



Maximal Lactate Steady State and Lactate Thresholds in the Cross-Country Skiing Sub-Technique Double Poling

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ABSTRACT

International Journal of Exercise Science 12(2): 57-68, 2019. The response of blood lactate concentration (BLC) to exercise is a commonly used approach to set training intensities and to determine the anaerobic threshold, which are important in evaluation of endurance exercise performance. The maximal lactate steady state (MLSS) is defined as the highest workload or BLC that can be maintained without continual lactate accumulation over time. The aim of this study was to investigate MLSS in the cross-country skiing sub-technique double poling and to assess the validity of a fixed blood lactate threshold (OBLA and the 45° tangent of the lactate curve). Eight well-trained cross-country skiers (age = 27.6±8.8 years [mean±SD], body mass = 73.9±6.2 kg, height = 179.3±7.0 cm) performed an incremental test to determine OBLA and Individual Anaerobic Threshold (IAnT) and several constant workload tests of 30 min to determine the MLSS. Lactate concentration at MLSS in double poling was 6.7±1.3 mmol·L⁻¹ which was significantly higher compared to OBLA ($p<0.001$) and IAnT ($p<0.01$). Despite significant correlations in velocities between MLSS-IAnT and MLSS-OBLA ($r=0.95/0.95$, $p<0.001$), significant ($p<0.01$) differences between MLSS (21.4±2.8 km·h⁻¹) versus IAnT (20.6±3.6 km·h⁻¹) and OBLA (19.9±3.0 km·h⁻¹) was observed. It was concluded that both OBLA and IAnT underestimate MLSS in double poling. A fixed value of 7 mmol·L⁻¹ would be more appropriate in lactate testing of cross-country skiers using the double poling technique, yet dissuaded because of intra-individual variations. Direct determination of MLSS is the recommended approach for useful exercise thresholds, important for training interventions in elite cross-country skiers.

KEY WORDS: Onset of blood lactate, exercise test, submaximal exercise, exercise intensity, exercise prescription, lactate kinetics, anaerobic threshold

INTRODUCTION

The response of blood lactate concentration (BLC) to exercise is a commonly used approach to set aerobic training intensities and to determine the anaerobic threshold (AnT), which are important in evaluation of endurance exercise performance (10, 17). When performing tests to detect the AnT, the purpose is to identify the highest exercise intensity one can maintain over time without blood lactate accumulation, often referred to as the Maximal Lactate Steady State (MLSS) (4). The MLSS is defined as the highest workload or velocity (MLSS_v) or BLC (MLSS_c)

that can be maintained without continual lactate accumulation over time and is considered the gold standard measurement of IAnT (5, 6, 17). To appropriately estimate the MLSS, several constant workload tests on different days at various exercise intensities must be done. The predominantly used definition of MLSS is the highest workload with an increase of BLC less than $1.0 \text{ mmol} \cdot \text{L}^{-1}$ during the final 20 min during a constant submaximal workload exercise (5, 6, 31).

One common AnT concept is to use a fixed BLC of $4.0 \text{ mmol} \cdot \text{L}^{-1}$ known as the Onset of Blood Lactate Accumulation (OBLA) (2, 6, 10, 17). However, it is known that OBLA does not take into account the considerable inter-individual differences in lactate metabolism and that it may overestimate or underestimate the MLSS (10, 17, 39). Great variability in MLSSc can be seen in different sport events with MLSSc ranging from 2.0 to $8.0 \text{ mmol} \cdot \text{L}^{-1}$ (6). Evidently, MLSSc depends on the type and total volume of engaged muscles and that it is negatively related to the total active muscle mass (5). It has been shown that MLSSc is $4.5 \pm 1.0 \text{ mmol} \cdot \text{L}^{-1}$ in cycling (5), $5.4 \pm 0.7 \text{ mmol} \cdot \text{L}^{-1}$ in kayaking (31), and $2.7 \pm 0.6 \text{ mmol} \cdot \text{L}^{-1}$ in rowing (5), where the latter motor pattern indeed includes more muscle mass. The method of OBLA is a poor predictor of MLSS and therefore, more advanced methods for determining the Individual Anaerobic Threshold (IAnT) have been developed (10, 17, 39). One of these concepts is to determine the IAnT at a certain inclination of the lactate curve, such as a 45° tangent (38, 42). To diminish uncertainties that come with the graphical determination of a tangent to the lactate curve, mathematical determination of a polynomial fitting line is most convenient (42).

