Maximal lactate-steady-state independent of performance

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ABSTRACT

BENEKE, R., M. HÜTLER, and R. M. LEITHÄUSER. Maximal lactate-steady-state independent of performance. *Med. Sci. Sports Exerc.*, Vol. 32, No. 6, pp. 1135–1139, 2000. **Purpose:** The maximal lactate steady state (MLSS) corresponds to the highest workload that can be maintained over time without a continual blood lactate accumulation. MLSS and MLSS intensity have been speculated to depend on performance. Experimental proof of this hypothesis is missing. **Methods:** 33 male subjects (age: 23.7 ± 5.5 yr, height: 181.2 ± 5.3 cm, body mass: 73.4 ± 6.4 kg) performed an exhausting incremental load test to measure peak workload and three to six 30-min constant load tests on a cycle ergometer to determine MLSS. **Results:** MLSS (4.9 ± 1.4 mmol·L^{-1}) was independent of MLSS workload (3.4 ± 0.6 W·kg^{-1}) and peak workload (4.8 ± 0.6 W·kg^{-1}). MLSS intensity (71.1 ± 6.7%) did not correlate with peak workload or MLSS ($P > 0.05$). A positive correlation was found between peak workload and MLSS workload ($r = 0.82$, $P < 0.001$). **Conclusions:** MLSS and MLSS intensity are independent of performance but subjects with higher maximum performance have higher MLSS workloads. The combination of various fitness related effects on both, the production and the disappearance of lactate during exercise, may explain that different MLSS workloads coincide with similar levels of MLSS and MLSS intensity. **Key Words:** GLYCOLYSIS, OXIDATIVE METABOLISM, PROLONGED CONSTANT WORKLOAD, FITNESS

The maximal lactate steady state (MLSS) corresponds to the highest workload that can be maintained over time without a continual blood lactate accumulation (4,6,19,21). Measurement of MLSS demands several subsequent constant load tests that have to be performed with different workloads at different days (see Fig. 2). Test by test, the workload is increased until blood lactate concentration (BLC) accumulates more or less continuously during the constant load (4,6,22–24,51). Such an increase of BLC indicates a higher glycolytic rate compared with the rate of pyruvate oxidation. Thus, MLSS indicates an individual workload intensity above which the rate of lactate production exceeds lactate clearance (4,6,22–24,35,51).

MLSS directly indicates the upper border of exercise intensities resulting in steady states of BLC. Determination of the anaerobic threshold is supposed to be an indirect measure of the latter utilizing incremental or ramp test protocols (22,23,35,36,40,48,51). Since 1964, numerous concepts of anaerobic threshold have been developed based on ventilatory data, heart rate, and constant or individually varying lactate responses (3,15,19,27,29,41,46–49,52). Selected concepts of anaerobic thresholds are based on fixed BLC levels like 4 mmol·L^{-1} (29,36,47). On principle, this procedure presumes that only the workload at the anaerobic threshold is different between fit and unfit subjects. In contrast to the latter, numerous concepts of individual anaerobic thresholds have been developed, which are based on the hypothesis that the BLC at the anaerobic threshold may decrease with increasing performance capacity (22,27,40,46). Also a relationship between fitness and exercise intensity at the anaerobic threshold has been speculated (1,17,27,39,40,46,48,49). However, an effect of specific concepts of the determination of anaerobic thresholds on the inconsistently observed relationship between fitness and selected anaerobic lactate thresholds cannot be excluded (4,22,23).

Possible effects of performance capacity on the upper border of exercise intensities resulting in a steady state of BLC can only be evaluated utilizing constant load tests and the direct determination of the MLSS. However, the experimental proof of a possible relationship between performance and MLSS, MLSS workload, or MLSS intensity is missing. The aim of the present study was to analyze possible relationships between performance capacity expressed as peak workload reached at the end of an incremental load test and MLSS, MLSS workload, and MLSS intensity measured during constant workload.

METHODS

A total of 33 male subjects (age: 23.7 ± 5.5 yr, height: 181.2 ± 5.3 cm, body mass: 73.4 ± 6.4 kg) volunteered for this study. Ten subjects were endurance athletes utilizing cycling training with a training volume of 8–25 h·wk^{-1}. All

