Differences in the relationship of heart rate and blood lactate values between running on track versus inclined treadmill

Improving laboratory testing to accurately prescribe exercise intensities

Axel Bramell

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Handledare: Michael Svensson Universitetslektor
Granskare: Apostolos Theos Med Sc Phd

Abstract

The purpose of the study was to evaluate the generalisability of the heart rate-blood lactate relationship determined in laboratory testing in comparison to running over ground. This plays a crucial role to prescribe exercise intensity from laboratory results. Ten well trained runners performed a maximal oxygen uptake (VO_2max) pre-test and an incremental submaximal test performed at a two degrees inclined treadmill and a running track. Statistical analysis included student's t-test of heart rate at interpolated blood lactate levels and comparison of second order polynomial regression lines. VO_2max was 60,4 ± 6 ml/kg/min for men and 56,3 ± 4,3 ml/kg/min for women. There was no significant difference in heart rate at interpolated blood lactate of 3 and 4 mmol/L. There was no significant difference between heart rate values at any running velocity. A significant difference between blood lactate values was observed 14km/h (p=0,04). When considering blood lactate values up to 6mmol/L, heart rate-blood lactate relationships were similar. In conclusion, lactate threshold testing on treadmill through incremental test protocols on a two degrees incline gives similar heart rate-blood lactate relationship as running over ground and may be used to prescribe intensity in training performed over ground.

Key words: Exercise testing, lactate threshold, running, lactic acid, field testing,

Table of content 1

Introduction

The anaerobic threshold is a long studied concept in human exercise physiology (Wasserman, 1986), as well as the relating changes in blood lactate (bLa) (Svedahl & MacIntosh, 2003; Wasserman, 1986, 1987). In sports, bLa is studied because it is connected to metabolic stress, anaerobic metabolism, muscular fatigue (Faude, Kindermann, & Meyer, 2009) and the accumulation of bLa during increasing exercise intensity to the point where bLa concentrations increase drastically (Wasserman, 1987). This concept is often referred to as a breakpoint or threshold and is thought to represent the maximal workload at which an equilibrium occur between lactate appearance and removal, defined as the maximal lactate steady state (MLSS) and represents the maximal aerobic effect of the engaged skeletal muscle where mitochondrial capacity still matches glycolytic rate (Billat, Sirvent, Py, Koralsztein, & Mercier, 2003). MLSS might be considered the golden standard in bLa threshold testing, but it is an expensive method that requires extensive testing on several occasions (Billat et al., 2003).

Several attempts have been made to develop valid single visit protocols that accurately determine the MLSS. As an effect, there are different test protocols aiming to identify this workload, as well as several definitions of the concept itself (Bosquet, Léger, & Legros, 2002; Faude et al., 2009). These include fixed thresholds (Hurley et al., 1984; Kindermann, Simon, & Keul, 1979; LaFontaine, Londeree, & Spath, 1981) with the onset of blood lactate accumulation (OBLA) (Sjödin & Jacobs, 1981) at 4 mmol/L being the most widespread. Fixed threshold concentrations such as OBLA are highly standardised, but does not account for individual variation in bLa concentration at the MLSS. Other protocols have accounted for these individual differences: it has been defined as the individual anaerobic threshold (IAnT) based on bLa kinetics during incremental exercise to exhaustion and the following recovery and bLa clearance (Stegmann, Kindermann, & Schnabel, 1981), as the lactate threshold (D-max) based on the maximal distance between the lactate curve and a line formed by its two endpoints (Cheng et al., 1992) and as 1mmol/l bLa above baseline values (Coyle et al., 1983). A more complete account of the nomenclature and criteria for different lactate threshold concepts is provided by Bosquet, Léger, & Legros (2002). Because the comparison of lactate threshold criteria is beyond the scope of the present essay, the idea of a disruption in bLa steady state will be referred to as the lactate threshold (LaT) without referring to other definitions with the same nomenclature.

The intensity at which the LaT occurs has been recognised as one of the limiting factors of performance in endurance sports (Bosquet, Léger, & Legros, 2002). Although lactate does not likely impair performance of skeletal muscle directly (Ellis, Simmons, & Miller, 2009), its accumulation coincides with muscular fatigue (Sahlin, Harris, Nylind, & Hultman, 1976). Other metabolites accumulating during exercise are likely responsible for muscular fatigue to a greater extent, including inorganic phosphate (Millar & Homsher, 1992; Potma, van Graas, & Stienen, 1995; Stienen, Roosemalen, Wilson, & Elzinga, 1990), hydrogen ions (Lamb & Stephenson, 1994; Potma et al., 1995) and magnesium ions (Lamb & Stephenson, 1994). Among other effects, these metabolites may decrease muscular force production through inhibiting cross-bridge interactions and impairing both the release and re-uptake of calcium to the sarcoplasmatic reticulum (Lamb & Stephenson, 1994; Millar & Homsher, 1992; Potma et al., 1995; Stienen et al., 1990). Even though the role of bLa in muscular fatigue during exercise has been largely questioned (Cairns, 2006), it still remains an indicator of exercise intensity (Ralph Beneke, Leithauser, & Ochentel, 2011; Billat et al., 2003; Billat, 1996; Bosquet et al., 2002; Faude et al., 2009).

Measurements of bLa are used in the prediction of performance (Coyle, 1995), as well as a tool to guide and evaluate the training process (Kumagai et al., 1982; Lorenz, Reiman, Lehecka, & Naylor, 2013; Wasserman, 1986, 1987). In running – amongst other endurance sports – athletes are engaged in training that result in a right shift of the bLa curve. This leads to bLa accumulation to occur at a a higher velocity, percentage of VO_2max and maximal heart rate (HR), which is highly related to performance during endurance based competition (Bosquet et al., 2002). This right shift of the LaT is a result of physiological adaptions of the exercising muscles, including higher oxidation of fat and bLa as a result of mitochondrial biogenesis (Jones & Carter, 2000). Higher fat oxidation leads to a lower glycolytic rate for a given intensity, which in turn depletes less glycogen (Jones & Carter, 2000). During high volumes of training it is vital for athletes to retain adequate glycogen stores in order to perform high intensity workouts (Maughan et al., 1997). In contrast, a higher bLa response at a given submaximal intensity indicates a low aerobic effect in the exercising muscles, indicating a high glycolytic rate which depletes glycogen at a higher rate (Jones & Carter, 2000). When the exercising muscle cannot match the rate of glycolytic activity by mitochondrial activity, lactate is transported to the blood from muscle via the monocarboxylate transporter (MCT) system (Bonen, 2000) and is consumed by other organs such as the brain use bLa as fuel (Schurr, 2006). Even if this shows that lactate is not a dead end waste product, in terms of endurance performance it would be preferable to utilize glycogen for muscle contraction since carbohydrate stores of the muscles can be a limiting factor in endurance performance (Yoshida, 1984).