The MLSS has mostly been studied in the context of running and cycling but never in any sub-technique in cross-country skiing where high aerobic capacity and MLSSv are of great importance for performance as well (14, 17). Cross-country skiers are using many modes of exercise and it is known that these results in different heart rates and BLC at any given VO_2 (26, 30). During the last two decades, the double poling technique has advanced dramatically and in some races it is the only used technique (41). Double poling is essentially the only used technique during long distance racing, in which the pace often is steady during prolonged periods. Today, skiers have a well-developed upper-body endurance and strength, as well as a developed technique to use double poling in moderate and even steep terrain when they overlook the use of kick wax to lower friction (13). Lately, several researchers have assessed the physiology and biomechanics of double poling (7, 9, 13, 44). However, data regarding lactate kinetics and high-intensity steady state double poling needs to increase.

In the double poling technique propulsive forces are generated exclusively by the upper body, whereas the lower body muscles primarily providing stability and assistance (27, 40). Regarding lactate kinetics and muscle mass, it is evident that exercising arm compared to leg muscles results in higher lactate production at the same relative intensity (12, 43). This is due to higher amount of the more glycolytic fast twitch muscle fibers in the arms and upper body, compared to the lower extremities (29). In addition, O_2 extraction is lower and lactate arteriovenous oxygen difference is higher in the arms than the legs at both high and moderate exercise intensities (40). Therefore it is not surprising that the double poling technique is known to produce the highest BLC at a given workload as compared to diagonal-stride and double poling with kick (26, 30).

The aerobic capacity of the upper body is of great importance for performance in cross-country skiing, and discipline-specific testing is needed (14, 32, 37). In cross-country skiing, testing of VO_2max and AnT is mostly performed with the diagonal-stride technique on a motor driven treadmill, or even treadmill running (14, 30). This could cause great error when the results are used for other techniques, such as double poling. Since the MLSSv is widely used as a parameter in training prescription by coaches, a good agreement between AnT concepts and MLSS is essential (25).

In double poling, due to the great involvement of the upper body which is more glycolytic and lactate producing than the lower extremities, the lactate kinetics may be differed in comparison to lower-body activities (29, 30). The purpose with the present study was to measure MLSSc using the double poling technique in cross-country skiing. A second aim of the study was to compare MLSSc and MLSSv with corresponding values for OBLA and IAnT using the 45° tangent method (38, 42) to evaluate their agreement. It was hypothesized that the MLSSc would be significantly higher than 4 mmol $\cdot\text{L}^{-1}$.

METHODS

Participants

Six male Swedish cross-country skiers (age = 28.7 ± 0.1 years, body mass = 76.3 ± 4.7 kg, height = 181.0 ± 6.9 cm) and two females (age = 25 & 24 years, body mass = 63.5 & 70.0 kg, height = 170.0 & 178.0 cm respectively) volunteered to participate in the study. All participants were well-trained athletes, including three that were competing at the national elite level. The participants were fully informed about the nature of, and the procedures used, in the present study before giving their written informed consent to participate. Annual training loads were 466 ± 122 hr, with an average weekly training frequency of 6.7 ± 1.5 times per week.

Protocol

The test procedures were performed in accordance to the Medical Association Declaration of Helsinki (2013) (24). The study was approved by the Regional Ethics Committee at Umeå University. The tests were conducted during February and March 2016, which is mid to end season for cross-country skiers. Participants initially performed an incremental submaximal test to determine OBLA and IAnT. Thereafter, three to five submaximal constant workload tests were performed on separate days to directly determine the MLSS. The participants performed all their tests (four to six events) within 10 to 16 days, as depicted in Figure 1. Vigorous activity was not allowed 24 hr before the test and at least 48 hr were given between two testing sessions. Participants performed all their tests during the same time of the day (9 AM to 4 PM) ± 2 hr to minimize day-to-day biorhythmic fluctuations. Before and in between the tests, participants were instructed to keep their usual diets and be adequately prepared for the tests, which

included to be rested, hydrated, and well-nourished. Low carbohydrate diets, alcohol, and caffeine prior to testing were deprecated.

