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ASSESSMENT OF MAXIMAL LACTATE STEADY STATE IN ELITE FEMALE KAYAKERS

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Abstract

Introduction: Endurance training at an exercise intensity level reaching a maximal lactate steady state (MLSS) may result in increase in exercise adaptation while minimizing the risk of overtraining. Measuring MLSS in the laboratory is labor intensive; however, time trial events are relatively simple and often completed in endurance sports.

Methods: To determine whether a relationship between the average workload during a 6 km kayaking time trial and MLSS workload exists, female elite kayakers (age: 22.9 ± 1.9 yrs, $\dot{V}O_2$ peak: 46.3 ± 2.8 ml/kg/min, N = 23) underwent a maximal power output test on the kayak ergometer (max power: 259 ± 16 W), and MLSS was determined by using 30 min constant workload bouts of kayaking (mean MLSS: 2.64 ± 0.12 mmol/l). Subsequently, subjects completed a 6 km time trial to determine time and mean power.

Results: A significant relationship was found between mean power output and MLSS workload ($r^2 = 0.853$, $p < .001$). Mean power output during the 6 km time trial (214 ± 12 W) was greater than the average MLSS power output (168 ± 8 W). Utilizing the regression equation: $y = 0.7429x + 10.913$, where x = mean 6 km time trial workload and y = MLSS workload, individual MLSS intensity can be predicted. For kayakers, while the time to complete a 6 km time trial decreases, MLSS workload increases. **Conclusions:** The results suggest that training to improve MLSS workload may improve a 6 km time trial performance.

***Key words**: kayaking, MLSS, threshold, time trial*

Introduction

Competitive endurance athletes continuously strive to improve their performance. While an athlete's success depends on a number of factors (1), one variable that influences one's training effectiveness, and perhaps event performance, is through the way the lactate is handled by the body during the exercising intensity. Lactate response during exercise can be quantified by measuring the performance related variable known as maximal lactate steady state (MLSS). The concept of MLSS was first introduced by Margaria et al. (2,3) in the 1960s when subjects underwent five to eight separate constant load tests in which blood lactate measurements were taken. MLSS is defined as the highest power output an athlete can maintain for a period of a 30 minute steady workout where lactate level does not vary by more than 1mM during the final 20 minutes of the 30 minute test (4). The MLSS power output occurs when the presence of lactate in the blood is equal to the clearance level of lactate from the blood. When lactate level increases, fatigue and loss of the ability to sustain a workload eventually follows (5). The MLSS workload allows for prediction of maximum performance in activities lasting 30-60 minutes (6,7). Therefore, according to many researchers, the knowledge of MLSS is beneficial in designing training programs aimed at maximizing the effectiveness and reduction of risk of injury or overtraining (8-12).

Methods of estimating lactate levels have been carried out for several types of athletic events. While the method of estimating MLSS in some athletes has been met with a doze of success (9,13-16), such prediction has not been completed, nor a method is established for the sport of kayaking.

Measuring the MLSS in the laboratory setting is both labor intensive and costly due to both high cost of laboratory equipment and the qualified personnel necessary to complete the required physiological tests. Conversely, athletic time trial events are completed often in endurance sports and are relatively simple. Also, the vast majority of athletes do not have an access to licensed exercise physiologists or laboratory equipment necessary to perform the evaluation of physiological parameters. If kayakers were able to predict the power output associated with MLSS intensity from a time trial, more athletes would become aware of their MLSS power output. Subsequently, numerous athletes and coaches would be able to utilize the MLSS power output to design training programs and improve performance.

The purpose of this study was to investigate a means of estimating MLSS power output. More specifically, it intended to examine the relationship between MLSS power output and the average workload during a 6 km time trial on a kayak ergometer. Two hypotheses were tested. First, a significant positive relationship between laboratory measured MLSS power output and average power output during a 6 km time trial on a kayaking ergometer was tested. Secondly, it was hypothesized that there would be no difference between MLSS power output and the average power output of a 6 km time trial on a kayaking ergometer.

Methods

Subjects

Twenty three Caucasian female kayakers (age range: 19-26 yrs), members of the Hellenic National Team volunteered to participate in the study. All competitors had considerable previous experience and had competed at an international level for at least 3 years, practicing regularly for an average of 11 months per year, 6 $d \cdot wk^{-1}$ for a minimum of 3 $h \cdot d^{-1}$. The Institutional Human Subjects Review Board approved the experimental design; the study was carried out according to the Declaration of Helsinki protocol, and written informed consent was obtained from all participants. None of the participants was on medication at the time of the exercise test and no history of injuries was reported.

