Maximal lactate steady state in young male athletes

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ABSTRACT

Maximal lactate steady state (MaxLass) is defined as the highest and stable blood lactate concentration (BLC) during constant workload. There is a lack of data concerning BLC at which this MaxLass occurs in young athletes. The main purposes of this study were: (1) to investigate at which BLC MaxLass occurs in young athletes; (2) to find out if 4 mmol/l is a good index for aerobic capacity assessment in this population; (3) to know if there exists a relationship between MaxLass and the competitive level of the subjects; (4) to determine the lactate workload range for aerobic capacity development in young athletes. Fourteen young male runners (age 16±1.35 yrs) were tested. The subjects performed from 2 to 4 constant workload tests (30') until detection of MaxLass was possible. The tests were conducted on a 400m synthetic track with warning sounds every 100m and a trained pacemaker to ensure a uniform speed. The 30 min test was interrupted every 5 min to take blood samples from the ear lobe, which was immediately analyzed to determine BLC using a Yellow Springs Instruments 1500L-Sport. MaxLass was the highest workload achieved during the continuous tests in which the difference in BLC between the 10th and the 30th minute was under 1mmol/l. MaxLass was considered as the mean lactate value of the last four collects. The relationship between MaxLass and MaxLass workload was determined by linear regression analysis. The mean MaxLass values were 5.07±1.13 mmol/l (2.87-7.12 mmol/l). The mean MaxLass workload was 3.94±0.30 m/s (3.4-4.3 m/s). Linear regression analysis between MaxLass and MaxLass workload revealed an insignificant relationship (r=0.42, p>0.05). Our results show (1) an average value of near 5 mmol/l as corresponding to the MaxLass; (2) that the fixed value of 4 mmol/l seems to be a reasonable index for aerobic capacity evaluation in young male athletes; (3) that there was no dependency relation between MaxLass and MaxLass workload and (4) that, although suggesting that a higher lactate workload range might be considered for the development of aerobic capacity in young athletes, it seems pertinent to keep on resorting to a low lactate workloads in continuous running to enhance endurance.

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Usual work includes long-term physiological testing in elite and young athletes. Among other topics in exercise physiology and biochemistry, special interest has been focused on training control of aerobic capacity of runners.

Introduction

Blood lactate concentration (BLC) has been considered a relatively accurate physiological parameter for the estimation of workload intensity in exercise training (Mader, 1991; Hartmann and Mader, 1994). The workload that depicts the transition from aerobic to partially anaerobic endurance exercise presumably represents the highest constant workload that can be performed by oxidative metabolism (Heck et al., 1985; Mader, 1991). During constant workload this transition is assumed to correspond to the highest and stable BLC, i.e. equilibrium between lactate production and clearance (Heck et al., 1985; Beneke and von Duvillard, 1996). This level of BLC is referred to as maximal lactate steady state (MaxLass) and is influenced by several factors such as the maturation state of the subjects (Williams et al., 1990a,b; Williams and Armstrong, 1991; Beneke et al., 1996a; 1994; Pfitsinger and Freedson, 1997a,b), the level of aerobic capacity (Föhrenbach et al., 1987; Krüger et al., 1990; Borch et al., 1993; Urhausen et al., 1993; Foxdal et al., 1996), the sport discipline (Beneke et al., 1993a; Beneke and von Duvillard, 1996) and the intrinsic characteristics of test protocol used in its determination (Heck et al., 1985a; Beneke et al., 1993b; 1996b).

Moreover, the appearance of lactate in blood seems to be related to some physiological characteristics of the subjects. Changes in muscle fiber type composition (Ivy et al., 1980; Tesch et al., 1981), capillary density and capillary/fiber ratio (Soares, 1992), the rate and type of substrate mobilization (Brooks and Mercier, 1994; Duncan and Howley, 1999) and muscle respiratory capacity (Tesch et al., 1981) have each been described as influencing BLC (directly or indirectly) through the impact that each has on lactate production and removal mechanisms.

Recently, new evidence related to lactate transport through cell membranes, including the sarcolemma, and from cytosol to mitochondria, has been reported (Bonen, 2000; Brooks, 2000; Gladden, 2000a,b). In fact, the monocarboxylate transporter proteins (MCT proteins) play an additional role concerning the lactate shuttle theory. It is known that oxidative muscle fibers are metabolically suited for lactate oxidation and have a greater capacity for lactate transport through sarcolemma and other cellular membranes than glycolytic muscle fibers (Gleden, 2000b). The evidence seems to indicate that endurance training improves the muscle's capacity for lactate uptake and utilization by increasing MCT1 isoform concentration mainly in slow twitch skeletal muscle fibers (Bonen, 2000; Brooks, 2000; Gleden, 2000a,b).

