# Time to exhaustion at maximal lactate steady state is similar for cycling and running in moderately trained subjects

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ORIGINAL ARTICLE

# Time to exhaustion at maximal lactate steady state is similar for cycling and running in moderately trained subjects

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**Abstract** We compared time to exhaustion ($t_{lim}$) at maximal lactate steady state (MLSS) between cycling and running, investigated if oxygen consumption, ventilation, blood lactate concentration, and perceived exertion differ between the exercise modes, and established whether MLSS can be determined for cycling and running using the same criteria. MLSS was determined in 15 moderately trained men (30 $\pm$ 6 years, 77 $\pm$ 6 kg) by several constant-load tests to exhaustion in cycling and running. Heart rate, oxygen consumption, and ventilation were recorded continuously. Blood lactate concentration and perceived exertion were measured every 5 min. $t_{lim}$ (37.7 $\pm$ 8.9 vs. 34.4 $\pm$ 5.4 min) and perceived exertion (7.2 $\pm$ 1.7 vs. 7.2 $\pm$ 1.5) were similar for cycling and running. Heart rate (165 $\pm$ 8 vs. 175 $\pm$ 10 min$^{-1}$; $P < 0.01$), oxygen consumption (3.1 $\pm$ 0.3 vs. 3.4 $\pm$ 0.3 l min$^{-1}$; $P < 0.001$) and ventilation (93 $\pm$ 12 vs. 103 $\pm$ 16 l min$^{-1}$; $P < 0.01$) were lower for cycling compared to running, respectively, whereas blood lactate concentration (5.6 $\pm$ 1.7 vs. 4.3 $\pm$ 1.3 mmol l$^{-1}$; $P < 0.05$) was higher for cycling. $t_{lim}$ at MLSS is similar for cycling and running, despite absolute differences in heart rate, ventilation, blood lactate concentration, and oxygen consumption. This may be explained by the relatively equal cardiorespiratory demand at MLSS. Additionally, the similar $t_{lim}$ for cycling and running allows the same criteria to be used for determining MLSS in both exercise modes.

**Keywords** Endurance capacity · $t_{lim}$ · Exercise modes · Submaximal performance

## Introduction

Maximal oxygen consumption is a widely used parameter when classifying endurance performance. Traditionally, high maximal oxygen consumption has been associated with high endurance performance (Åstrand 1976). However, persons with a similar maximal oxygen consumption can differ in performance (Allen et al. 1985; Noakes 2008). In addition, well-trained individuals can markedly improve endurance performance without pronounced changes in maximal oxygen consumption, indicating that other factors play a more important role (Ivy et al. 1980). Such a factor is the anaerobic threshold (Allen et al. 1985). They showed that athletes with a similar anaerobic threshold have comparable running times when competing in a 10-km run, despite maximal oxygen consumption differences of up to 9%. Thus, the anaerobic threshold, in our and other's opinion (Beneke 2003; Billat et al. 2003) best defined as workload at the maximal lactate steady state (MLSS), is a key player when determining aerobic performance.

MLSS is defined as the highest performance where blood lactate concentration reaches the final steady state, i.e., blood lactate concentration does not increase more than 1 mmol l$^{-1}$ between min 10 and 30 in a constant-load test (Beneke 2003). However, blood lactate concentration differs between cycling, rowing, and speed skating at MLSS (Beneke and von Duvillard 1996) and despite these differences in blood lactate concentrations, a uniform

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definition of MLSS is applied (Beneke and von Duvillard 1996). Obviously, a blood lactate concentration difference of 1 mmol $l^{-1}$ relative to a blood lactate concentration of 8 mmol $l^{-1}$ is less significant than one relative to 5 mmol $l^{-1}$. With the determination of MLSS, the workload possible for at least 30 min at MLSS is known, but not the time to exhaustion ($t_{lim}$) at this workload. Running $t_{lim}$ at MLSS in endurance-trained middle-aged subjects can reach 44 ± 10 min (Billat et al. 2004) and 55.0 ± 8.5 min (Baron et al. 2008) in well-trained young men on a cycle ergometer. $t_{lim}$ is improved by training (Billat et al. 2004; Burgomaster et al. 2005), deteriorates by detraining (Madsen et al. 1993), and it changes independently of peak oxygen consumption (Burgomaster et al. 2005; Markov et al. 2001; Spengler et al. 1999; Thomsen et al. 2007). Thus, $t_{lim}$ at MLSS adds an additional dimension when classifying endurance performance, and finally decides on victory or defeat in longer endurance competitions.

