It was also shown that a regular 8-week training using workload at the individual anaerobic threshold (IAT) level did not significantly change the MLSS value (lactate concentrations between the 10th and 30th min of a submaximal exercise) [12].

Until recently, no MLSS data have been obtained in female rowers. The results of the present study indicate that the MLSS values estimated in the elite Polish female rowers correspond to the lower blood lactate level than those determined in their male counterparts (2.72±0.54 vs. 3.66±0.93 $mmol \cdot l^{-1}$) although the difference was not statistically significant (Fig. 2). A tendency towards lower lactate concentrations at MLSS in the blood of the females may be explained by differences in the exercise metabolism between men and women [10,11]. Indeed, this type of metabolism predisposes women to longer but less intense exercises, the observation related to a higher content in a woman's muscles of the slow-contracting fibres relying on the aerobic metabolism. It was also shown that, compared to males, the level of free fatty acids in the females' blood during this type of exercises can be even twofold higher. The reason for this may be a different mechanism of activation of adrenergic receptors in the fatty tissue of men and women [9]. Increased utilization of lipids as the energy substrates in a woman's body during the long-lasting submaximal exercises is associated with a decreased production of lactate and may result in lower values of MLSS than those detectable in men.

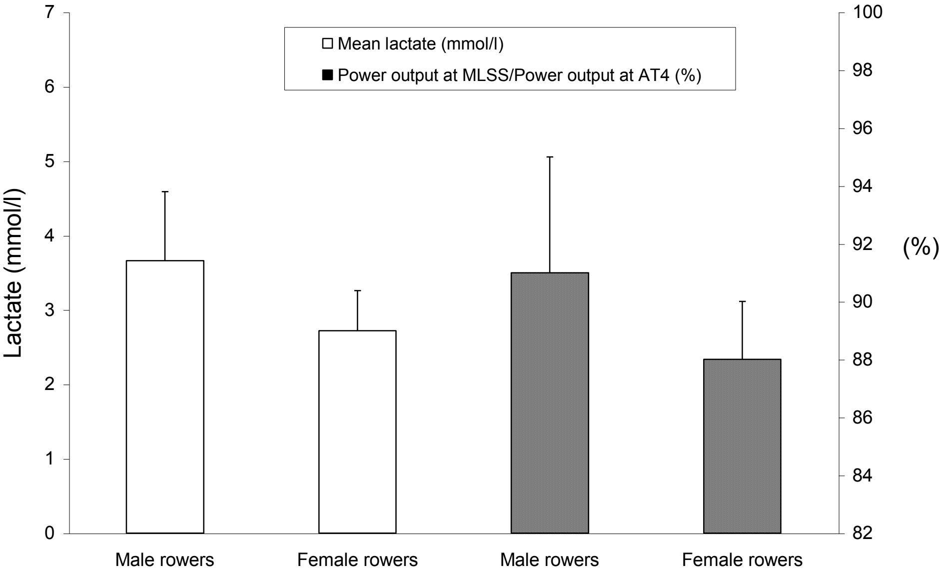

Fig. 2
Maximal lactate steady state - MLSS (expressed as the mean lactate concentration in the blood at the 10th, 20th and 30th min of exercising at a constant power output) and the workload at MLSS related to the anaerobic threshold - AT4 (%) in male (n=14) and female (n=5) rowers; statistically insignificant (p>0.05) differences between the males and females

As shown in Table 2, the values of power output at AT4 in the male and female rowers were significantly higher than the respective values at MLSS (Table 2). The mean power output at MLSS constituted 91±4% (male rowers) and 88±2% (female rowers) of the power output at AT4; the differences noted for this parameter in the two examined groups were statistically insignificant (Fig. 2). Likewise, as shown by the results of another study in rowers, AT4 and the individual anaerobic threshold (IAT) corresponded to workloads exceeding the MLSS value [1].

Therefore, intensity of the exercising at 95% of IAT was recommended for the intensive endurance training while that at 80-90% of IAT was recommended for the extensive endurance training [21]. The results of our own as well as of other authors' studies suggest that the power output at AT4 used in training as the upper value of the intensity shaping the aerobic metabolism may result in overestimation of the applied workloads. Moreover, the great variety (ranging from 1.83 to 5.93 $\text{mmol}\cdot\text{l}^{-1}$) of the lactate concentration at MLSS in both the male and female rowers indicates that the workloads used in training should be individually designed.

In contrast to the aforementioned studies, other authors showed that in the medium- or long-distance runners [4], cyclists [22], and rowers [23] IAT may be comparable to MLSS, although this was not the case in all of the studied subjects [21]. Importantly, the differences between MLSS and AT4 may be affected by a method of the gradual increase of the workload. Keskinen *et al*. [13] demonstrated that, depending on the protocol used, changes were noted not only in the values of the swimming velocity and HR at AT4 but also the post-exercise blood lactate levels varied in the same athletes. Noteworthy, the AT4 values usually result in overestimation of the workload at MLSS even when the time of workload during the incremental exercise test ranges from 4 to 5 min. Shortening of the duration of the workload in such tests results in the higher power output at 4 $\text{mmol}\cdot\text{l}^{-1}$ blood lactate level leading to an even more pronounced surpassing of MLSS in the long-lasting, submaximal exercises [21].