In contrast, a study conducted by Løkkegaard et al., (2001) did not find any significant correlation between MaxLass values and lactate transporters (MCT 1 and MCT4) or between MaxLass and percentage of type I muscle fiber (slow twitch) in m. vastus lateralis. However, there was a tendency toward a positive correlation ($r=0.52$, $p=0.08$) between skeletal muscle buffering capacity and MaxLass.

Age dependent physiological pathways that lead to lactate production and clearance have been considered responsible for distinct BLC differences between children and adults. While controversial, some reports have suggested that there are different capacities for lactate production and clearance due to changes induced by the maturation process in muscle oxidative and glycolytic enzyme activity; in glycogen content as well as in mitochondria to myofibrilar volume ratio (for references see Pianosi et al., 1995; Williams et al., 1990; Pfitzinger and Freedson, 1997a, b; Boisseau and Delamarche, 2000). Additionally, concerning energy substrate utilization in steady-state exercise, results obtained in young individuals indicate a tendency toward greater fat oxidation in this population than in adults, expressed by a lower respiratory exchange ratio for the same relative exercise intensity (for references see Boisseau and Delamarche, 2000).

Even though lactate is a dynamic metabolite and its appearance in blood may arise from a variety of metabolic pathways, BLC is still considered a useful tool on physiological assessment of training (Föhrenbabh et al., 1987; Mader, 1991; Hartmann and Mader, 1994).

In spite of all those factors, a BLC of 4 mmol/l has been considered a reasonably

good aerobic index, highly and positively correlated with MaxLass in adult populations (Mader et al., 1976; Heck et al., 1985; Mader, 1991; Hartman and Mader, 1994). However, there is a lack of data about the BLC at which MaxLass occurs in young male athletes.

The main purpose of the present study was, therefore, to investigate at which BLC MaxLass occurs in young male athletes and, based on this objective, to determine the lactate workload range for aerobic capacity training and assessment. It was anticipated that the outcomes of the current investigation might help to determine whether differences between adults and young athletes should lead to changes in aerobic training intensities for younger athletes.

Methods

Subjects

Fourteen young male athletes (mean±sd, age 16±1.35 yrs, weight 62.2±7.87kg, training age 3.07±1.49 yrs) were recruited for the study. All them achieved a non-specific training program with aerobic, lactic and alactic anaerobic training schedules. All athletes were instructed not to engage in strenuous activity 3 days before exercise tests. They were also informed about the content of the test protocols and they maintained normal dietary patterns.

Procedure

The subjects performed an incremental load test and several sets of (2–4) 30 minutes constant running workload for aerobic-anaerobic threshold and MaxLass determination, respectively, separated by 2-3 days. The tests were conducted on a 400m synthetic track with warning sounds and a trained pacemaker to ensure a uniform speed. The collected blood samples were immediately analyzed to determine blood lactate concentration using a Yellow Springs Instruments - 1500L Sport.

Incremental Load Tests

Before MaxLass determination, the subjects performed an incremental workload test with 5 min 30 sec to 6 min progressive exercise bouts (Table 1). Depending on the level of the subjects, workload ranges were between 3.0 to 4.6 m/s. After every work stage the test was interrupted by a 30 – 40 min break for blood sample collecting and, at the beginning of the next stage the speed was increased by 0.4m/s according to Mader et al., (1976) procedures (Figure 1).

v (m/s)	**400m**	**800m**	**1200m**	**1600m**
3.0	2'13"33	4'26"67	6'40"00	-
3.4	1'57"65	3'55"29	5'52"94	-
3.8	1'45"26	3'30"53	5'15"79	7'01"05
4.2	1'35"24	3'10"48	4'45"71	6'20"95
4.6	1'26"96	2'53"91	4'20"87	5'47"83

Table 1: *BLC during incremental test; the test began at 3.0 m/s and the speed was increased 0.4 m/s at least every 5min 30sec bout until a BLC over 4 mmol/l had been reached.*