Which factors influence $t_{lim}$ is still unclear (Baron et al. 2008). Nevertheless, objectively measurable physiological parameters, such as heart rate, oxygen consumption, ventilation, and blood lactate concentration, are important. During exhaustive exercise, these parameters influence perceptual ratings and lead to high perceived exertion (Robertson and Noble 1997). Therefore, also perceived exertion may affect $t_{lim}$ directly or indirectly (Baron et al. 2008; Doherty et al. 2001). Thus, differences in physiological variables and perceived exertion between exercise modes may lead to a different $t_{lim}$ in cycling and running.

Indeed, differences in physiological variables at comparable intensities between cycling and running exist (Beneke and von Duvillard 1996; Roecker et al. 2003). According to Roecker et al. (2003), heart rate is lower in cycling compared to running at exhaustion as well as at a comparable submaximal intensity. Whether these differences also exist at MLSS and evoke different $t_{lim}$, is unknown. However, since relative submaximal heart rate (% of maximal heart rate) was comparable for recreationally active subjects in cycling and running (cycling 81% and running 89% of maximal heart rate, respectively; Roecker et al. 2003), we do not expect a difference concerning $t_{lim}$ at MLSS in cycling and running in moderately, non-specific endurance-trained subjects. If this is the case, we suggest that using a uniform definition for MLSS determination is reasonable, despite differences in blood lactate concentration.

The aims of this study were to compare $t_{lim}$ at MLSS between cycling and running, and to investigate, if MLSS can be determined during cycling and running using the same criteria, despite differences in submaximal blood lactate concentrations. We hypothesised that $t_{lim}$ at MLSS is similar in cycling and running and that a uniform definition of MLSS can be applied to cycling and running despite differences in submaximal blood lactate concentrations.

## Methods

### Subjects

A total of 15 moderately trained men volunteered to participate in this study. Subjects had the following characteristics: age 30 ± 6 years, height 180 ± 5 cm, and body mass 77 ± 6 kg. Participants were recreationally active people (weekly training load per subject: 3.7 ± 1.6 h $week^{-1}$). They all performed cycling and running on a regular basis and similarly distributed to both exercise modes. Training bouts were noted before (2 weeks) and during the study, and training load had to be kept constant during this time. After the completion of a routine health questionnaire, subjects were informed of the procedures applied and of the associated risks. All subjects gave their informed consent. The experimental protocol was approved by the ethics committee of the ETH Zurich and the study was performed in accordance with the ethical standards laid down in the Declaration of Helsinki for human experimentation.

### Overview of experimental design and the equipment used

After the determination of anaerobic threshold by a lactate minimum test, several constant-load tests were performed until exhaustion in order to determine MLSS. Time between tests was 3–10 days. Each participant performed cycling (Ergoline 800S, Ergoline, Bitz, Germany) and running (Quasar, HP-Cosmos, Traunstein, Germany) in a randomised order. Heart rate was measured beat per beat (Vantage NV, Polar, Kempele, Finland), oxygen consumption and ventilation were collected breath by breath (Oxycon gamma, Jäger, Höchberg, Germany), and blood lactate concentration was analysed enzymatically (BIOSEN 5040, EFK Industrie–Elektronik, Barleben, Germany). The Oxycon gamma was calibrated before and after each test according the manufacturer's recommendations using a standard concentration gas mixture and a 3-l calibration syringe. For the acquisition of perceived exertion, a modified scale from 0 to 10 was used (Wilson and Jones 1991).

### Testing procedures

#### *Lactate minimum test*

Initially, subjects performed a lactate minimum test on a cycle ergometer and on a treadmill in order to estimate lactate minimum (Braumann et al. 1991). The first part of the test started with 100 W (cycle ergometer) or 9 km $h^{-1}$ [treadmill, gradient angle: 1%; (Jones and Doust 1996)] with increments of 50 W or 1.5 km $h^{-1}$ every minute until exhaustion. After 8 min of recovery, the second part of the lactate minimum test started with 100 W and 9 km $h^{-1}$, respectively. Increments during the second part were 25 W every 90 s and 1 km $h^{-1}$ every 2 min until exhaustion. During both parts of the test, heart rate, oxygen consumption, and ventilation were measured continuously, whereas perceived exertion was recorded at the end of every increment. Blood lactate concentration was measured at exhaustion of part 1, during early recovery (after 2, 4, and 7.5 min) of part 1, and at the end of each stage of part 2. During the first 2 min of part 1, pedalling rate was freely chosen by each subject and then kept constant (±5 revolutions $min^{-1}$) throughout all cycling tests.