The non-invasive methods of selection of the proper training intensity have long been used in the training practice. Indeed, such methods decrease financial costs of the training and improve psychological comfort of the athletes [6]. In some sports, owing to the training conditions, measurements of parameters determining the intensity of the exercise, such as running speed, mean rowing power output, etc., is not feasible. In many cases, when HR is the only available indicator of the required exercise intensity, it is necessary to use a range of HRs rather than a fixed value, such as the one corresponding to AT4. The possibility of estimation of MLSS based exclusively on measurements of HR was suggested by the results of studies performed in cyclists and runners in which such measurements allowed for the accurate estimation of this parameter in 80% of the cases [18]. Likewise, the study of cyclists demonstrated adaptability of the laboratory exercise tests so that the HR value at MLSS could be determined for the training purposes [20]. Although the available evidence indicates that, compared to the use of HR, the training workload at MLSS can be better selected based on direct measurements of the blood lactate level, it has been stressed that simple non-invasive methods devoid of the necessity to collect blood samples should be viewed as highly useful. For example, in 68% of speed skaters trained on the skating track the MLSS values were estimated from the control of the exercise intensity based solely on the measurements of HR [5].

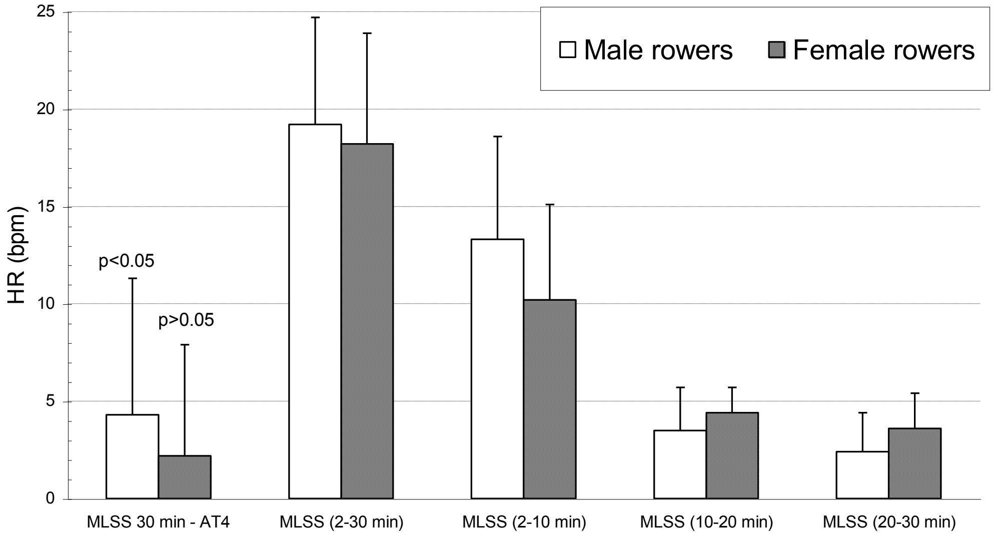

Fig. 3
Differences between heart rates (HR) measured at the 30th min of exercising at the maximal lactate steady state (MLSS) and the values of HR estimated at the anaerobic threshold level (AT4) as well as increases in HR at MLSS in male (n=14) and female (n=5) rowers

Apparently, for the selection of the training workloads increases in HR with time of the exercises (the so called cardio-vascular drifts) should be used instead of the constant HR values. The described examinations of the Polish rowers demonstrated that differences between HR_{MLSS30} and HR_{AT4} varied widely (ranging from (–) 8 to (+) 15 bpm), pointing to the highly diversified increase in the HR values from the beginning to the end of the 30-min exercising with the intensity at MLSS. In both groups of the athletes a significantly higher increase (by 12 bpm) in HR was noted between the 2nd and 10th min of the exercise compared to the subsequent phases (increases by 4 bpm and by 3 bpm between the 10th and 20th min and the 20th and 30th min of the exercise, respectively). The total increase in HR between the 2nd and 30th min of the exercise averaged to 19 bpm, i.e. to 10% of the HR_{max} (Fig. 3). The HR value estimated at the 2nd min was regarded as the one corresponding close to the steady-state. In other reports, cardio-vascular drift estimated in runners and cyclists from the beginning to the end of the 30-min exercising with the intensity at MLSS equalled to 12 bpm, i.e. to 6-7% of the HR_{max} [18]. Based on the herein demonstrated kinetics of changes in the values of HR at MLSS estimated in the Polish rowers it is advisable that the higher increases in HR detected during the first ten min compared to the later phases of training be considered in the constant workload training aimed at shaping the aerobic capacity of athletes.

In summary, it should be stressed that utilization of the threshold indices for the control of submaximal training workloads (including those estimated in the specific-effort tests) needs to be verified during the 30-min constant workload exercises according to the MLSS assessment criteria. It is suggested that the power output lower by about 10% than the anaerobic threshold (AT4) be recommended as the average workload for the intensive endurance training of both male and female rowers on the Concept II ergometer.

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