Procedures

Maximal power output measurement

During the initial visit to the laboratory, the athletes' age, height, and weight were recorded before they underwent a maximal power output test on a kayak ergometer (K1 Ergo, Garran, Australia). Prior to and during the maximal power output test, both heart rate and oxygen consumption were continuously measured. Heart rate was quantified and recorded via telemetry (Polar Instruments Inc., Oulu, Finland). Oxygen consumption was measured using an on-line gas analysis system calibrated according to the manufacturer's specifications (Vmax 229; Sensor Medics, Anaheim, CA). The protocol to determine maximal power output on the kayak ergometer was initiated at an intensity of 60 watts and increased by 20 watts every minute. The kayakers were instructed to paddle at a comfortable stroke rate during each stage and to increase the wattage level with an increasing effort per stroke. The test was terminated due to a participant's volitional exhaustion or when the subject was no longer able to maintain the prescribed workload during the testing stage. The final workload reached (workload defined as maximal power output) was the largest wattage which the subject could maintain for at least 30 seconds. The highest value of oxygen consumption reached during the test was recorded as $\dot{V}O_2$ peak.

Maximal lactate steady state measurement

Following the maximal power output test, MLSS was determined for each subject. To ensure that the athletes were in a similar nutritional condition, all athletes consumed an identical pre-exercise snack (Ensure, 6 kcal/kg, 0.96g/kg of carbohydrate, 0.14g/kg of fat, 0.22g/kg of protein) 3 hours prior to each MLSS trial. The athletes arrived at the laboratory 30 minutes prior to the MLSS tests and were instructed to warm up on the kayaking ergometer. The subjects were instructed to complete a typical warm up for an intense steady state kayaking exercise session. Measurement of MLSS was performed using methods similar to those established by Beneke (17). For each MLSS trial, the subjects were instructed to paddle at a constant workload for 30 minutes and maintain a stroke rating between 70-80 strokes per minute. Blood samples were collected and heart rate was recorded at rest (prior to the warm-up) and every 5 minutes for the duration of the 30 minute paddling period. During the rowing time, toe, ear, and finger blood sampling sites offer equal concentrations of lactate (18). Therefore, to avoid test interruptions, blood samples were collected via toe stick during each sample time point (0, 5, 10, 15, 20, 25, 30 minutes). Two 25μl samples of blood were obtained and immediately analyzed (YSI 2300 Sport Lactate Analyzer, Yellow Springs, Ohio) to determine blood lactate concentration (mmol/l). The lactate analyzer was calibrated with known concentrations of lactate according to the manufacturer's instructions prior to each trial. The average of two samples was recorded as the lactate concentration at each time point. To ensure a consistent workload was maintained throughout the 30 minute trial, the average workloads and stroke ratings were recorded every 2 minutes.

The initial 30 minute MLSS trial occurred at a workload equal to 65% of the individual's maximal workload achieved during the maximal power output test. If, during the initial MLSS trial, lactate concentration remained steady, the workload was increased by 5% of the initial value for each subsequent MLSS trial (i.e. 65% of maximal workload followed by 70% of maximal workload, etc.) until no steady state in lactate could be reached. If, on the other hand, during the initial MLSS trial, there was a rise in lactate level, the workload was decreased by 5% of the initial value for each subsequent MLSS test (i.e. 65% of maximal workload followed by 60% of maximal workload, etc.) until a steady state in lactate was reached. The trial associated with the highest workload during which lactate did not change by more than 1 mmol/l in the last 20 minutes of the 30 minute paddling period was deemed to be the MLSS power output (17). The MLSS heart rate was recorded as the average heart rate during the final 20 minutes of the 30 minute trial deemed to be the MLSS power output. Each subject underwent at least 2 MLSS trials but no more than 4 trials. Figure 1 displays typical data collected from each subject. Trials were separated by at least 48 hours period and subjects were instructed to engage only in easy kayaking exercise, if any, throughout the data collection period.