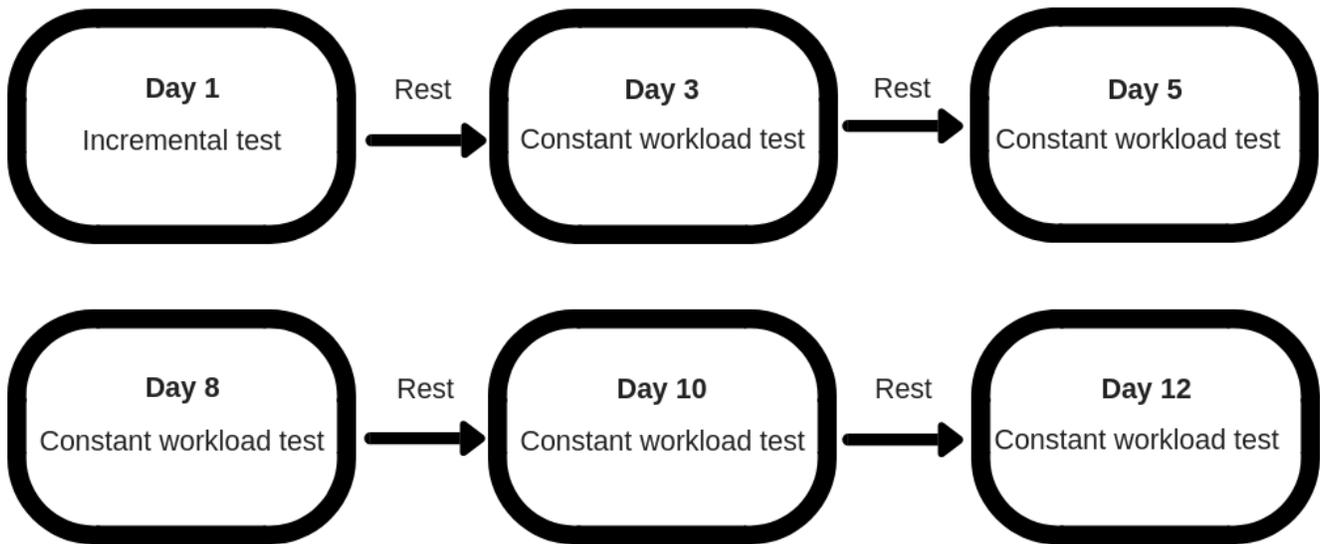


Figure 1. A typical testing schedule for one participant in the study. Incremental test lasted five to six stages of five minutes each with a blood sampling period of 60 seconds in between stages. Constant workload tests lasted 30 minutes with blood sampling periods of 60 seconds at minute 10, 20 and directly after the test. Vigorous activity was not allowed 24 hours before the test and at least 48 hours where given between two testing sessions. Participants performed all their tests during same time of the day ± 2 hours.

All the tests were conducted at the Sports Medicine Laboratory, Umeå University, Sweden. Ambient conditions were kept similar during the testing period. Temperature was $19.5^{\circ}\text{C} \pm 0.25^{\circ}\text{C}$, relative humidity was $26\% \pm 0.2\%$ and atmospheric pressure was 996 ± 7 mBar. The tests were performed on a 2.5×3.5 -m motor-driven treadmill (Rodby Innovation, Vänge, Sweden) specially designed for tests using roller-skies. During all tests, incline was set to 1° . Roller-skies (Pro-ski C2, Sterners, Nyhammar, Sweden) and poles (Oneway, Diamond Storm, Helsinki, Finland) with special tips (Biomekanikk A/S, Oslo, Norway) were provided from the laboratory. Participants used the same skies with standard wheels during all tests to minimize variations in rolling resistance. Length of the poles were self-selected by the participants and corresponded to what they usually use for classical skiing ($86\% \pm 3\%$ of body length). When skiing on the treadmill, participants were secured by a safety harness which was connected to an emergency stop.