Training to enhance endurance performance is often structured and prescribed in varying intensities to create a specific physiological stimulus. To determine the appropriate exercise intensities for each athlete, exercise intensity is usually expressed in relative terms (Mann, Lamberts, & Lambert, 2013). In exercise physiology, exercise intensity is often regarded as a percentage of maximal aerobic effect, that is maximal oxygen consumption (VO_2max) (Meyer, Gabriel, & Kindermann, 1999). To further individualise intensity of exercise for an athlete, it is useful and perhaps more important to consider the relative intensity of VO_2max at which the LaT occurs, which signifies the maximal workload that can be maintained for an extended period of time between 30-60 minutes (Foxdal, 1994). In the daily training, this intensity is usually expressed as workload (running velocity) or HR to guide training. Through the relationship between HR and bLa obtained in exercise testing, HR can be used to achieve specific bLa responses, making HR a cheap and convenient way to guide training.

In running, LaT testing can be performed either on a treadmill or over ground, usually in track running or road running. Testing on a treadmill often takes place in a laboratory setting, which allows controlling the environment for confounding factors such as wind, temperature and humidity. The constant workloads of the treadmill also simplify testing procedures and enables in depth research of both physiological and biomechanical parameters. Because of these advantages, research in the field of exercise physiology often involves testing with treadmills, rowing or cycle ergometers.

When applying laboratory results in a wider context - for example to prescribe exercise intensity and guide training - the generalisability of the results to other conditions should be considered, both in terms of absolute workload and the HR-bLa relationship. One of the differences between treadmill and over ground running that has gained most attention is the resistance from air flow and is seen as the main cause of differences in energy requirement (Bassett et al., 1985; Leger & Mercier, 1984; Pugh, 1970, 1971; van Ingen Schenau, 1980). Since air resistance increases with higher running velocities, so do also the differences in energy requirements (Pugh, 1971). This was confirmed by Jones and Doust (1996), who showed that oxygen uptake at lower velocities did not differ significantly between level running on a treadmill or over ground, but there was significant differences in oxygen uptake at running velocities from 3,75 m/s to 4,58 m/s. These authors also investigated the effect of treadmill incline to compensate for the lack of air resistance and found a 1% incline to represent this at most velocities, but their data revealed that an incline of 2 or 3% would be preferred at higher velocities. Even though Jones and Doust (1996) work is valuable, they did not include bLa measurements.

Comparisons of HR and bLa values between treadmill running and running over ground is sparse (Di Michele, Di Renzo, Ammazzalorso, & Merni, 2009; Kunduracioglu, Guner, Ulkar, & Erdogan, 2007). Kunduraciogu, Guner, Ulkar & Erdogan (2007) studied bLa and HR values at running on a treadmill compared to the running at the same velocity over ground and on natural grass. They found no significant differences in HR, but bLa concentrations were significantly higher running over ground. Di Michele, Di Renzo, Ammazzalorso, and Merni (2009), showed significantly higher bLa and HR values in soccer players when running on synthetic turf compared to treadmill, but no significant difference between treadmill and natural grass. Furthermore, Di Michele et al. (2009) noted that synthetic turf generally demanded more energy for locomotion compared to natural grass, which supports the notion that the characteristics of running surface elicits specific physiological demands at least in part due to surface stiffness and elasticity, with increased cost of locomotion on more compliant surfaces (Lejeune, Willems, & Heglund, 1998). Another study compared HR and bLa responses of running on a treadmill compared to a running track at running velocity corresponding to the LaT (Gidewall & Johnsson, 2005), which revealed a higher physiological response in HR and bLa running on the track. These comparisons of running on a treadmill to running over ground all used a level grade treadmill and did therefore not compensate for air resistance. Together these studies suggest differences in the physiological response running on a treadmill or over ground, but could not explain if lack of air flow resistance explained all of the difference or if there exist some other inherent difference between running on a treadmill and over ground that affects HR and bLa.

Treadmill incline has been used to match energy expenditure at the same velocity as over ground running, but little is known concerning the effect of incline on the relationship between HR and bLa. Changes in motor pattern is known to alter the bLa concentration at MLSS (R Beneke, Leithäuser, & Hütler, 2001). The capability of different muscle fibres to produce and utilise lactate varies (L B Gladden, 2000) and muscle fibre type distribution varies between muscles (Staron, 1997). As a result, the maximal net bLa appearance for each movement pattern is a result of the fibre type distribution in the engaged muscles and the extent of activation in each muscle (L. Bruce Gladden, 2011).

Personal experience and empirical findings of others (Di Michele et al., 2009; Gidewall & Johnsson, 2005; Kunduracioglu et al., 2007) has raised suspicion that differences in the HR-bLa relationship between running on a treadmill and over ground exist. More specifically, a given heart rate seems to elicit a higher bLa response when running over ground compared to a level grade treadmill. Based on this assumption, prescription of exercise intensity based on heart rate would then result in a higher bLa response than intended. In a larger perspective, this might affect the overall training stimulus and have detrimental effects of performance over time which questions the generalisability of bLa measurements obtained in laboratory settings and its usefulness to athletes.

Treadmill incline alters biomechanical patterns of running (Swanson & Caldwell, 2000) with increased step rate (Padulo, Powell, Milia, & Ardigò, 2013) and lower ground reaction forces (Gottschall & Kram, 2005; Padulo et al., 2013) and alters the degree of activation in the different muscles of the legs (Gostill, Jansson, Gollnick, & Saltin, 1974; Sloniger, Cureton, Prior, & Evans, 1997). This raises some interesting questions on how treadmill incline not only compensates for air resistance, but at the same time could alter bLa at a given HR to more closely match that of running over ground. To my best knowledge, no previous research has investigated the effect of a treadmill incline on the HR-bLa relationship compared to over ground running. Furthermore, previous attempts to compare absolute HR and bLa values between treadmill and over ground running have not included an inclined treadmill.

The main purpose of the present study was to investigate the relationship between HR and bLa when running on a treadmill incline of two degrees compared to running on a level surface over ground on an indoor 200 meters running track. This was done to evaluate the generalisability of the gradient specific HR-bLa relationship from laboratory to field conditions. In addition, the study aimed to investigate the interchangeability of running velocity at the two degree inclined treadmill to running over ground in terms of absolute HR and bLa values. The specific incline was based on previous pilot (n=3) work comparing different inclines at the same absolute workload. The chosen incline tended to result in a greater bLa response at the same workload, as set to equal heart rate, compared to lower inclines.

Research question

Is there a significant difference ($p \leq 0,05$) in HR at 3 and 4 mmol/L bLa when running on a two degree inclined treadmill compared to running on a 200m indoor track?