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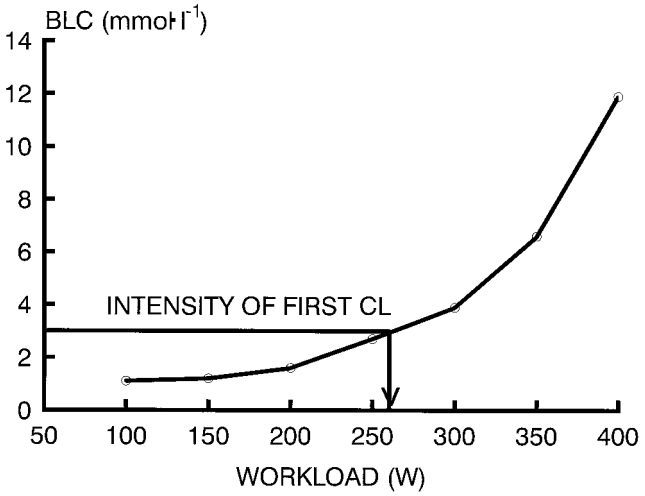

Figure 1—BLC during an incremental load test; the test starts with 100 W and workload is increased every 3rd minute until exhaustion.

other subjects did not perform endurance training on a regular basis. Informed consent was obtained from all subjects after explanation of the nature and risks involved in participation in the experiments, which conformed to the policy statement regarding the use of human subjects (37).

The subjects performed an incremental load test and three to six constant load tests on a cycle ergometer (Elema Schönander 380, Siemens, Berlin, Germany). Cycle ergometry was performed at pedalling rates between 70 and 90 RPM with time intervals between testing sessions of 48–72 h. The incremental load test started with 100 W and was increased to exhaustion by 50 W by every 3rd minute (Fig. 1). The constant load tests lasted 30 min. Workload of the first constant load test corresponded to the BLC of 3.0 mmol·L^{-1} measured during the incremental load test. According to the procedure published previously (4,6), constant load tests with higher or lower workloads were applied at subsequent days until MLSS was found and verified. MLSS was defined as the highest BLC that increased by no more than 1.0 mmol·L^{-1} during the final 20 min of constant workload (Fig. 2). The MLSS was calculated as average

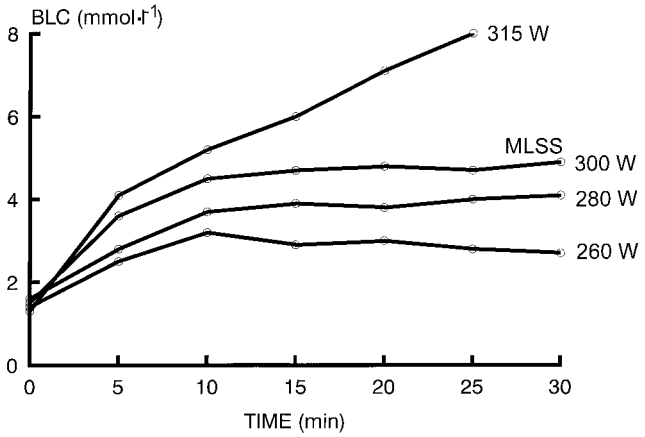

Figure 2—Determination of MLSS; workload of the first constant load test corresponds to 3.0 mmol·L^{-1} measured at the incremental load test. Constant workload was increased test by test until no steady state of BLC could be observed.

TABLE 1. MLSS, absolute and relative MLSS-, and peak workloads, and MLSS intensity.

	Mean ± SD	Minimum	Maximum
MLSS (mmol·L^{-1})	4.9 ± 1.4	1.9	7.5
MLSS-workload (W)	248.3 ± 40.5	160	310
rel. MLSS-workload (W·kg^{-1})	3.4 ± 0.6	2.1	4.2
Peak-workload (W)	349.5 ± 48.1	250	425
rel. Peak-workload (W·kg^{-1})	4.8 ± 0.6	3.3	5.7
MLSS-intensity (%)	71.1 ± 6.7	54.3	82.7

value of the BLC measured at min 15, 20, 25, and 30 of the MLSS workload (4).

Capillary blood samples (20 μL) were taken from the hyperemic earlobe (Finalgon forte®, Thomae, Bieberach, Germany) before each test and during the final 15 s of every 3rd (incremental load test) or every 5th (constant load test) minute. The BLC was analyzed by the enzymatic photometric method (Boehringer, Mannheim, Germany). The coefficients of variation for repetitive analysis of the identical samples were $< 5\%$ (5).

Data are reported as mean values and standard deviations (SD). The relationship between variables was examined by multiple and simple linear regression analyses. For all statistics, the significance level was set at $P < 0.05$.

RESULTS

Descriptive data of MLSS, MLSS-, and peak workload expressed as absolute as well as relative values related to body mass and also MLSS intensity as percent of peak workload are presented in Table 1.

In a multiple stepwise regression model with MLSS as dependent variable the latter was independent of absolute and relative MLSS- and peak workloads or of MLSS intensity. Corresponding simple plots are shown in Figure 3 to 5. MLSS intensity did not correlate with relative peak workload (Fig. 6). A positive correlation was found between MLSS workload and peak workload (Fig. 7).