After a five-min warm-up, participants performed a submaximal incremental workload test. The test consisted of five to six stages of five minutes with a one-minute blood sampling period in between stages to allow deceleration of the treadmill and skier, as well as blood sampling. The incremental test ended when OBLA and a likely IAnT was reached. That is, a $\text{BLC} \geq 5 \text{ mmol} \cdot \text{L}^{-1}$ including a drastic rise in BLC. The IAnT was defined as the 45° tangent to the third-degree polynomial line of the lactate curve, which resulted in the corresponding values for IAnT velocity (IAnTv) and BLC (IAnTc). The 45° tangent method was chosen for validation based on minimizing arbitrarily bias when defining the IAnT. Other methods, such as the D-max proposed by Cheng, Kuipers, Snyder, Keizer, Jeukendrup and Hesselink (16) requires end

points of the BLC-curve, i.e. a minimum and maximum-value, which will be more dependent on the incremental test procedure and graphical matters (48). While a thorough discussion on the topic is outside the scope of this study, Foxdal, Sjodin, Sjodin and Ostman (1994) and Jamnick, Botella, Pyne and Bishop (2018) have covered these questions in previous studies.

On a separate day, participants performed a constant workload test of 30 min or until volitional exhaustion. A 10-min warm-up preceded the test. The first constant workload test was performed with a velocity corresponding to OBLA (OBLA_v), which was linearly interpolated from the incremental test protocol. Velocity in the following constant workload test were chosen at 3% to 6% higher or lower than the previous, depending BLC in the last trial. If the last test resulted in a lactate steady state, defined as a BLC increase less than 1 mmol · L⁻¹ during the final 20 min, the velocity was increased. If the last test resulted in a rise in BLC higher than 1 mmol · L⁻¹, or exhaustion prior to the end of the test. A change in velocity less than 3% was considered inadequately low, considering calibration and measurement errors in blood sampling, lactate analysis equipment and treadmill speed.

During constant workload tests, lactate measurements were taken before the test and at min 10, 20 and 30. The blood sampling period lasted one min. The highest velocity with a change in BLC less than 1 mmol · L⁻¹ during the final 20 min of the test was defined as MLSS_v. The MLSS_c was defined as the mean BLC calculated from the three samples during the constant workload test.

During all tests, capillary blood samples were obtained with finger stick method and collected in capillary tubes prior to analysis. Two different instruments were used in this study (YSI 2300 Stat Plus, Yellow Spring Instruments and Co, Ohio, USA and Biosen C-line Clinic, EKF Diagnostics GmbH, Cardiff, England). Both uses a membrane-bound enzyme electrochemical measurement principle. For Biosen C-line analyses, 20 µl of blood was taken up by an end-to-end capillary and samples were suspended into a micro test tube pre-filled with a haemolysing solution. Samples were inverted for 15 seconds to dilute it completely and thereafter analysed within one min in the Biosen C-line. For the YSI 2300, 50 µl of blood was taken up by an end-to-end capillary and thereafter drawn into the YSI 2300. The buffer solution contained a lysing agent; hence, all blood samples were haemolysed. Both instruments in the current study is proven valid with similar coefficients of variation at 1.5% (11, 18).

Statistical Analysis

Normal distribution was confirmed with a Shapiro-Wilks test. Data are reported as means and standard deviations (SD), and when applicable also with range.

A one-tailed a priori power analysis indicated a sample size of 8 was need with power set to 0.8 and Effect Size (ES) to 1.0 (with previous similar research in consideration(31)) and $\alpha = 0.05$, samples size is = 8. With day to day variations and measurement errors in consideration, it was considered that this study could detect a true difference in BLC values of 20% or more, with a sample size of eight. Hence, a sample size of eight participants was seen adequate to detect statistically significant and meaningful results.