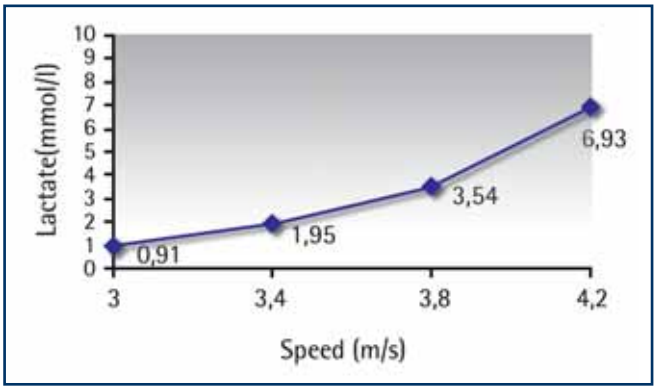

Figure 1: *Distance, speed and duration concerning the workloads used in the field tests for determination of aerobic-anaerobic threshold (V_4).*

Constant Load Tests

The subjects performed from 2 to 4 constant workload tests with 30 min duration until detection of MaxLass was possible. Workload intensity for the first constant load was the velocity corresponding to the blood lactate concentration of 4 mmol/l (V4)

obtained during the previous incremental test. The constant load tests were interrupted every 5 min to take blood from the ear lobe. If blood lactate steady state was attained or decreased during constant workload, subsequent constant load tests with speed increments of 0.1–0.2m/s were performed on separate days (to allow muscle glycogen repletion), until a continuous and sustained increase in blood lactate concentration was observed (Figure 2).

Results

The average lactate value for MaxLass was 5.07±1.13 mmol/l (2.87-7.12) (Figure 3) corresponding to a mean workload of 3.94±0.30 m/s (3.4-4.3) (table 2). The average V4 was 3.82±0.26 m/s (3.44-4.63). Linear regression analysis indicated an insignificant relationship between MaxLass and MaxLass workload (r= 0.42, p>0.05) (Figure 4).

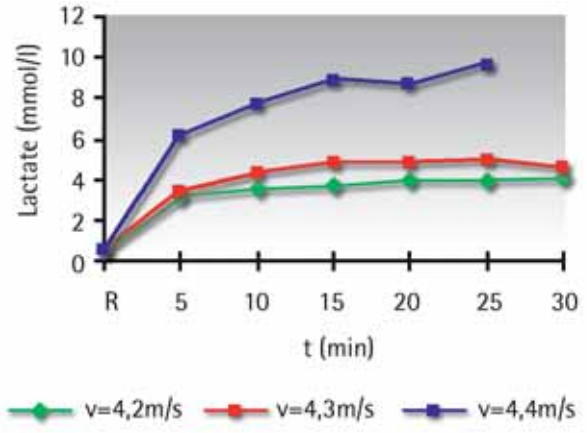

Figure 2:
Lactate – time curves related to the prolonged constant load tests; BLC were in steady state at the first two exercise bouts (4.2 and 4.3 m/s) and were progressively increasing throughout the last running load (4.4 m/s).

Aerobic – Anaerobic Threshold

According to the procedure originally published by Mader et al., (1976), aerobic-anaerobic threshold is determined as the workload corresponding to the BLC of 4.0 mmol/l during an incremental load test.

MaxLass

According to Heck et al., (1985), maximal lactate steady state is defined as the highest possible BLC that increases no more than 1mmol/l during the last 20 min of a 30 min constant workload test.

Statistics

The data were reported as mean values and standard deviations (mean±sd). MaxLass was calculated as the average value of the 15, 20, 25, and 30 min collects of the MaxLass workload (Heck et al., 1985). The relationship between MaxLass and MaxLass workload was determined by linear regression analysis. For all statistics the significance level was 5%.

Athlete	Maxlass (mmol/l)	Maxlass workload (m/s)	V_4 (m/s)
A	2.87	3.8	3.88
B	5.74	4.3	4.10
C	4.85	4.3	4.36
D	4.16	3.8	3.89
E	4.66	4.2	4.06
F	4.91	3.9	3.78
G	3.86	3.4	3.55
H	5.25	3.8	3.44
I	4.59	3.8	3.54
J	6.29	4.2	4.01
K	5.60	4.3	3.96
L	7.12	4.2	3.86
M	4.57	3.6	3.63
N	6.62	3.6	3.54
Mean±sd	**5.07±1.13**	**3.94±0.30**	**3.82±0.26**

Table 2: *MaxLass individual and mean values (±sd) concerning the workload and blood lactate concentration achieved in the continuous tests, as well as individual and mean values of V4 achieved in the incremental step tests.*