### *Determination of MLSS and $t_{lim}$*

After the lactate minimum test, subjects performed 3–5 constant-load tests at least 72 h apart until the criteria of MLSS were fulfilled (Heck et al. 1985): difference in blood lactate concentration ≤1 mmol $l^{-1}$ during 20 min after a 10-min steady-state phase and difference in blood lactate concentration ≥1 mmol $l^{-1}$ with slightly higher intensities (power +5 W; velocity +0.25 km $h^{-1}$). Tests started with a 6-min warm-up phase at 60 and 80% of the target intensity, respectively, and lasted until exhaustion. The first constant-load test was performed with the power/velocity of the estimated lactate minimum, and in subsequent tests power/velocity was adjusted according to the outcome of the last test (±5 W/0.25 km $h^{-1}$ or ±10 W/0.5 km $h^{-1}$). During all cycling tests, pedalling rate was kept the same as during the lactate minimum test (±5 revolutions $min^{-1}$), and during the treadmill tests the gradient angle was 1% (Jones and Doust 1996). We defined task failure as the point in time, when the subjects left the previously defined pedalling rate (±5 revolutions $min^{-1}$) for the second time or stopped pedalling/running.

### Statistical analysis

We determined "lactate minimum" as the lowest blood lactate concentration during part 2 of the lactate minimum test by putting a third class polynomial into blood lactate concentration values (Statview 5.0.1, SAS Institute, Cary, NC, USA) and calculating the minimum of the function. Then, we determined power or velocity corresponding to this blood lactate concentration and approximated to 5 W and 0.25 km $h^{-1}$ (Mathlab, The MathWorks, Natick, MA, USA). Peak heart rate, peak oxygen consumption, and peak ventilation were determined by calculating the mean of the highest values obtained either in the first or the second part of the lactate minimum test (averaged over 30 s). For peak blood lactate concentration, the highest single value during recovery after part 1 was recorded. Peak workload was calculated as "power of the last completed stage (W) + time elapsed on the uncompleted stage (s)/60 s × 50 W or 1.5 km $h^{-1}$."

$t_{lim}$ corresponded to the performance time to exhaustion at the workload at MLSS. On the treadmill, net running time (excluding the 30 s breaks for blood sample collection) was calculated. For heart rate, oxygen consumption, and ventilation, every 5 min the mean of 30 s (min 4 to min 4:30) was taken. These values were then averaged from min 11 to min 30. Blood lactate concentration and perceived exertion were recorded every 5 min (min 4:30 to min 5) and averaged (min 11 to min 30). Means of heart rate, oxygen consumption, ventilation, and blood lactate concentration were then put into relation to peak values (% of peak values).

After checking data for normality using Q–Q plots, means of $t_{lim}$, heart rate, oxygen consumption, ventilation, blood lactate concentration, and perceived exertion from min 11 to min 30, as well as maximal values, were compared between cycling and running (SPSS 11.0, Chicago, IL, USA). Statistical significance was tested with Student's paired $t$ test. Level of significance was $P < 0.05$. Data are presented as means ± standard deviation (SD).

## Results

### Maximal lactate steady state

#### *Time to exhaustion*

$t_{lim}$ was similar between cycling (37.7 ± 8.9 min) and running (34.4 ± 5.4 min). Individual times to exhaustion ranged from 30.0 to 65.2 min on the cycle ergometer and 30.0 to 50.3 min on the treadmill. Workloads at MLSS were 248 ± 31 W in cycling and 13.2 ± 0.8 km $h^{-1}$ in running. Individuals could maintain a higher percentage of peak workload at MLSS in running (71 ± 4%) than in cycling (62 ± 5%; $P < 0.001$).