DISCUSSION

With respect to fitness and endurance training, adaptations of heart (33), blood (44,45), muscles (9,18,25,31,34),

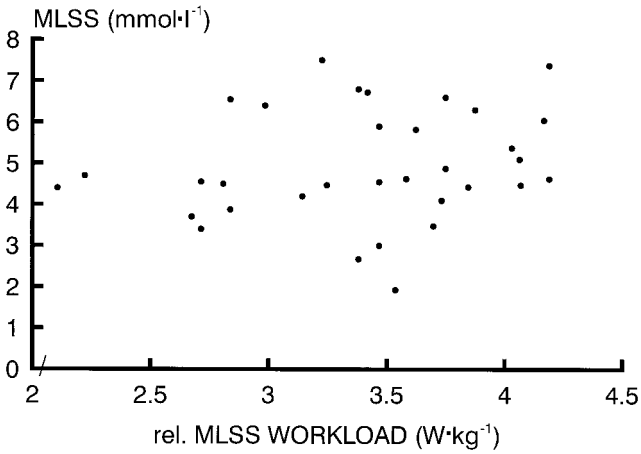

Figure 3—No correlation between MLSS and relative MLSS workload.

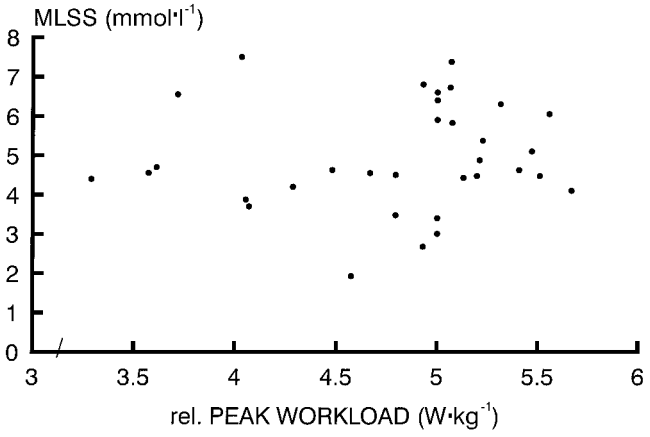

Figure 4—No correlation between MLSS and relative peak workload.

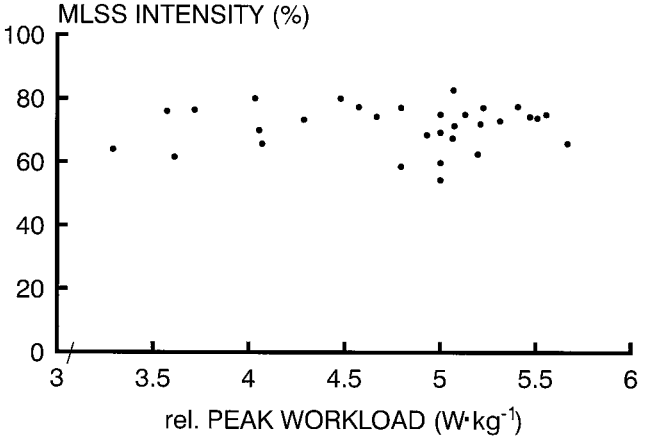

Figure 6—No correlation between MLSS intensity and relative peak workload.

and hormones (38) have been discussed to modify production, distribution, and elimination of pyruvate, and consequently BLC levels at given workloads. Already in 1939, Christensen and Hansen (12) observed that at a given workload, highly endurance trained athletes have a lower respiratory exchange ratio (RER). This indicates a reduced rate of glucose metabolism combined with a higher rate of fat utilization. Compared with untrained subjects, athletes with high endurance capacity have a lower increase of catecholamines and glucagon, and higher concentrations of insulin at a given workload (38). This affects glycolysis, gluconeogenesis, and lipolysis (2,10,26,38,50). Numerous studies confirmed that in endurance trained athletes, muscle glycogen decreases less than in untrained subjects (13,26,28,42,50). Thus, at a given workload, increased endurance performance reduces the glycolytic rate, increases the rate of fat oxidation, and leads to lower BLC levels. However, the present study demonstrates that MLSS does not indicate a given workload but an exercise intensity.

During 30-min constant workload at 80% of peak oxygen uptake, which covered the upper range of exercise intensities of MLSS in the present investigation, in subjects with low and high endurance capacity, plasma concentrations of epinephrine, norepinephrine, glucagon, and insulin, and the availability of glucose were independent of performance (14). This underlines and extends other results concerning glucose and fat metabolism at given exercise intensities (7,20,26,32). The latter also seems to support the present results, and the concept of MLSS, which is based on the theory that MLSS indicates an exercise intensity above which metabolism changes qualitatively. According to this theory, the duration of aerobic exercise up to MLSS intensity is limited by stored energy. Above MLSS intensity, contributing to the energetic needs of exercise, pyruvate production exceeds lactate clearance; muscular creatine phosphate concentration, muscle and blood pH decrease (4,6,22–24,35,51), which causes the termination of exercise.