Differences amongst BLC and velocity at MLSS, OBLA and IAnT were compared using one-sample Student's t-test. Linear relationships between the variables were performed with the test of Pearson product-moment correlation coefficient (r). The uncertainty of the correlation coefficient is presented with respect to 95% confidence intervals (CIs). The Bland-Altman method was used to determine mean bias and limits of agreements (LoA) between the different methods (8). It is suggested that two methods may be significantly related without agreeing, and that the Bland-Altman method is the method of choice when assessing comparability (17, 20). Moreover, the mean bias and LoA is an adequate way of reporting agreement of AnT concepts to MLSS (17). In the context of Bland-Altman plot and agreement, data are presented as mean bias and LoA. Statistical significance was set at 0.05. LoA is defined as mean \pm 1.96SD. All the statistical analyses were performed using the software JMP 12.0 (SAS Institute, Cary, NC, USA).

RESULTS

The MLSSc and MLSSv were determined in all participants. The IAnT and OBLAv were determined in seven participants only, due to low lactate curve-slope and BLC respectively. One outlier with rarely low BLC-values was identified. This certain participant did not reach a BLC of 4.0 mmol · L⁻¹ during the incremental test despite hard effort, and IAnTc was 2.5 mmol · L⁻¹. These results are considered to not be a cause by experimental or methodological error and were consequent throughout all the five tests for the participant. Therefore, its data was not excluded fully. However, data is presented without the outlier, when nothing else is stated, to make the findings more generalizable for the general athletic population. Descriptive data of MLSSc, MLSSv during constant workload tests; OBLAv, IAnTc and IAnTv measured during incremental tests, are depicted in Table 1.

Table 1. Velocity and Blood Lactate Concentrations in Different Lactate Threshold Concepts in Double Poling.

Variable	Measure	Mean \pm SD	Mean \pm SD ^a	Range	Range ^a
MLSSc	mmol/L	6.7 \pm 1.3 ^{***, †}	6.0 \pm 2.4 [*]	5.0 – 8.7	0.9 – 8.7
MLSSv	km/h	21.4 \pm 2.8 ^{**} , †	21.5 \pm 2.6	18.2 – 25.2	18.2 – 25.2
OBLAv	km/h	19.9 \pm 3.0	20.6 \pm 3.5	17.2 – 24.9	17.2 – 24.9
IAnTc	mmol/L	5.1 \pm 0.9 ^{**}	4.6 \pm 1.3	2.1 – 6.3	2.1 – 6.3
IAnTv	km/h	20.6 \pm 3.6 ^{**}	21.0 \pm 3.4	17.5 – 26.6	17.5 – 26.6

Note: ^a = outlier included. Abbreviations: MLSSc, lactate concentration at maximal lactate steady state; MLSSv, velocity at maximal lactate steady state; OBLAv, velocity at onset of blood lactate accumulation (4 mmol · L⁻¹); IAnTc, lactate concentration at individual anaerobic threshold. ^{*}Significant difference from OBLA concept: p \leq 0.05; ^{**}Significant difference from OBLA: p \leq 0.01; ^{***}Significant difference from OBLA: p \leq 0.001; [†]Significant difference from IAnTc: p \leq 0.05; [‡]Significant difference from IAnTv: p \leq 0.01.

A boxplot showing the distribution of BLC using the IAnT and MLSS concept is displayed in Figure 2.