#### *Cardiorespiratory and metabolic parameters as well as perceived exertion*

At MLSS, heart rate and ventilation were lower ($P < 0.01$) for cycling compared to running in absolute terms (Figs. 1a, 2a); when compared relatively, no differences were found (Figs. 1b, 2b). In contrast, subjects showed higher absolute blood lactate concentration while cycling than while running ($P < 0.01$; Fig. 3a). Again, when

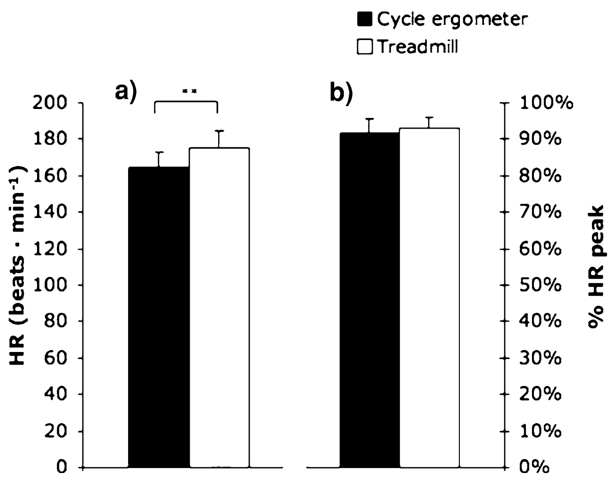


**Fig. 1** Heart rate (HR) at maximal lactate steady state on the cycle ergometer and treadmill in **a** absolute terms and **b** % peak heart rate; ** $P < 0.01$; $n = 15$

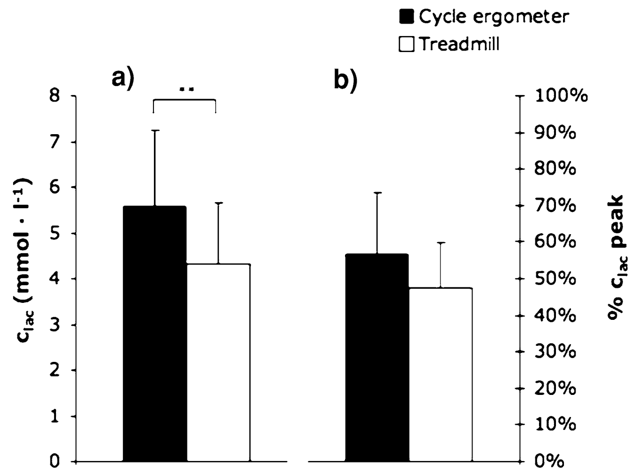


**Fig. 3** Blood lactate concentration ($c_{lac}$) at maximal lactate steady state on the cycle ergometer and treadmill in a) absolute terms and b) % peak blood lactate concentration; ** $P < 0.01$; $n = 15$

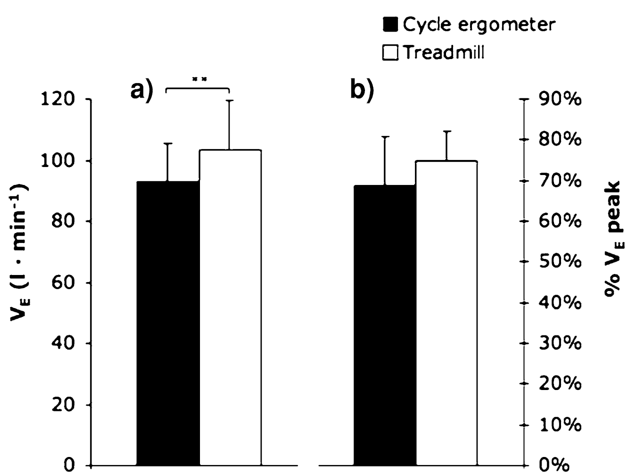


**Fig. 2** Minute ventilation ($\dot{V}_E$) at maximal lactate steady state on the cycle ergometer and treadmill in **a** absolute terms and **b** % peak ventilation; ** $P < 0.01$; $n = 15$

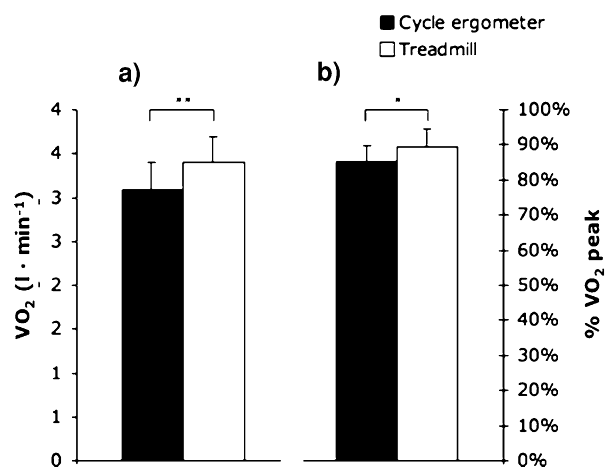


**Fig. 4** Oxygen consumption ($\dot{V}_{O_2}$) at maximal lactate steady state on the cycle ergometer and treadmill in **a** absolute terms and **b**) % peak oxygen consumption; * $P < 0.05$, ** $P < 0.01$; $n = 15$