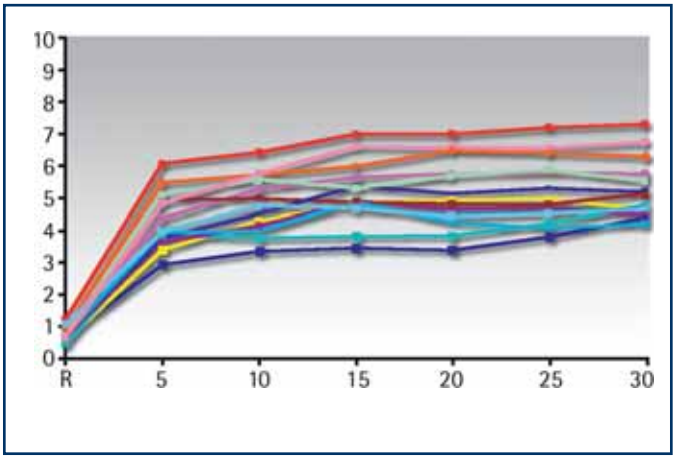

Figure 3: Constant load tests of all the subjects corresponding to the range of MaxLass workloads for the particular sample of our study

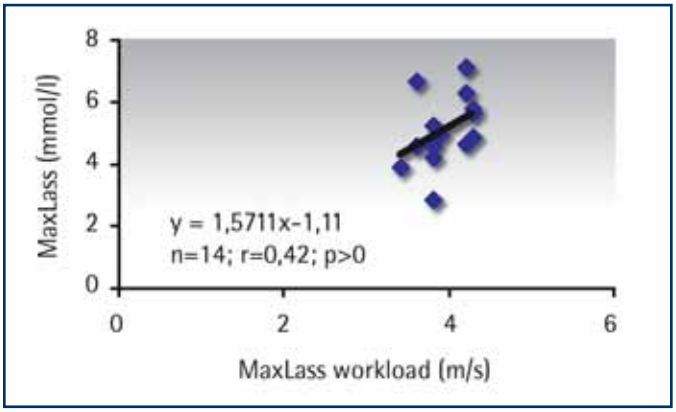

Figure 4: Linear regression between maximal lactate steady state (mmol/l) and the corresponding workload (m/s)

Discussion

The main result of our study was the apparent difference between the mean BLC corresponding to MaxLass of our young male subjects (5.07±1.13 mmol/l) and the mean BLC that is generally considered to correspond to MaxLass in adults (4.0 mmol/l), as determined by previous investigations (Heck et al., 1985; Mader, 1991). In view of the wide range of MaxLass values amongst our subjects (2.87-7.12 mmol/l), however, we do not view this difference as having any significant physiological meaning in terms of training or assessment of aerobic capacity. Regarding evaluation and control of aerobic development in young athletes through anaerobic threshold testing, there would appear to be no obvious advantage in establishing 5 mmol/l, instead of 4 mmol/l, as the mean turn point lactate value between aerobic and anaerobic metabolism.

Our results were similar to those described by Morcellin et al., (1991) in children and relatively higher when compared with the data of other authors (Williams et al., 1990a,b; Williams and Armstrong, 1991), who reported values ranging from 2.5 mmol/l to 4 mmol/l. However, some of the test protocols used by other investigators for MaxLass determination were considerably different from the one we used. Morcellin et al., (1991) used exercise bouts of only 16 minutes duration (capillary blood sample collects every 4 minutes) and they considered Maxlass as the highest, stable BLC at which lactate differences were under 1mmol/l between the 4th and 16th minute of that exercise bout. Williams and Armstrong (1991) showed mean MaxLass values around 2.5 mmol/l using exercise running bouts of 10 minutes duration. Differences in testing protocols (Beneke et al., 1993b; Beneke and Hohl-Radke, 1998; Beneke and Leithäuser, 1998) and the different age ranges (Beneke et al., 1994) of subjects certainly make it difficult to compare results.

Detailed studies using tracer material on animals and humans have shown that lactate is a dynamic metabolite both at rest and during exercise (Brooks, 1986; Brooks et al., 1999). At rest and during moderate exercise, lactate is produced and removed

at equal rates. But more must be understood about the mechanisms related to production and removal of lactate if we are to improve our understanding of exercise at steady state BLC. Studies using lactate tracers could provide additional information, for example, about whether MaxLass values are, predominantly, a result of elevated production or, on the other hand, a result of differing capacities for lactate clearance.