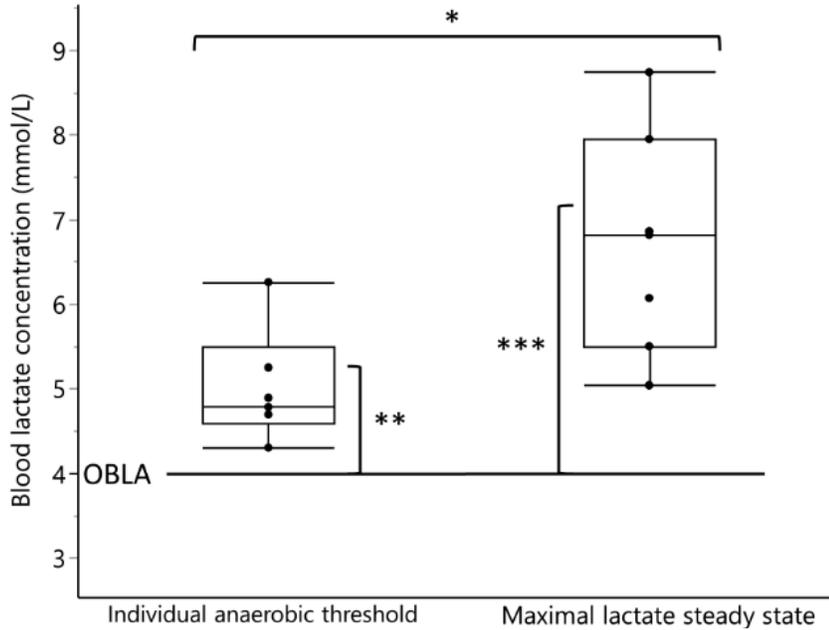


Figure 2. A Tukey boxplot demonstrating the distribution in lactate concentration for individual lactate threshold and maximal lactate steady state among participants when double poling. *Significant difference, $p \leq 0.05$. **Significant difference, $p \leq 0.01$. ***Significant difference, $p \leq 0.001$. Abbreviations: OBLA, onset of blood lactate accumulation ($4 \text{ mmol} \cdot \text{L}^{-1}$).

In all participants where OBLAv was determined, MLSSv and IAnTv were higher than OBLAv, depicted in Figure 3. The MLSSv was significantly correlated to OBLAv ($r = 0.95$, CI = 0.72 to 0.99, $p < 0.001$) and IAnTv ($r = 0.95$, CI = 0.69 to 0.99, $p = 0.001$). Calculations of mean bias and 95% LoA for BLC and velocity at MLSS, IAnT and OBLA is presented in Table 2.

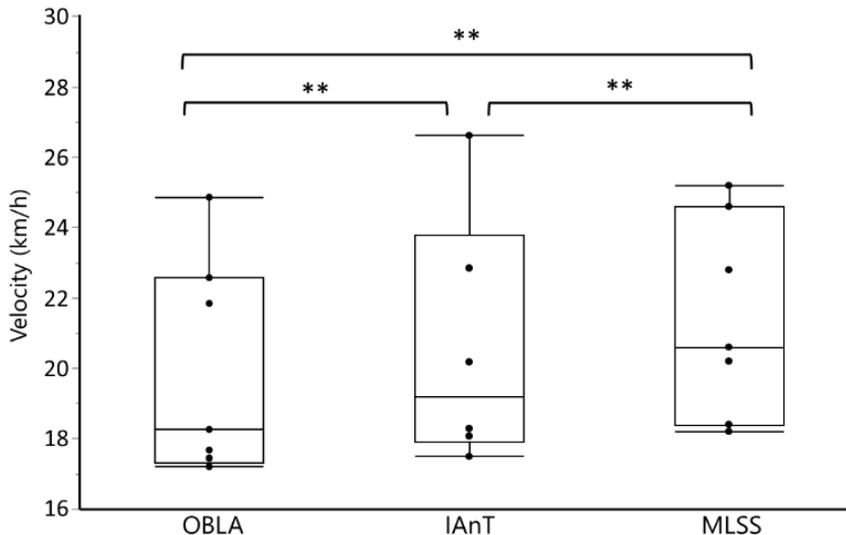


Figure 3. A Tukey boxplot showing the corresponding velocity to different lactate threshold concepts in double poling. **Significant difference, $p \leq 0.01$. Abbreviations: MLSSv, velocity at maximal lactate steady state; IAnT, Individual lactate threshold during incremental test; OBLA, Onset of blood lactate accumulation ($4 \text{ mmol} \cdot \text{L}^{-1}$).