Method

Participants

Six men and four women with engaged in various running activities such as track running, orienteering and multisport were recruited through an open invitation which was posted in sport specific social media for local sport clubs and sports medicine students. Those who showed interest were then asked to give information about their training history and results from recent competitions to determine their level of performance. The participants were further informed about the study through a paper describing the procedures in detail. The inclusion criteria for the study stated that the participants should be well trained with a self-reported history of at least 3 days of running each week for the last 12 months. They should be fully familiar with TM running and perfectly healthy. The exclusion criteria stated that the participants did not have a history of cardiovascular disease or other conditions related to increased health risks during exercise. Participants with low haemoglobin values (< 120 g/L for women and < 130 for men g/L) and high blood pressure (> 140/90 Hg, < 90/60 Hg) were excluded. Physical characteristics of study participants are presented in Table 1. Furthermore, participants received detailed instructions on preparations during the days prior to each test. These instructions included diet, exercise, rest, sleep and everyday activities as to control the biggest potential confounders that could affect bLa and HR values during the tests.

Table 1. Physical characteristics of study participants presented in means and standard deviations.

	Age	Height, cm	Weight, kg
Men	31 ± 10	183 ± 6	76 ± 7
Women	19 ± 4	162 ± 2	51 ± 3

Design and procedures

All participants performed three running tests within one week with one rest day between each test. Each participant performed the tests at the same time of the day. First, an incremental treadmill test for determination of VO2max and maximal heart rate was conducted. This was done to evaluate each participant's capacity to guide further testing. Secondly, a submaximal incremental test protocol was performed twice: both on a treadmill and on a track. Participants were divided into two groups and each group performed the tests on two separate weeks. The submaximal incremental tests were done in a reversed cross over fashion to counterbalance any effect attributed to test order as presented in Figure 1.

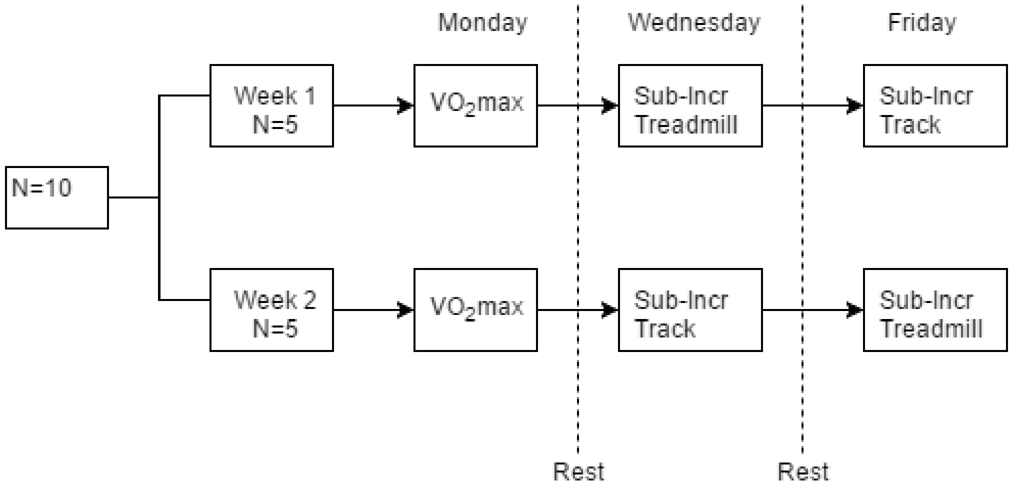

Figure 1. Schematic flowchart of study design. VO_2max: Maximal oxygen uptake test. Sub-Incr: Submaximal incremental test.

Maximal oxygen uptake test (VO_2max)

Participants performed a 10 minute warmup at self-selected pace prior to testing. The running velocity was constant during the test and ranged from 13-15km/h depending on the training background of the participant. Initial incline was 0° and was increased 1° after the first minute and thereafter 0.5° every minute. The test continued until volitional exhaustion. The highest oxygen uptake obtained as a mean over 30 seconds was considered the VO2max during the test.

Submaximal incremental tests

The incremental test protocol was performed twice: both on a 2° incline treadmill and a level indoor running track. After a 10 minute warmup at a velocity 1 km/h lower than the initial test velocity, the participants performed 6-7 stages lasting 3 minutes each with a 1 minute rest between stages. Running velocities were individualised based on the results of the VO2max test and initial running velocity at the track was generally 1 km/h lower than on the treadmill.

Measurements of physiological parameters

Oxygen consumption was measured using the AMIS 2015 mixing bag online analyser (Innovision, Glamsbjerg, Denmark). During both lactate threshold tests, blood samples were taken from a peripheral venous catheter (PVC) at the bend of the arm in between running stages for determination of bLa. A one minute pause allowed for the collection of 400-800 µL of venous blood using a syringe. Blood samples for the first five participants were analysed using an YSI 2300 Stat Plus (Yellow Springs Instrument Co., Yellow Springs, Ohio) and the following blood samples were analysed using an EKF Biosen C-Line (EKF-diagnstic GmbH, Berleben, Germany). Blood samples obtained during testing on the track that was analysed with the YSI 2300 Stat Plus were stored in EDTA tubes (Becton, Dickinson and Company, New Jersey, USA) containing sodium fluoride to prevent coagulation and transported to the laboratory for analysis. HR was monitored continuously at 5 second intervals by short range radio telemetry (Polar 610 S, Polar Electro, Oy, Finland). During the submaximal incremental tests, HR was calculated for each minute during running. The average HR during the last minute of each stage is taken as the representative HR for that stage. In the case of technical issues to store data, HR during the last 10 seconds of each stage was noted.

Apparatus

Laboratory tests were conducted with a room temperature between 19,3-20,7°C. Running was performed on a calibrated treadmill, Rodby RL 2500E (Rodby, Sweden). The track test took place on an indoor 200 meter running track with banked curves with a room temperature previously reported between 19,1-20,4°C. Participants were instructed to run at the inner line of the first lane of the track minimise any effect of the banked curves. Prior to testing, each participant was given verbal and written information about the execution of the test protocol. To maintain a constant pace for each stage in the running protocol, participants wore a watch eliciting a beep at a time interval equivalent the time to cover 100 meter at the targeted pace, including a digital countdown to the next beep. The track was marked every 100 meter to provide participants with direct feedback on running pace. In addition, participants received continuous feedback from the test leader on their current pace every 200 meter. To make sure participants was familiar with this kind of pacing, the warmup was controlled using the same method. Since all participants were experienced runners, they were familiar with running at an even pace.

Statistical analysis

Descriptive statistics are presented as means ± standard deviation (SD). Statistical significance was set to α=0,05. HR values between treadmill and track running were compared at linearly interpolated bLa concentrations corresponding to 3 and 4 mmol/L using student's t-test. Regression analysis using a second degree polynomial was conducted to inspect the y-intercept and the slope of the regression line. To compensate for differences in maximal heart rate, linear regressions for heart rate and oxygen uptake was calculated to allow expression of heart rate in percentage of maximal oxygen uptake.