compared relatively, the difference in blood lactate concentration disappeared (Fig. 3b). Significant differences were found for oxygen consumption at MLSS: absolute ($P < 0.05$; Fig. 4a) as well as relative ($P < 0.01$; Fig. 4b) oxygen consumption at MLSS were lower for cycling than for running. Averaged perceived exertion in cycling (7.2 ± 1.7) and running (7.2 ± 1.5) at MLSS was equal. PE increased from 4 to 9 in both exercise modalities while performing at MLSS from min 11 to exhaustion.

### Lactate minimum test

Peak workloads were obtained in all subjects during the first part of the lactate minimum test (cycling, 402 ± 52 W; running, 18.5 ± 1.5 km h$^{-1}$). Peak heart rate was significantly lower in cycling than in running (180 ± 7 and 188 ± 9 beats min$^{-1}$, respectively; $P < 0.01$). There was no difference in peak oxygen consumption (3.6 ± 0.4 and 3.8 ± 0.3 l min$^{-1}$, respectively), peak ventilation (138 ± 25 and 139 ± 23 l min$^{-1}$, respectively) or peak blood lactate concentration (9.9 ± 1.6 and 9.3 ± 2.4 mmol l$^{-1}$, respectively) between cycling and running. Workload at lactate minimum was 224 ± 30 W in cycling and 13.7 ± 0.9 km h$^{-1}$ in running.

## Discussion

The novel finding of this study is that $t_{lim}$ at MLSS does not differ between cycling and running in healthy, moderately trained young men, who are familiar with both exercise modalities. The similar $t_{lim}$ in cycling and running is, despite significantly different absolute variables (heart rate, ventilation, blood lactate concentration, and oxygen consumption; Figs. 1a, 2a, 3a, 4a), accompanied by similar perceived exertion and relative parameters (heart rate, ventilation, blood lactate concentration; Figs. 1b, 2b, 3b). Furthermore, the comparable $t_{lim}$ was paralleled by slight, yet non-significant differences in peak oxygen consumption. However, since $t_{lim}$ seems to change independently of peak oxygen consumption (Burgomaster et al. 2005; Markov et al. 2001; Spengler et al. 1999; Thomsen et al. 2007), this discrepancy can be explained and the current results add further credit to the independency of these two parameters.

While absolute heart rate differed significantly, subjects were able to perform with almost the same relative heart rate (92 ± 4% of peak heart rate in cycling and 93 ± 3% of peak heart rate in running; Fig. 1b). The same relative heart rate at MLSS indicates a similar cardiovascular demand of the two exercise modes and is explained by the fact that the different peak heart rate were paralleled by differences in absolute heart rate at MLSS (Fig. 1a). Based on our results, we assume that perceived exertion is not affected by differences in absolute heart rate, but rather influenced by heart rate in relative terms. The same relative heart rate may therefore partly explain the same $t_{lim}$.

In addition to different absolute heart rates at MLSS, we found absolute oxygen consumption at MLSS to be lower in cycling than in running (Fig. 4a). Since peak oxygen consumption was only slightly lower in cycling, also relative oxygen consumption at MLSS was lower in cycling compared to running (Fig. 4b). Nevertheless, the higher relative oxygen consumption in running at MLSS may not have influenced perceived exertion and $t_{lim}$. A possible explanation for the higher absolute oxygen consumption in running is the greater amount of muscle mass involved (e.g. for the active stabilisation of the trunk). Involving more muscle mass leads to a higher energy expenditure (Bergh et al. 1976). The more upright position and also movements of the trunk and upper limbs in running consume additional energy compared to cycling (Kravitz et al. 1997).

Reflecting the pattern of absolute heart rate at MLSS, absolute ventilation at MLSS was also lower in cycling compared to running, yet equal when put into relation to peak ventilation (Fig. 2). Again, as with relative heart rate, relative ventilation may partly explain the similar perceived exertion and $t_{lim}$ in cycling and running.