Table 2. Mean Bias (Difference [MLSS – OBLA] & [MLSS – IAnT]) and 95% Limits of Agreements (LoA) in Blood Lactate Concentration and Velocity for Different Lactate Threshold Concepts in Double Poling.

	Mean bias (km/h)	LoA (km/h)	LoA (% of the mean)		Mean bias (mmol/L)	LoA (mmol/L)	LoA (% of the mean)
OBLAv	-1.5	± 1.8	± 9	OBLA	-2.7	± 2.6	± 49
IAnTv	-0.3	± 1.3	± 6	IAnTc	-1.4	± 2.8	± 49

Abbreviations: MLSS, maximal lactate steady state; OBLA, onset of blood lactate accumulation ($4 \text{ mmol} \cdot \text{L}^{-1}$); OBLAv, velocity at onset of blood lactate accumulation; IAnTc, lactate concentration at individual anaerobic threshold (45° tangent); IAnTv, velocity at individual anaerobic threshold concentration. LoA (%) shows how much the absolute LoA corresponds to in relative difference to the mean of MLSS and the IAnT concept.

DISCUSSION

The main result in the present study was the finding that MLSSc in double poling was $6.7 \pm 1.3 \text{ mmol} \cdot \text{L}^{-1}$. Lactate values at IAnT was in between MLSSc and OBLA with a value of $5.1 \pm 0.9 \text{ mmol} \cdot \text{L}^{-1}$. Although there were significant correlations amongst MLSSv to OBLAv and IAnTv, the under-estimation of OBLA ($-2.7 \pm 2.6 \text{ mmol} \cdot \text{L}^{-1}$) and IAnTc ($-1.4 \pm 2.8 \text{ mmol} \cdot \text{L}^{-1}$) is of great physiological importance and corresponds to significant differences in velocities. This stresses the fact that linear correlations are dependent on the range of values in the analyzed sample and does not assess the bias or absolute agreement between two methods (8, 17). Moreover, there was a significant difference between MLSSv and OBLAv, emphasizing the lack of agreement between the concepts. In almost all participants, OBLA and IAnT underestimated the actual MLSS. This was probably not the case in the one subject with a rarely low BLC at MLSS and IAnT of $0.9 \text{ mmol} \cdot \text{L}^{-1}$ and $2.5 \text{ mmol} \cdot \text{L}^{-1}$ respectively.

This study suggests that it is unrealistic to rely on an AnT concept with a fixed BLC such as OBLA or a certain tangent to predict an accurate MLSS in the context of double poling. In the context of AnT and MLSS, it is essential to assess the agreement between different methods and not only to rely on differences and correlations that some investigators surprisingly do.

The results of the present study are in line with similar studies which states that fixed concepts often under- or overestimates the actual MLSS in sports events such as cycling (2), running (19), rowing (3), and kayaking (31). This is not surprising due to MLSSc being highly dependent on the motor pattern of exercise, muscle fiber type characteristics (34), and the blood volume lactate is distributed in (33).

In relation to other sports, a BLC at MLSS of $6.7 \pm 1.3 \text{ mmol} \cdot \text{L}^{-1}$ in double poling can be considered high and could be explained by several factors. Firstly, it is known that the MLSSc is negatively correlated to the volume of the primarily engaged muscle mass (5, 6). For instance, MLSSc in the whole-body exercise rowing, has been shown to be $2.7 \pm 0.6 \text{ mmol} \cdot \text{L}^{-1}$ and $3.0 \pm 0.7 \text{ mmol} \cdot \text{L}^{-1}$ (3, 5). In the upper body exercise kayaking, MLSSc was $5.4 \pm 0.7 \text{ mmol} \cdot \text{L}^{-1}$ (31). The muscles that are relatively less activated play a role of lactate consumers (21), in this case, the lower extremities. This could in turn allow for a higher MLSSc in double poling. Secondly, due to the higher content of fast twitch muscle fibres in arms and upper body and a relatively large amount of moderately active muscle mass in the lower extremities, a higher BLC at MLSS is possible in double poling. As shown by several authors, the arms exhibit higher lactate

production, and lower O₂ extraction, than legs at the same relative workload (1, 12, 30, 40, 43). Therefore, it is not surprising that the primarily upper-body exercise double poling elicits a high BLC at MLSS.