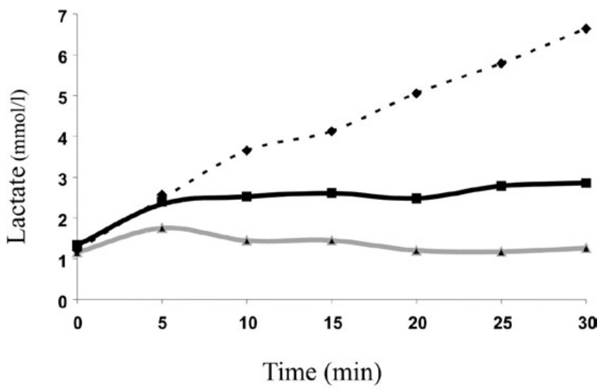

Fig. 1. *Example maximal lactate steady state (MLSS) data plot for one subject. Blood samples were collected at rest and every 5 minutes during exercise and analyzed for lactate concentration. Each line represents a constant workload measured in watts where: grey triangles = 130 W, black squares = 150 W, and dashed black line = 160 W. MLSS is defined as the highest lactate concentration that can be maintained with no change in concentration greater than 1 mmol/l in the last 20 minutes of a 30 minute constant workload paddling. Here, the black line with square marks (150 W) is the MLSS intensity. The dashed black line represents an increase in lactate over the exercise bout and corresponds to an intensity above MLSS*

6 km time trial

Subsequent to MLSS determination, each kayaker completed a 6 km time trial on the kayaking ergometer. Kayakers were asked to complete the 6 km distance as if they were racing and to demonstrate the fastest possible time to complete the distance. Once more, the subjects were instructed to perform a proper warm up session prior to engaging in test and to paddle at the most effective stroke rate. The kayaking ergometer electronically measured the power output of each kayaking stroke and consequently calculated the average power output for the total 6 km distance. Total time to complete the 6 km distance was also recorded.

Statistical Analysis

The mean and standard error of the mean (SEM) were calculated for all data. To measure the relationship between MLSS power output and average time trial power output, linear regression was performed. To determine if MLSS power output was different than the power output associated with a 6 km time trial, a student's t test was performed with alpha level set *a priori* at $p < 0.05$. A useable prediction equation was developed so that MLSS intensity could be predicted following the completion of a 6 km time trial on a kayaking ergometer.

Results

Descriptive parameters

Complete data was collected on 23 female elite kayakers. Descriptive statistics and results of the $\dot{V}O_2$ peak test are presented in Table 1. The Power Output $_{max}$ and $\dot{V}O_2$ peak achieved were 259 ± 16 W (range: 230 - 290 W) and 46.3 ± 2.8 ml·kg^{-1}·min^{-1} (range: 40.3 - 50.8 ml·kg^{-1}·min^{-1}), respectively. There is a broad range in the maximum workload achieved and $\dot{V}O_2$ peak. While the population differs in age by not more than 6 years, the number of years spent in training as a kayaker was more diverse and likely contributed to the range in max workload and $\dot{V}O_2$peak.

Table 1. *Descriptive data for elite female kayakers (N = 23)*

Variable	
Age (years)	22.9 ± 1.9
Height (cm)	173.3 ± 4.4
Weight (cm)	72.3 ± 3.5
Heart Rate $_{max}$ (bpm)	191 ± 4
Power Output $_{max}$ (W)	259 ± 16
$\dot{V}O_2$ peak (l·min^{-1})	3.35 ± 0.09
$\dot{V}O_2$ peak (ml·kg^{-1}·min^{-1})	46.3 ± 2.8

Data are presented as mean ± SEM

Maximal lactate steady state

The results of the MLSS testing are presented in Table 2. The subjects displayed a large variance in absolute power output associated with MLSS. However, the relative intensity at which MLSS occurred contained much less variability. This suggests that the athletes in this study present similar fitness levels, in terms of MLSS, when measured relatively to their own maximal capacity.

Table 2. *Selected variables at MLSS for elite female kayakers (N = 23)*

MLSS Variable	
Power Output (W)	168 ± 8
Power Output (% P $_{max}$)	64.9 ± 3.1
Lactate (mmol·l^{-1})	2.64 ± 0.12
Heart Rate (bpm)	169 ± 3
Heart Rate (% HR $_{max}$)	88.6 ± 1.1

Data are presented as mean ± SEM

6 km time trial

The results of the 6 km time trial are presented below in Table 3. Some of the highest speed times are comparable to the standards for the Hellenic Kayaking National Team. An "elite" national team female kayaker in Greece is expected to paddle 6-km faster than 28 minutes, whereas a national team kayaker in the developmental category standard is faster than 29 minutes and 30 seconds. The mean and range of times demonstrated during the 6 km time trial indicates the high quality of the subjects' talent in this study as compared to other, well trained female kayakers.