Methodological considerations

Day to day variability of the participants' physiological status presents a limitation when comparing HR and bLa values between the two submaximal incremental tests. In terms of nutrition, a low carbohydrate intake during the days prior to testing lowers bLa concentrations during exercise at both relative and absolute workloads (Maassen & Busse, 1989), affecting the intensity at which fixed bLa concentrations occur (Yoshida, 1984). In order to observe the differences in bLa between treadmill and track participants were highly encouraged to maintain a balanced diet with adequate amounts of carbohydrates prior to and between all tests. The counterbalanced design of the submaximal incremental tests was adopted to prevent an order effect due to accumulating fatigue between tests. Time of day affect exercise performance (Fernandes et al., 2014). To avoid these confounding effects, all participants performed all tests at the same time of the day. This also allowed participants to maintain the same dietary strategy throughout testing.

During the submaximal incremental test on the track, constant running velocity had to be maintained by the participants and not by an automated treadmill. To minimise this potential source of error, experienced runners was recruited since they usually are more used to maintain a constant pace as well as running on given lap times. Because running velocity increased every stage and stage duration was constant, participants covered greater distances as the test proceeded. This meant that participants completed each stage at different positions of the running track. Distance covered during each stage was calculated prior to testing in order to predict where bLa sampling would take place. Even though this method required more time to prepare each test, determination of both fixed and individual threshold concepts is dependent on stage duration (Foxdal, 1994) and can be seen as a strength of the study compared to field testing based on constant distance during stages. If distance is held constant, stage duration will decrease with increasing velocities, which might overestimate the LaT (Foxdal, 1994). On the other hand, participants had to walk a maximum of 50 meters to the closest 100 meter mark before starting the next stage. During the submaximal incremental test performed on the treadmill, participants stood still during the time between stages. This constitutes a weakness in the study design, because active recovery might increase bLa clearance (McArdle, Katch, & Katch, 2015) between stages.

Ethical considerations

The study was permitted by the Regional Ethics Committee at Umeå University and was conducted in accordance with the World Medical Association Declaration of Helsinki (2013). All subjects were well informed about test procedures and gave written informed consent (see appendix 1) before participating in the study. Participants were informed that they were allowed to stop the tests at any time. Data was treated confidentially and participants were informed on the right to see their personal test results at any given time. Participants may have experience small discomfort associated to the insertion of the PVC. This was performed by experienced medical personnel under secure conditions. The tests included a maximal effort, but participants were all active runners engaging in performance enhancing training and should be used to strenuous exercise. On the other hand, the information gained from participating in the study as well as the scientific results of the study can be of great value to the athletes. Overall, the total sum of discomfort and risks for the participants was considered small and acceptable compared to the potential benefits.

Results

Mean maximal oxygen uptake during the first test was 60,4 ± 6 ml/kg/m for men and 56,3 ± 4,3 ml/kg/m for women. Mean running velocity and HR values corresponding to fixed bLa concentrations of 3 and 4 mmol/L during the submaximal incremental treadmill and track tests are presented in Table 2. There was no significant difference between HR at 3 and 4 mmol/L bLa. Comparison of velocity at the same bLa concentrations showed no significant difference ($p=0,06$ and $p=0,07$ for 3 and 4 mmol/L respectively). Due to inadequate rest between tests, one of the participants was excluded from all analysis. Yet another participant did not reach 3 mmol/l bLa during the track test. Therefore the analysis HR and velocity at fixed bLa concentrations of 3 and 4 mmol/L included 8 participants.

Table 2. Mean heart rate and velocity at interpolated blood lactate concentrations of 3 and 4 mmol/L.

	Heart rate (bpm)	
	Treadmill	Track
3 mmol/L bLa	173 ± 12	177 ± 11
4 mmol/L bLa	179 ± 10	180 ± 9
	Running velocity (km/h)	
3 mmol/L bLa	13,2 ± 1,5	14,9 ± 1,5
4 mmol/L bLa	14 ± 1,4	15,5 ± 1,4

Means and standard deviations for heart rate and running velocity when running on a two degree inclined treadmill and a track during submaximal incremental tests. Fixed blood lactate concentrations were linearly interpolated from the two adjacent bLa measures from respective test. bLa = blood lactate.

A visual comparison of the specific bLa/HR relationship as a response to running on the two degree inclined treadmill compared to running on the track is presented in Figure 2.

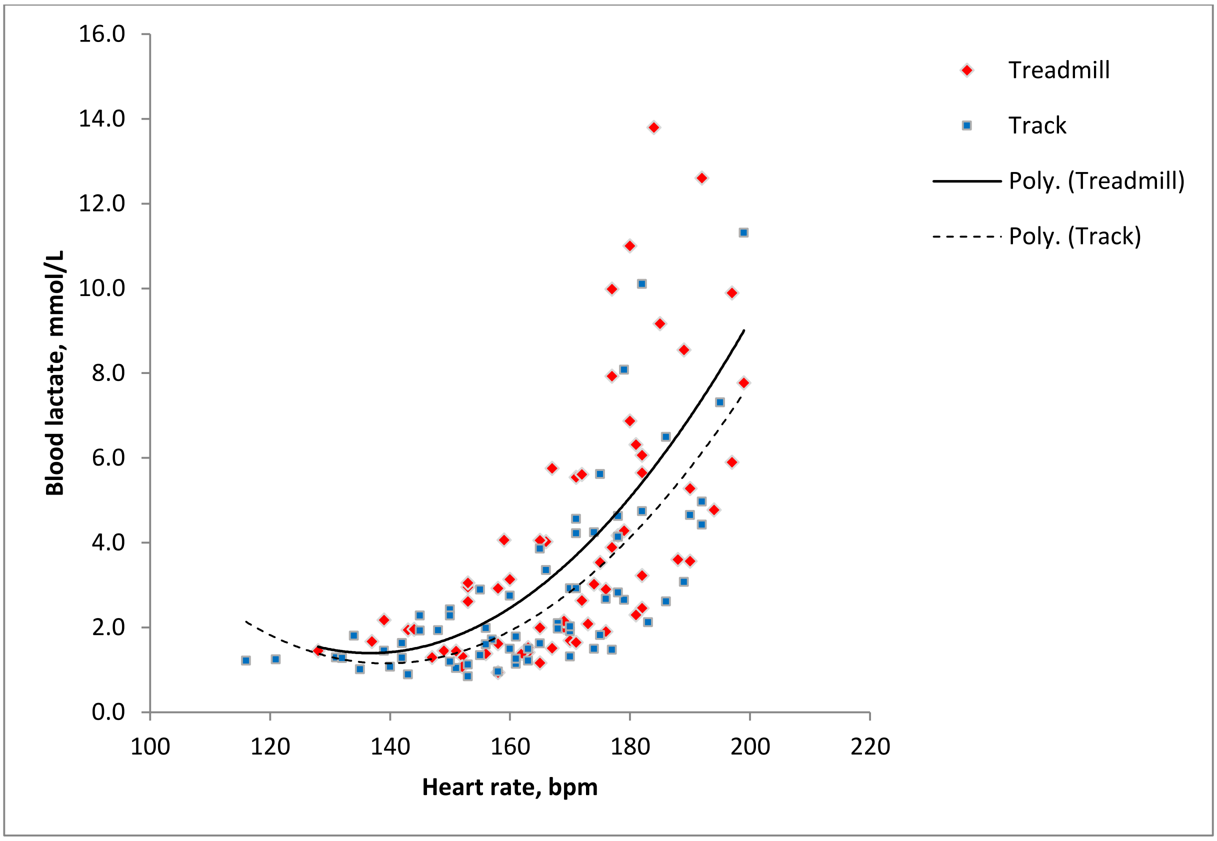

Figure 2. Blood lactate concentration/heart rate relationship for nine participants during incremental tests for the two degree inclined treadmill and the track (second-order polynomial regression model).