At MLSS, besides lower absolute heart rate, oxygen consumption, and ventilation, we found higher absolute blood lactate concentration in cycling compared to running. Differences in blood lactate concentration at MLSS for different exercise modes have previously been reported by Beneke and von Duvillard (1996). An explanation for different blood lactate concentration between exercise modes, despite comparable workloads, is the different metabolic cost of exercise modes (Carter et al. 2000; Hill et al. 2003). However, when blood lactate concentration at MLSS is calculated as % of peak blood lactate concentration, the difference disappears. Therefore, blood lactate concentration shows the same pattern as heart rate and ventilation: different in absolute terms, but equal in relative terms. The same relative blood lactate concentration indicates a similar metabolic demand of cycling and running at MLSS and possibly explains the similar perceived exertion and $t_{lim}$.

As high absolute blood lactate concentration is traditionally associated with high ratings of perceived exertion and task failure (Doherty et al. 2001), one would expect perceived exertion to be increased and $t_{lim}$ to be shorter in cycling compared to running, which was not the case. The independence of perceived exertion from any single variable was also previously shown by Green et al. (2006). Additionally, Baron et al. (2008) showed that exhaustion at MLSS was associated with an increase in the ratings of perceived exertion (as also shown by our results), while physiological reserve capacity still existed. The similarity of perceived exertion between the two exercise modes is in line with the similar relative cardiorespiratory variables, and indicates that performing with comparable intensities is similarly demanding in cycling and running.

The similar $t_{lim}$ in cycling and running in this study suggests that the intensity at MLSS was comparable despite different blood lactate concentration and heart rate (Beneke and von Duvillard 1996; Roecker et al. 2003). In a time range of 30–50 min, $t_{lim}$ is similar in cycling and running despite different physiological and biomechanical requirements, such as contraction mode and delta efficiency (Bijker et al. 2002). Therefore, absolute differences in blood lactate concentration and heart rate between cycling and running play a minor role when determining MLSS.

We conclude that $t_{lim}$ at MLSS is similar in cycling and running in moderately trained subjects, despite absolute differences in heart rate, ventilation, blood lactate concentration, and oxygen consumption. This finding may be best explained by the fact that the cardiorespiratory demand at MLSS is relatively equal in cycling and running and that absolute differences in cardiorespiratory variables may not affect $t_{lim}$. The comparable $t_{lim}$ indicates that similar to relative heart rate, $t_{lim}$ can be transferred between the two exercise modalities in moderately trained men for designing training recommendations. Additionally, the similar $t_{lim}$ for cycling and running allows the same criteria to be used for determining MLSS in both exercise modes.

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**Conflict of interest statement** None.

## References

Allen WK, Seals DR, Hurley BF, Ehsani AA, Hagberg JM (1985) Lactate threshold and distance-running performance in young and older endurance athletes. J Appl Physiol 58:1281–1284

Åstrand PO (1976) Quantification of exercise capability and evaluation of physical capacity in man. Prog Cardiovasc Dis 19:51–67. doi:10.1016/0033-0620(76)90008-6

Baron B, Noakes TD, Dekerle J, Moullan F, Robin S, Matran R, Pelayo P (2008) Why does exercise terminate at the maximal lactate steady state intensity? Br J Sports Med 42:528–533. doi:10.1136/bjsm.2007.040444

Beneke R (2003) Methodological aspects of maximal lactate steady state—implications for performance testing. Eur J Appl Physiol 89:95–99. doi:10.1007/s00421-002-0783-1

Beneke R, von Duvillard S (1996) Determination of maximal lactate steady state response in selected sports events. Med Sci Sports Exerc 28:241–246. doi:10.1097/00005768-199602000-00013

Bergh U, Kanstrup IL, Ekblom B (1976) Maximal oxygen uptake during exercise with various combinations of arm and leg work. J Appl Physiol 41:191–196

Bijker KE, de Groot G, Hollander AP (2002) Differences in leg muscle activity during running and cycling in humans. Eur J Appl Physiol 87:556–561. doi:10.1007/s00421-002-0663-8

Billat V, Sirvent P, Py G, Koralsztein JP, Mercier J (2003) The concept of maximal lactate steady state: a bridge between biochemistry, physiology and sport science. Sports Med 33:407–426. doi:10.2165/00007256-200333060-00003