Table 3. *6-km Time trial data for elite female kayakers (N = 23)*

6-km Time Trial Variable	
Completion time (min)	29.30 ± 0.37
Power Output (W)	214 ± 12

Data are presented as mean ± SEM

Relationship between MLSS power output and time trial power output

MLSS workload was significantly lower than the average workload sustained during a 6 km time trial (Figure 2). Linear regression analysis was performed to measure the relationship between MLSS workload and average 6 km time trial workload. Figure 3 presents a graphical scatter plot of data collected on 23 kayakers. An average 6 km time trial workload (predictor variable) is plotted on the x-axis, while MLSS workload (predicted variable) is plotted on the y-axis. There is

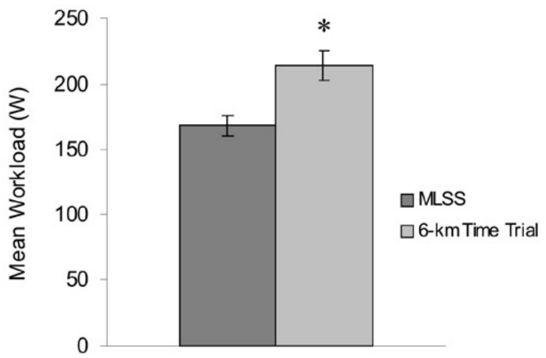

Fig 2. *Mean workload ± SEM for two kayaking ergometer tests (6-km time trial, MLSS = Maximal Lactate Steady State) in female kayakers of the Hellenic National Team (N = 23). * MLSS is significantly different than 6-km TT (p < 0.05)*

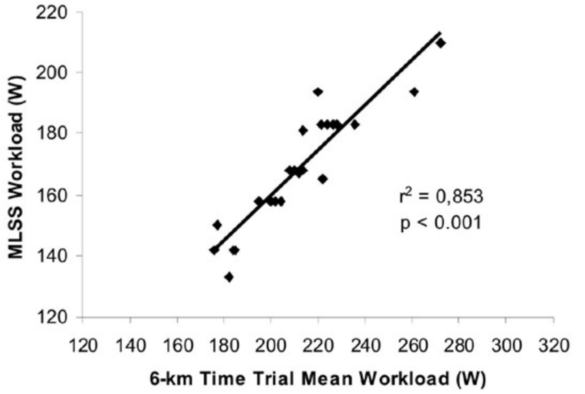

Fig. 3. *Relationship between 6-km time trial mean workload and MLSS workload in female kayakers of the Hellenic National Team (N = 23)*

a strong positive relationship evidenced by a Pearson correlation coefficient of 0.924. Furthermore, the r^2 value indicates that nearly 85% of the variance in MLSS workload can be accounted for by the 6 km time trial average workload. Using linear regression analysis, the following prediction formula was produced:

$y = 0.7429x + 10.913$

where: x = average 6 km time trial workload (watts) and y = MLSS workload (watts).

This formula predicts MLSS workload with an average 6 km time trial workload.

Discussion

Determination of MLSS in the laboratory is costly and time consuming. In addition, the number of endurance athletes and coaches interested in this physiological variable is substantial, and the number of technicians available to collect appropriate data is small. Consequently, the methods of estimating lactate concentrations have been established for several types of athletic events (9,13-16). However, an estimation procedure for MLSS in kayaking has not yet been established.

The purpose of this study was to investigate a method of estimating MLSS workload in elite female kayakers. The hypothesis that there would be a significant relationship between MLSS workload and average 6 km time trial workload was supported. It was determined that a 6 km time trial can predict MLSS power output for elite female kayakers. Conversely, the hypothesis that the average power output of a 6 km time trial and MLSS power output would be similar, was not supported. It was observed that the power output maintained during a 6 km time trial was significantly greater than the MLSS power output.

Previous studies have investigated methods of estimating MLSS in several athletic populations (9,13-16). When testing the trained speed skater subjects, Foster et al. used a process based on running velocity to determine whether a steady state in lactate concentration was achieved at a speed equal to 78-88% of the individual maximal velocity and 84-92% of max heart rate (9). Typically, speed skaters reach high blood lactate concentrations between 4.0 and 6.5 mmol/l. In the current study, the kayakers were able to maintain 64.9% of their individual maximum aerobic power output and showed lower lactate values at MLSS. For speed skaters, the prediction of MLSS intensity of heart rate (as opposed to velocity) is valuable. The conditions between training sessions for speed skaters may vary and velocity can be affected by the ice conditions and other environmental parameters. Conversely, velocity is not influenced by external factors for kayakers while training on a kayaking ergometer.