Figure 3 presents the relationship between heart rate and blood lactate expressed as percentage of heart rate at maximal oxygen consumption for measures below 6 mmol/L bLa. Due to technical problems in heart rate monitoring during one of the maximal oxygen uptake test, one additional participant was excluded in this analysis which then included eight participants.

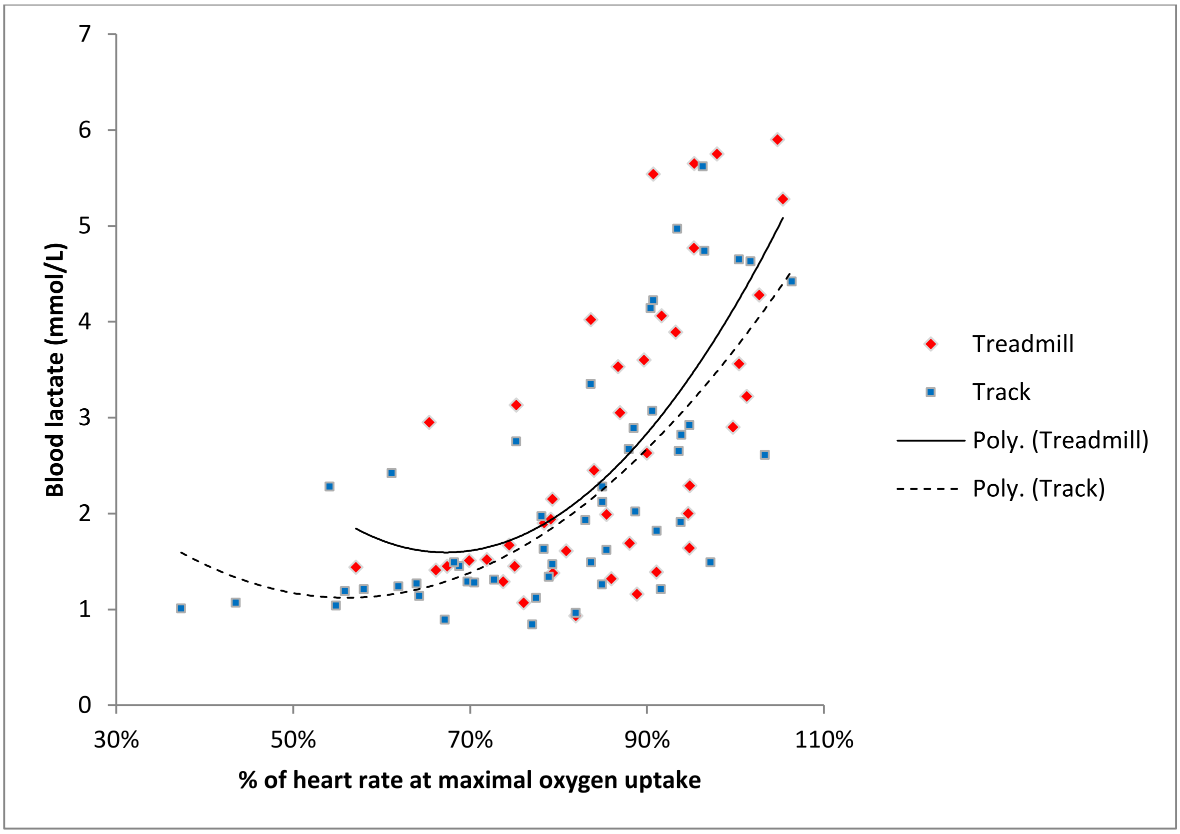

Figure 3. Relationship between heart rate expressed in percent of heart rate at maximal oxygen uptake and blood lactate during submaximal incremental test on a two degree inclined treadmill and a running track (second-order polynomial regression model).

Mean heart rate and standard deviations for the two degrees inclined treadmill and track at each running velocity is presented in Figure 4. There was no significant differences in heart rate between heart rate, but a trend towards a difference at 11km/h (p=0,06) and 12km/h (p=0,07).

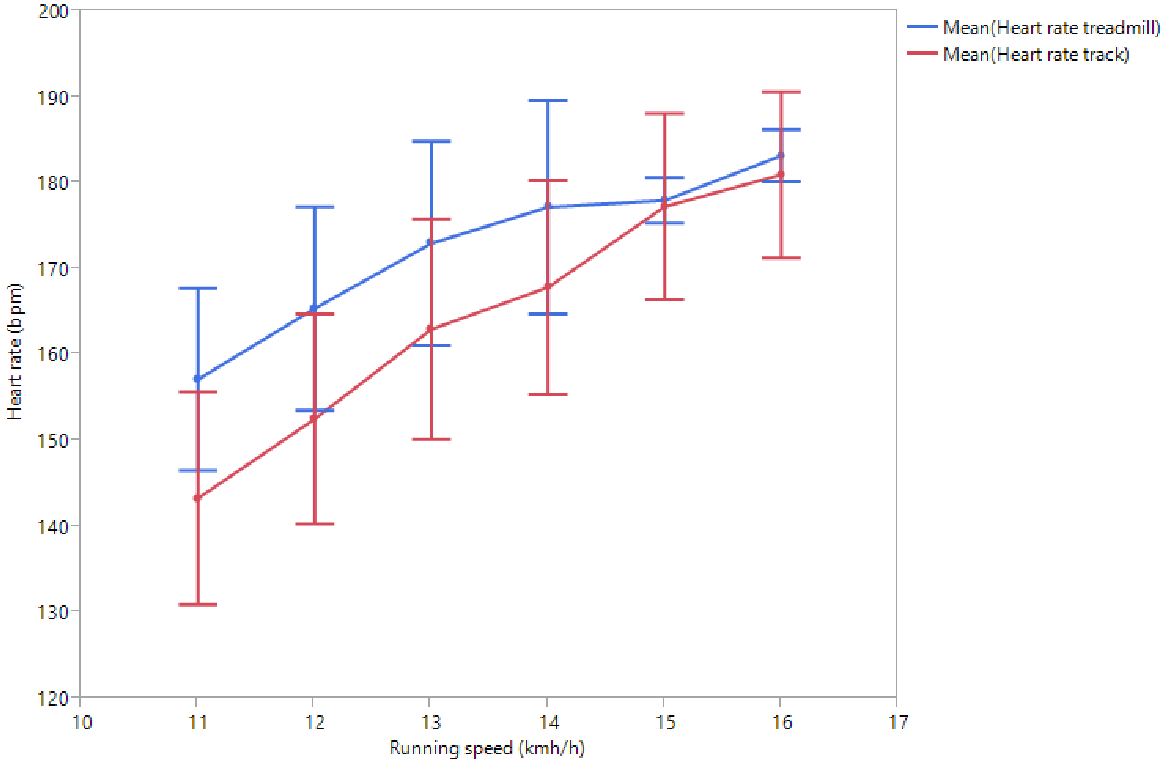

Figure 4. Mean heart rate and standard deviations for each running velocity during incremental submaximal tests on a two degree inclined treadmill and track.