Billat V, Sirvent P, Lepretre PM, Koralsztein JP (2004) Training effect on performance, substrate balance and blood lactate concentration at maximal lactate steady state in master endurance-runners. Pflugers Arch 447:875–883. doi:10.1007/s00424-003-1215-8

Braumann K, Tegtbur U, Busse M, Maassen N (1991) Die “Laktatsenke”—Eine Methode zur Ermittlung der individuellen Dauerleistungsgrenze. Dtsch Z Sportmed 42:240–246

Burgomaster KA, Hughes SC, Heigenhauser GJ, Bradwell SN, Gibala MJ (2005) Six sessions of sprint interval training increases muscle oxidative potential and cycle endurance capacity in humans. J Appl Physiol 98:1985–1990. doi:10.1152/japplphysiol.01095.2004

Carter H, Jones AM, Barstow TJ, Burnley M, Williams CA, Doust JH (2000) Oxygen uptake kinetics in treadmill running and cycle ergometry: a comparison. J Appl Physiol 89:899–907

Doherty M, Smith PM, Hughes MG, Collins D (2001) Rating of perceived exertion during high-intensity treadmill running. Med Sci Sports Exerc 33:1953–1958. doi:10.1097/00005768-200111000-00023

Green J, McLester J, Crews T, Wickwire P, Pritchett R, Lomax R (2006) RPE association with lactate and heart rate during high-intensity interval cycling. Med Sci Sports Exerc 38:167–172. doi:10.1249/01.mss.0000180359.98241.a2

Heck H, Mader A, Hess G, Mücke S, Müller R, Hollmann W (1985) Justification of the 4-mmol/l lactate threshold. Int J Sports Med 6:117–130. doi:10.1055/s-2008-1025824

Hill DW, Halcomb JN, Stevens EC (2003) Oxygen uptake kinetics during severe intensity running and cycling. Eur J Appl Physiol 89:612–618. doi:10.1007/s00421-002-0779-x

Ivy JL, Withers RT, Van Handel PJ, Elger DH, Costill DL (1980) Muscle respiratory capacity and fiber type as determinants of the lactate threshold. J Appl Physiol 48:523–527

Jones AM, Doust JH (1996) A 1% treadmill grade most accurately reflects the energetic cost of outdoor running. J Sports Sci 14:321–327. doi:10.1080/02640419608727717

Kravitz L, Robergs RA, Heyward VH, Wagner DR, Powers K (1997) Exercise mode and gender comparisons of energy expenditure at self-selected intensities. Med Sci Sports Exerc 29:1028–1035. doi:10.1097/00005768-199708000-00007

Madsen K, Pedersen PK, Djurhuus MS, Klitgaard NA (1993) Effects of detraining on endurance capacity and metabolic changes during prolonged exhaustive exercise. J Appl Physiol 75:1444–1451

Markov G, Spengler CM, Knopfli-Lenzin C, Stuessi C, Boutellier U (2001) Respiratory muscle training increases cycling endurance without affecting cardiovascular responses to exercise. Eur J Appl Physiol 85:233–239. doi:10.1007/s004210100450

Noakes TD (2008) Testing for maximum oxygen consumption has produced a brainless model of human exercise performance. Br J Sports Med 42:551–555. doi:10.1136/bjsm.2008.046821

Robertson RJ, Noble BJ (1997) Perception of physical exertion: methods, mediators, and applications. Exerc Sport Sci Rev 25:407–452. doi:10.1249/00003677-199700250-00017

Roecker K, Striegel H, Dickhuth H (2003) Heart rate recommendations: transfer between running and cycling exercise? Int J Sports Med 24:173–178. doi:10.1055/s-2003-39087

Spengler CM, Roos M, Laube SM, Boutellier U (1999) Decreased exercise blood lactate concentrations after respiratory endurance training in humans. Eur J Appl Physiol 79:299–305. doi:10.1007/s004210050511

Thomsen JJ, Rentsch RL, Robach P, Calbet JA, Boushel R, Rasmussen P, Juel C, Lundby C (2007) Prolonged administration of recombinant human erythropoietin increases submaximal performance more than maximal aerobic capacity. Eur J Appl Physiol 101:481–486. doi:10.1007/s00421-007-0522-8

Wilson RC, Jones PW (1991) Differentiation between the intensity of breathlessness and the distress it evokes in normal subjects during exercise. Clin Sci (Lond) 80:65–70