In male and female runners, Weltman et al. inspected a method of estimating lactate levels during running (15,16). The study identified that a 3,200 meter time trial could be used to predict both $\dot{V}O_2$max and running speed corresponding to lactate concentrations of 2.0, 2.5, and 4.0 mmol/l for male and female runners (15,16). While this study determined methods of predicting running speed for particular lactate concentrations, it did not specify which lactate concentrations would be equivalent to the maximal lactate steady state concentration level. All lactate values used for prediction were collected during a graded maximal capacity test and not during steady state exercise. While they developed equations for predicting fixed lactate values, an individual runner may not know which value would correspond to MLSS.

In another project administered to cyclists and runners, maximal lactate steady state was predicted by calculating the percentage of maximal heart rate (13). The authors accounted for cardiac drift by prescribing a MLSS heart rate at 10, 20 and 30 minutes for a 30 minute steady state exercise bout. The results conclude that the mean percent of maximal heart rate after 10, 20, and 30 minutes period was 83, 86, and 89% for cyclists and 91, 93, and 95% for runners. These values are similar to the percentage of maximal heart rate during MLSS in kayakers. In the present study it was observed that MLSS power output occurs at a heart rate of 88.6% of maximal heart rate intensity in the final 20 minutes of the 30 minute bout.

A 6 km time trial distance for the estimation of MLSS was used in this study for several reasons. Typically, for elite female kayakers, the time to complete 6 km on a kayak-ergometer is between 27.5 and 29 minutes. The duration of the time trial is similar to the duration of MLSS trials. Also, a 6 km distance time trial is a common performance measurement on the ergometer. Athletes are conditioned, mentally and physically, to complete 6 km as fast as possible. The familiarity of the kayakers with the distance increases the consistency of performance and is a more repeatable, and reliable measurement than an unfamiliar time trial distance.

The observation that MLSS power output differed from average 6 km time trial power output is noteworthy. While 6 km time trial power output is a strong predictor of MLSS power output, the two intensities are not equal. Since the 6 km time trial is regarded as a "race against time", most athletes begin and end the kayaking piece at higher intensities than those that can be maintained throughout the duration of the paddling. Therefore, metabolic demands of a 6 km time trial are not equal to the demands of MLSS kayaking. In a future study, it may be of benefit to determine if the power output of the middle section of a 6 km time trial is similar to MLSS power output, since most kayakers maintain an even pace through the middle of a 6 km time trial while they begin and complete the time trial at a faster pace.

The average lactate value corresponding with MLSS in this study was 2.64 ± 0.12 mmol/l. This value is similar to MLSS concentrations previously reported for male kayakers (average lactate = 3.1 mmol/l) (19). Currently, it has been established that the average MLSS value across different athletic modes is 4 mmol/L, with a range of 2-7 mmol/l. The large range of lactate values for MLSS may be partially due to the fact that MLSS is influenced by the power output per unit of muscle mass involved in the modality of exercise (19,20). Consequently, MLSS lactate concentration is modality specific (19), so it is necessary to evaluate kayakers while kayaking, especially if the results are to be used for kayak training.

We believe this to be the very first study to measure MLSS with blood samples collected from toe. Frequently, blood lactate testing is taken from the finger and ear area. In kayaking, collecting a sample from finger or ear area requires the subject to stop moving and thus interrupts the steady state condition of the exercise bout. Previous research demonstrates that a pause in exercise, as short as 30 seconds in a 30 minute bout, can increase the MLSS power output (21). If MLSS is associated with a higher intensity because of interruptions during testing, the result may be an inaccurate exercise prescription, especially when no break in the exercise is taken during the actual training sessions. Utilizing the toe as a sampling site enabled the subjects to paddle continuously and the intensity to be maintained without interruption. In addition, the toe, ear, and finger site offer equal concentrations of lactate level during rowing time (18).

Conclusions

It is possible to predict MLSS workload in elite female kayakers based upon the knowledge of the average workload achieved during a 6 km kayaking time trial. Specifically, the prediction formula outlined below can be used to estimate MLSS workload in female kayakers; members of the Hellenic National Team:

$y = 0.7429x + 10.913$

x = average 6-km time trial workload (watts) and y = MLSS workload (watts).

However, the workloads reached at MLSS and during a 6 km kayaking time trial are not the same. It appears that elite female kayakers are able to maintain a significantly higher workload during a 6 km time trial as compared to their MLSS workload. As this latter finding was unexpected and it was observed that the intensity at the start and finish of the time trial was higher than the average, it may be important for a future study to determine if the power output of the middle section of a 6 km trial is more similar to MLSS power output.

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