Figure 5 shows mean bLa and responses and standard deviations at each running velocity for the two degree inclined treadmill and track. There was a significant difference at 14km/h, p=0,04. Although there was no significant difference in bLa at other velocities there was a trend towards a difference at 11km/h (p=0,06), 12km/h (p=0,06) and 13km/h (p=0,07).

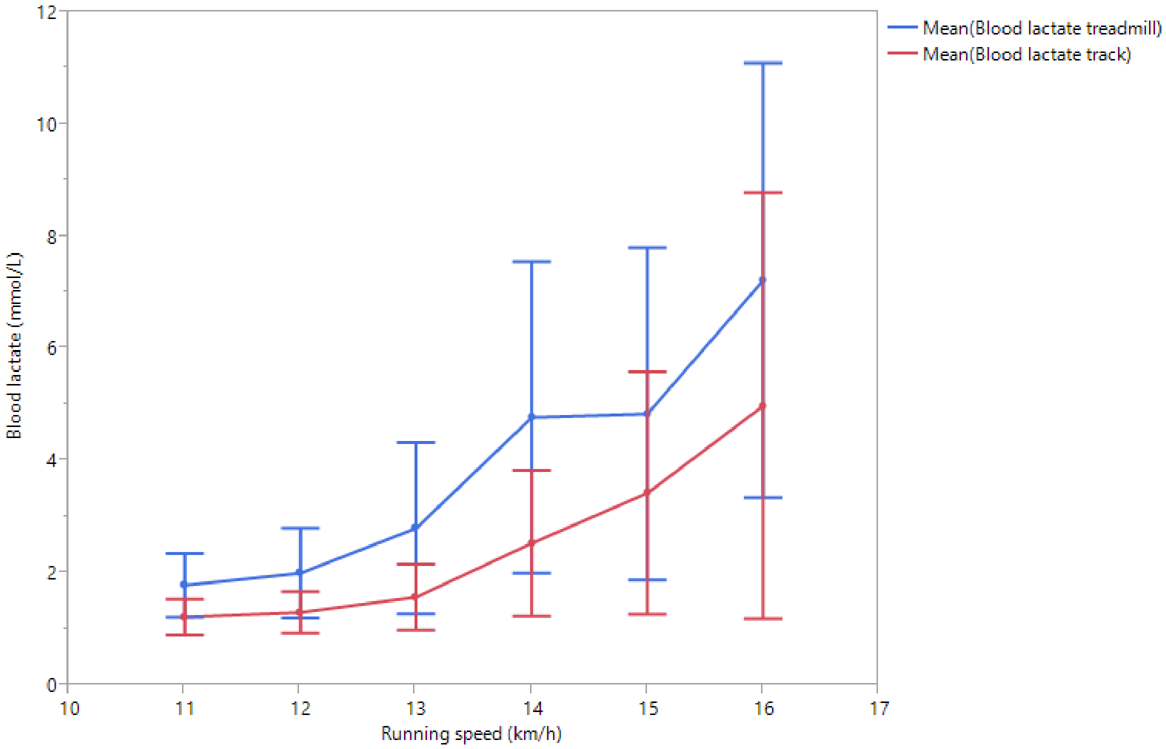

Figure 5. Blood lactate response to running velocity during incremental tests on a two degree inclined treadmill and a level track. Significant difference was observed at 14km/h (p=0,04).

Discussion

The main findings of the present study indicate no significant difference in the HR-bLa relationship at 3 and 4 mmol/L bLa when running on a two degree inclined treadmill as compared to running on a track. When comparing the heart rate response to the same running velocity there was no significant difference in heart rate, but a trend towards a difference at lower velocities. A significant difference was in bLa between treadmill and running track was observed at 14km/h with a trend towards a difference at higher running velocities.

In spite of no significant differences in HR at fixed bLa concentrations, the upward shift of the second degree polynomial regression line for treadmill running seen in Figure 4 suggests that running at a two degree incline tended to a greater increase in bLa for every increase in HR compared to running on the track. Since the two degree incline seemed to overcompensate the total energy expenditure at the same velocity, participants exercised at intensities farther above their LaT during the last stages of the test on the treadmill. Increases in running velocity above the intensity associated with LaT results in drastically higher bLa increases. Therefore, the greater differences in bLa at higher heart rates and the following upshift of the regression line can probably be attributed to the exponential nature of bLa accumulation at velocities exceeding the equilibrium of lactate production and removal. This upshift in the HR-bLa of the treadmill compared to running over ground is in contrast to previous investigations, showing a similar upshift in bLa response with increased velocity during running over ground as compared treadmill running (Di Michele et al., 2009; Kunduracioglu et al., 2007). This study used a level treadmill which probably did not compensate for air flow resistance to match total energy expenditure. Therefore participants probably reached their LaT at earlier stages of the test running over ground. It therefore seems that when comparing HR-bLa relationships including values far above the LaT, the running condition (for example running over ground) with the highest total energy requirement at a given velocity will often elicit an upshift in the HR-bLa curve.

Prescription of exercise intensity in endurance running based HR-bLa relationship is usually applied to intensities up to the LaT. For a more valid HR-bLa relationship between the running conditions, Figure 3 considers measures up to 6 mmol/L bLa. This cut off was based on previous studies showing that even when different definitions of the LaT was considered, the breakpoint in equilibrium of bLa appearance and removal for trained runners most often occurs below 6 mmol/L (Foxdal, 1994) In addition, due to the wide distribution in maximal heart rate, heart rate expressed as a percentage VO_2max was used. The HR-bLa relationships were closer related between the treadmill and track was observed when analysed in the relevant range of 2-6 mmol/L bLa concentrations.

As mentioned, it seems that a two degree incline overcompensates for the lack of air resistance resulting in greater heart rate and lactate levels over the range of tested running velocities between 11-16km/h. The trend towards differences in HR between treadmill and over ground decreased with higher running velocity and can probably be explained by the greater air flow resistance runners have to overcome at higher running velocities over ground. Even though there only was a significant difference in bLa at 14km/h, there was a trend towards a difference at several velocities. The lack of significant differences was probably because of large standard deviations in heart rate and blood lactate levels. A more homogenous group in terms of maximal heart rate and fitness level would likely reveal a significant difference as has been shown in other groups. Although previous research found that an 1% incline should be used during treadmill testing to compensate the higher energy cost of running with same velocity over ground (Jones & Doust, 1996), their data is indicating that higher inclines could be used at higher running velocities. Elite distance runners may have a running velocity corresponding to relevant bLa concentrations at close to 20km/h (Abe et al., 1999), which likely would require a steeper incline closer to the one used in the present study.