In this study, MLSSc ranged from 0.9 to 8.7 mmol · L⁻¹. However, with the lowest value excluded, the range was from 5.0 to 8.7 mmol · L⁻¹. These great inter-individual differences could be explained by individual muscle fibre type characteristics (22), and training background (36, 39), since this effects lactate kinetics. In the case of the extremely low MLSSc and IAnTc value of 0.9 and 2.5 mmol · L⁻¹ respectively, the participant was indeed highly aerobically trained focusing on long distance races. For this participant, MLSSv was far from near maximal intensity over 30 minutes. However, lactate steady state could not be achieved. Although speculative, the low BLC values could be a result of relatively higher age, high proportion of type I fibers resulting in low glycolytic and LDH activity, as well as the mostly aerobic training-routine for the participant (15, 35).

The stage durations during a step-wise incremental test must be considered since these will affect the estimated MLSS (17, 19, 28). Stage durations of three to five min is typically used and it is known that stage durations of five to six min will lead to a risk of overestimating the actual MLSS. Hence, longer stage duration in the step-wise incremental test could lead to even larger discrepancies between MLSS and values for OBLA and AnT. In addition, one needs to consider the intermittent-protocol for testing the MLSS used in this study, which eventually could lead to a small increase in MLSSc in comparison to continuous MLSS testing protocols (23).

The findings of this study widen the knowledge of MLSS and lactate kinetics in different motor patterns of exercise. It also provides further physiological data regarding the double poling technique, which has increased in importance in the modern type of cross-country skiing. Moreover, it questions the commonly used OBLA and tangent to lactate curve-methods as indicators for MLSS. The findings of this study could help coaches, athletes and test personnel to develop more accurate testing procedures, which in turn could improve the prescription of training intensities. A fixed threshold of 6.5 or 7 mmol · L⁻¹ would, according to the results in this study, be more accurate to predict the MLSS in double poling. However, due to great inter-individual differences the disagreement would still be too great if precision is wanted when estimating MLSS from a single incremental test.

From a statistical standpoint, a larger sample size would had been advantageous. Although, within the research field of MLSS, sample sizes of this magnitude are common (31). The method requires multiple test events to be done, which increases the time and resources needed and complicates the recruiting process of suitable participants. The sample size of this study is comparable with similar studies. In the research field of lactate kinetics and MLSS, there is scarce knowledge about lactate kinetics during constant workload and factors behind the great inter-individual differences in MLSSc. Further research could investigate these aspects, which could lead to more convenient test procedures to accurately predict the MLSS. A method to determine MLSS with less test occasions, and thus cheaper, than the most commonly used method as in this study would be a great finding. Concepts for predicting aerobic capacity and exercise intensities that do not include lactate measurements and the uncertainties it comes with, is

desirable. Moreover, further research on lactate kinetics in double poling covering different velocities and inclines, could widen the knowledge and optimize training and testing prescription.

It is concluded that the MLSSc in double poling is $6.7 \pm 1.3 \text{ mmol} \cdot \text{L}^{-1}$, with a relatively extensive range. The OBLA and IAnT concept tends to underestimate the true MLSSc and MLSSv, with the underestimation of IAnT being slightly smaller. Subsequently, this study demonstrates the risks of making inaccurate predictions of MLSS when using the OBLA and IAnT concepts, which agrees with several other studies investigating similar concepts. A fixed threshold 6.5 or 7 $\text{mmol} \cdot \text{L}^{-1}$ would be more appropriate to predict the MLSS in double poling than 4 $\text{mmol} \cdot \text{L}^{-1}$, when a single-occasion graded incremental test is used. Nevertheless, it is still an inadequate approach due to the great inter-individual differences in lactate kinetics and thus MLSSc. Several constant workload tests of at least 30 mins for determining the MLSS is recommended if precision is wanted for the true exercise intensity.

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