It is known that BLC is influenced by many factors. These include unique physiological characteristics of subjects such as fiber type composition (Ivy et al., 1980; Brooks and Mercier, 1994), capillary density (Tesch et al., 1981), the rate of carbohydrate and fat contribution required to perform at any given exercise intensity (Green, 1996; Henrikson, 1996; Holloszy, 1996; Beneke et al., 2000;) and the amount and rate of activity of the oxidative and glycolitic enzymes.

Endurance training itself can induce changes in these factors. It does so by enhancing the mechanisms associated with lactate removal and reducing the activity of energy glycolitic pathways, which leads to a decrease in lactate production. Also, aerobic training increases the efficiency of lactate shuttle mechanisms such as lactate uptake by muscle fibers and facilitates lactate cross-membrane transport through an increase in skeletal muscle monocarboxylate protein transporters – the main one being MCT1 isoform, found mostly in slow twitch skeletal muscle fibers and in heart and liver tissues (Bonen, 2000; Brooks, 2000; Gladden, 2000).

A prime determinant of the expression of MaxLass values, therefore, is the aerobic capacity of the subjects. An improved endurance level has the effect of moving the "accurate threshold moment" to a lower BLC (Föhrenbach et al., 1987; Krüger et al., 1990; Borch et al., 1993; Urhausen et al., 1993; Foxdal et al., 1996). On the whole, subjects in our study appeared to have low levels of aerobic capacity, demonstrated by the low mean values of V_4 and MaxLass workload. In this particular context, our data is in accordance with other investigations involving elite runners (Föhrenbach et al., 1987; Borch et al., 1993; Urhausen et al., 1993; Foxdal et al., 1996); studies indicating that the mean BLC corresponding to anaerobic threshold in well-trained endurance runners tends to be under 4mmol/l. One study conducted by Krüger et al., (1990) demonstrated lower MaxLass values in elite canoeists (near 4.5mmol/l) when compared with less trained athletes (around 7mmol/l). This difference confirms that there tends to be a predisposition for low MaxLass values induced by higher levels endurance training.

Differences in glycolytic flux, from one subject to the next, likely contributed to MaxLass variability in our investigation. At exercise intensities immediately below anaerobic threshold (65 – 85% VO_2máx, depending on the endurance training level), muscle glycogen is the most useful energy substrate (Books and Mercier, 1994; Duncan and Howley, 1999). The study by Giesen et al. (1998), in which respiratory quotient values around 1.0 were observed at intensities corresponding to MaxLass in elite male distance runners, supports this assertion. Endurance training has been shown to increase the relative capacity for lipid oxidation rather than to decrease carbohydrate utilization (Brooks and Mercier, 1994), which has the effect of lowering the net of glycolytic flux and, consequently, the rate of lactate production. Therefore, we may also speculate about inter-individual differences of our subjects in terms of glycogen synthesis and the replenishment of carbohydrate stores in the days between the tests as well as different patterns of energy substrate mobilization between subjects during the tests (Brooks and Mercier, 1994; Beneke et al., 2000). In fact, differing capacities in terms of glycogen repletion could lead to different subsequent patterns of blood lactate accumulation and, consequently, different MaxLass values.

One obvious and desired outcome of MaxLass assessment is a more accurate determination of the optimal range of exercise intensities for training and develop-

ment of aerobic capacity. Some authors have reported that elite marathon runners, with MaxLass values near 3mmol/l, normally make use of continuous running intensities between 0.65 and 1.5 mmol/l (Föhrenbach, 1991; Vassiliadis et al., 1997). Our findings of a MaxLass around 5mmol/l in young male athletes would seem to indicate that one shouldn't exclude the possibility of developing aerobic capacity using a much higher BLC. However, in order to enhance endurance, and considering continuous running as the prior training method, the oxidative metabolic adaptations induced by training certainly seem to occur at lower lactate workload ranges (0.5 – 3mmol/l - depending on the training volume of the subjects) (Mader, 1991). In view of the range of MaxLass values in our study (2.87-7.12 mmol/l), which is considered normal and acceptable in such studies (Heck et al., 1985), additional cross validation studies with larger samples and, if possible, with distinct aerobic conditions are necessary in order to establish more definitive MaxLass training levels for young athletes.

In summary, we conclude that according to our data, the fixed value of 4 mmol/l seems to be a reasonable index for aerobic capacity evaluation in young athletes. Moreover, we suggest that for groups of young athletes – who, inevitably, will have high inter-individual variation in MaxLass values similar to the group in our study – a low lactate workload should be selected for the development of aerobic capacity.

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