The practical setup of field testing might also affect the physiological response. Kunduracioglu et al. (2007) showed significant differences in absolute HR and bLa response between treadmill and running on grass. The field test was conducted using a 120 meter hexagonal track with directional changes marked by cones every 20 meters. Di Michele et al. (2009) used an oval 250 meter circuit during their field tests on natural and synthetic grass. The more distinct changes in direction inherent to the method used by Kunduracioglu et al. (2007) might lead to a more sport specific testing towards the demands of soccer, but probably confounded the comparison of threshold testing to the treadmill. They found significant differences in HR and bLa responses between treadmill and synthetic turf, but not between treadmill and natural grass, which was probably because of higher compliance in surface characteristics of the synthetic turf.

HR and bLa values obtained on a level treadmill are usually lower compared to over ground running at the same velocity (Di Michele et al., 2009; Kunduracioglu et al., 2007) and intensity prescription from test results based on running velocity might lead to a higher than optimal workload for athletes, potentially leading to inadequate recovery. Longer periods of insufficient recovery may lead to lower performance and potentially more severe consequences such as overtraining.

Since the effect of surface characteristics on the physiological response of running has to be considered, comparisons of treadmill results to over ground running should be done specifically to the surfaces athletes train on to accurately prescribe training intensity from the HR-bLa relationship. To my knowledge, no previous study has investigated the use of an incline during treadmill testing to investigate bLa and HR values compared to running on running track. The present study provides a more specific comparison of physiological for runners training and competing on a track.

No previous study has used a treadmill incline to more closely match both the HR-bLa relationship as well as the absolute physiological response to running velocity. As there was no significant difference in HR at bLa concentrations of 3 and 4 mmol/L, the use of a treadmill incline to more closely match the HR-bLa relationship to field conditions may be used by exercise laboratories, sports medicine facilities and other sport related settings using treadmills in training and testing. The two degree incline of the treadmill could be recommended for well-trained runners with running velocities corresponding to the LT closer to 20km/h, but overcompensate the absolute response at slower running velocities. Taken together, threshold tests would become a better tool to guide training through a more valid generalisation from treadmill to over ground running. In the present situation, a lot of resources are spent on testing that cannot be accurately generalised to running over ground. Because laboratory testing is quite costly and resources are often limited, it is important that coaches and athletes receive accurate information to ensure resources are utilised efficiently.

Strengths and weaknesses

Although participants received information to not perform any training in between tests, one of the participants' test results was excluded from the study because of inadequate rest between the VO_2max test and the first submaximal incremental test, leading to unrepresentative physiological measurements.

Due to an update in laboratory equipment the YSI 2300 Stat Plus was replaced with an EKF Biosen C-Line, which has been used extensively in previous studies (Glaister et al., 2009; Hegge et al., 2015; West et al., 2013). Both apparatus use the same technology and analyse haemolysed blood. However, since agreement of the two analysers has not been investigated, it cannot be ruled out as a threat to internal validity. Some of the blood samples for two of the participants were taken from capillary blood at the fingertip due to problems with the PVC. Haemolysed capillary blood has been shown to have 8-10% lower lactate concentrations than haemolysed venous blood and present a source of error to the present study.

Participants completed the distance for each stage with only a few seconds error from the three minute stage duration and therefore kept running velocity close to constant. To ensure even closer regulation of running velocity, markers should be placed every 25 or 50 meters and a watch set at a countdown for these marks. In addition, because an increase by 1km/h in running velocity added 50 meters to each stage, distance markers every 50 meters would allow participants to start the next stage without walking to the closest 100 meter mark. This would eliminate differences in bLa clearing between stages compared to treadmill testing as discussed earlier. The banked curves of the 200 meter track might have affected running technique, but participants were instructed to run at the inner line of the innermost track and practically ran on level ground throughout each lap.

It has been proposed that that insufficient treadmill familiarisation can confound the comparison of treadmill running to over ground running (van Ingen Schenau, 1980). All participants reported that they were fully familiarised with treadmill running. However since familiarisation was not established through measuring of running economy or a biomechanical parameter, differences in heart rate and bLa between the treadmill and running track could still be attributed in some part to insufficient. In addition as a result of uphill running performance may vary between individuals (Lauenstein, Wehrlin, & Marti, 2013). It has been shown that specific training including uphill enhances running economy during uphill running (Jensen, Johansen, & Kärkkäinen, 1999). Together, these individual differences in treadmill familiarisation and work efficiency during uphill running could possibly affect the comparison of HR-bLa relationships between the treadmill and track in the present study. It is of importance to ensure full familiarisation of the treadmill, as well as consider the training background of the athlete. For example, an athlete engaged in orienteering usually have a greater ability to run uphill than a track runner (Jensen et al., 1999) which may influence the choice of incline during testing.

Conclusion and further research

In conclusion, lactate threshold testing on treadmill through incremental test protocols on a two degrees incline gives similar heart rate-blood lactate relationship as running over ground and may be used to prescribe intensity in training performed over ground. However, caution should be taken when using running velocities interchangeably as the absolute values of heart rate and blood lactate are overcompensated by the incline compared at the same running velocity. More research is needed to investigate energy consumption and movement pattern at various treadmill inclines matched with over ground running at higher running velocities. Based on this, a range of velocities could be recommended for each incline in treadmill testing and training similar to that made by Jones and Doust (1996). Further research is also warranted to investigate the HR-bLa relationship of different treadmill inclines compared to level running at both treadmill and over ground running. This would clarify the effect of each treadmill incline to match the HR-bLa relationship of over ground running. In addition, measures of VO_2 would reveal the impact of incline on running economy at different inclines, which in turn might affect the HR-bLa relationship. I would also suggest more collaboration between biomechanics and exercise physiology to link movement patterns during different running conditions and muscle activation to the physiological response that interpretations in exercise testing are based on.

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Appendix 1

FORSKNINGSPERSONSINFORMATION

1. Bakgrund och syfte

Många känner till att det finns skillnader i sättet vi springer på löpband jämfört med fast underlag. Tidigare forskning har visat skillnader i både puls och laktat (mjölksyra) mellan löpband och fast underlag. I samband med testning för att utvärdera den fysiska kapaciteten vill vi kunna styra träningen på ett så effektivt sätt som möjligt. Därför är det viktigt att testresultaten kan generaliseras och användas i verkliga situationer.

Syftet med denna studie är att jämföra mätvärden i hjärtfrekvens och laktat mellan löpband och fast underlag. Vi kommer att undersöka effekten av löpbandets lutning på förhållandet mellan hjärtfrekvens och laktat och hur väl dessa mätvärden stämmer överrens med värden uppmätta på fast underlag.