This theory also seems to be supported by concepts prescribing endurance training. According to the latter, MLSS intensity corresponds to heavy-intensity endurance training (6,53). Such a training session normally lasts 30–60 min. If several training sessions per week are intended, the glycogen should not be depleted by more than 50%. A higher level of depletion needs up to 3 d for repletion (8,16,43). Muscle and liver glycogen provides more or less 95 kJ of aerobic energy per kg body mass (11). At MLSS, the RER is near 1, which indicates glycogen as the dominant fuel. The corresponding glycogen cost for 45 min exercise at a

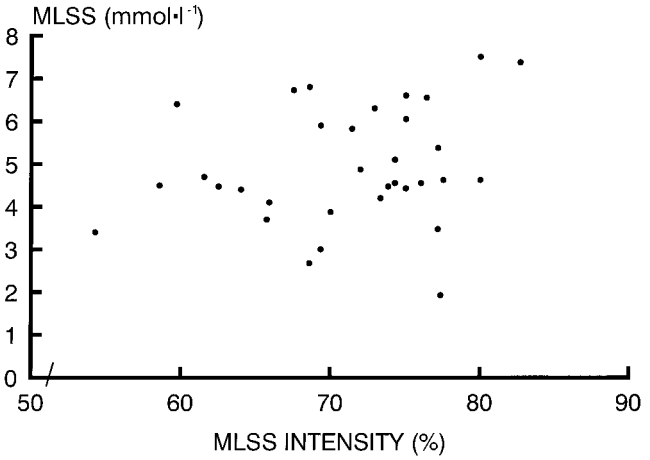

Figure 5—No correlation between MLSS and MLSS intensity.

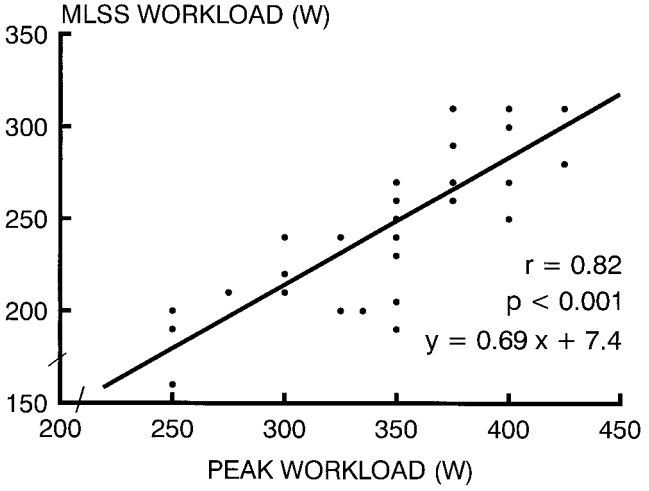

Figure 7—Correlation between MLSS workload and peak workload.

MLSS workload of 3.4 $W \cdot kg^{-1}$ and a working efficiency of approximately 20% depletes muscle and liver glycogen by more or less 50%. Due to the nonlinear relationship between workload intensity and maximum performance time (21), single bouts of higher constant workloads result in less glycogen depletion. For example, after 30 min constant workload at an intensity that is 10% higher than the abovementioned MLSS workload, the glycogen is depleted by approximately 35%. In spite of the latter, in the present study, at workload intensities slightly above MLSS intensity, numerous subjects terminated the tests between the 20th and the 30th minute of constant workload, independently of fitness. On principle, the latter indicates qualitative changes of metabolism with respect to limiting factors of exercise.

In conclusion, the present study is the first designed to investigate possible relationships between MLSS, corresponding workload, and performance. MLSS and MLSS intensity were not correlated with performance. Thus, previously published speculations that higher performance reduces the BLC at anaerobic threshold, and thus at the MLSS, and increases the corresponding workload intensity (1,17,23,27,30,39,40,46,48) could not be verified. This supports the hypothesis that an inconsistently observed relationship between selected anaerobic lactate thresholds and performances (23,24,30) may be an effect of the specific concepts of the determination of anaerobic thresholds rather than an effect of different fitness levels (4,22,24). At given workloads, high performance athletes have lower BLC levels than subjects with low fitness. However, the present study demonstrates that MLSS indicates an exercise intensity but no given workload. The combination of various fitness related effects on both, the production and the disappearance of lactate during exercise, may explain that different MLSS workloads can be performed at similar levels of MLSS and MLSS intensity.

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