2. Förfrågan om deltagande

I egenskap av van löpare tillfrågas du härmed om deltagande i denna studie.

3. Hur går studien till?

För att undersöka denna fråga kommer du som deltagare i studie att få göra tre olika tester under en vecka. Det första testet är ett maximalt syreupptagningstest på löpband. Därefter kommer två identiska laktattröskeltest att genomföras, ett på löpband och ett på löparbana inomhus. Du kommer att behöva vara tillgänglig vid tre tillfällen under denna vecka, se nedan för datum och tider.

Maximalt syreupptagningstest på löpband

Efter en uppvärmning på 10 minuter kommer du att göra ett stegrande test på löpband där vi mäter din syreupptagningsförmåga via en mask som fästs för ansiktet. Maximalt syreupptag är ett av de vanligaste måtten på en persons kondition. Testet innebär en maximal ansträngning och pågår till dess att du når ditt maximala syreupptag eller känner att du inte kan fortsätta. Puls kommer att mätas via pulsklocka under hela testet. Vi kommer även att mäta din stegrekvens (steg per minut) med en fotenhet.

Laktattröskeltest på löpband

Detta test görs för att undersöka din laktattröskel (mjölksyratröskel), vilket kan vara ett sätt att både utvärdera din fysiska kapacitet och ett redskap för att styra träningen. Efter en uppvärmning kommer du att springa sex intervaller om tre minuter vardera där ansträngningen kommer att öka för varje intervall. De sista intervallerna brukar skattas som anträngande men hanterbart. Du kommer att vila en minut mellan varje intervall och då tas även blodprover för att mäta laktat. Blodproverna tas via en kateter placerad i armvecket. Puls kommer att mätas via pulsklocka under hela testet. Vi kommer även att mäta din stegrekvens (steg per minut) med en fotenhet.

Laktattröskeltest på löparbana

Detta test görs för att undersöka hur dina puls- och laktatvärden på fast underlag skiljer sig från samma test på löparband. Testet kommer att utföras på en 200 meter lång löparbana inomhus. Efter en uppvärmning kommer du att springa sex intervaller om tre minuter vardera där ansträngningen kommer att öka för varje intervall. De första intervallerna ska upplevas som lätta och de sista intervallerna brukar skattas som ansträngande men hanterbara. Du kommer att vila en minut mellan varje intervall och då tas även blodprover för att mäta laktat. Puls kommer att mätas via pulsklocka under hela testet. Vi kommer även att mäta din stegrekvens (steg per minut) med en fotenhet. För att hålla rätt fart kommer du att få springa med en armbandsklocka som piper med jämna tidsintervall och motsvarar den tid det ska ta dig att springa 100 meter. På löparbanan finns markeringar placerade med 100 meters mellanrum och varje gång klockan piper ska du passera markeringen. Du kommer även att få muntlig feedback efter varje varv så att du vet hur du ligger till. Under uppvärmningen finns tillfälle att öva på denna typ av farthållning.

4. Prover
Laktat kommer att mätas via blodet från en venkateter placerad i armvecket av erfaren sjukvårdspersonal. Blodproverna från tröskeltestet på löpband kommer att förstöras direkt efter analys. Blodproverna från tröskeltestet på löparbana kommer att förvaras i provrör för att sedan transporteras till Idrottsmedicinska enheten vid Umeå universitet för analys och därefter analyseras.

5. Vilka är riskerna?
Det finns vissa risker med att genomföra dessa tester då det innebär en ansträngning eller maximal ansträngning för kroppen. Dessa innefattar onormalt blodtryck (högt eller lågt), avvikande hjärtrytm, svimning och i sällsynta fall hjärtattack. Därför är det viktigt att du som deltagare är fullt frisk och inte har några restriktioner angående på vilka sätt du får anstränga dig. På plats finns akututrustning och sjukvårdskunnig personal.

6. Finns det några fördelar?
Genom att delta i testerna kommer du som deltagare att få värdefull information om din fysiska status och hur du kan använda testresultaten för att styra din träning.

7. Hantering av data och sekretess
Som deltagare i studien behandlas dina uppgifter och testresultat konfidentiellt och kan inte kopplas till dig av någon utomstående part. Testresultaten kommer att avpersonifieras och inte kunna urskiljas på individnivå. Resultaten från varje test kommer att förvaras i pappersform på Idrottsmedicinska enheten vid Umeå universitet, men även på en säker dator som endast forskningshuvudmannen har tillgång till.

8. Hur får jag information om studiens resultat?
Efter studiens avslutande kommer du att kunna ta del av dina egna testresultat, dessa skickas till dig via e-post. Du kommer även få ta del av och kunna läsa studien när den är färdigställd.

9. Försäkring, ersättning
Ingen kompensation utgår vid till dig som försöksperson utifall att din medverkan skulle resultera i obehag eller skada.

10. Frivillighet
Ditt deltagande i undersökningen är helt frivilligt och du kan när som helst avbryta ditt deltagande utan motivering.

11. Ansvariga
Huvudansvarig för studiens genomförande är Axel Bramell
E-post: axelbramell@hotmail.com

Mobil: 076-634 49 12

Intressekonflikter
Det finns inga intressekonflikter hos den undersökande forskaren.

Förberedelser:
För att skapa förutsättningar att få representativa laktatvärden finns det förberedelser att beakta. Vi rekommenderar att du avstår från hård träning 48 timmar innan testet av maximalt syreupptag och vilar helt sista dygnet innan testet. Eftersom att det sedan endast är en dag mellan de kommande testerna rekommenderar vi starkt att du även vilar helt mellan dessa test. Är du sliten eller stressad kan du få onormalt höga laktatvärden. Under dessa dagar bör du även se till att äta som normalt, men inte slarva med kost och dryck. Vid intag av för lite kolhydrater kommer du inte att kunna nå ditt maximala syreupptag och låga kolhydratnivåer i kroppen kan även medföra för låga laktatvärden under de två tröskeltesten. Se även till att sova ordentligt nätterna innan testet. Om du har fått en morgontid kan det vara bra att ha ätit ett rejälare kvällsmål dagen innan. Du kommer att få mer information om förberedelser innan testerna.

Axel Bramell
Magisterstudent vid Idrottsmedicinska enheten, Umeå universitet.
Umeå den 22:e januari 2016

Informerat samtycke

- Jag bekräftar att jag tagit del av denna information angående studiens övergripande syfte och metod samt dess risker.
- Jag har fått tillfälle att ställa frågor och fått dem besvarade.
- Jag ger mitt samtycke till att delta i studien och vet att mitt deltagande är helt frivilligt.
- Jag är medveten om att jag när som helst och utan förklaring kan avsluta mitt deltagande.

………………………..	………………………..	………………………..
Datum	Namnteckning	Namnförtydligande

………………………..	………………………..
Målsmans namnteckning	Namnförtydligande