Interval Training Using the Lactate Retention Method: A Pilot Study

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INTERVAL TRAINING USING THE LACTATE RETENTION METHOD: A PILOT STUDY

by

Tyler M. Dundore

A thesis submitted to the Graduate College in partial fulfillment of the requirements for the degree of Master of Science Human Performance and Health Education Western Michigan University April 2020

Thesis Committee:

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Interval training (IT) is used to improve aerobic capacity and increase tolerance to lactate. Few studies to date have focused on trapping lactate in the muscles during recovery periods of IT, a method called “lactate retention”, or LR. **PURPOSE:** To determine if LR can produce greater improvements in lactate threshold (LT) and a faster rate of change in blood lactate concentration ([rΔBL]) compared to IT with active recovery (AR). **METHODS:** Ten cross-trained subjects (age 23.3 ± 4.7 years) participated; each came to the lab twice per week for the duration of the study. Visit 1 included an LT test to exhaustion. Visit 2 involved three Wingate anaerobic tests (WAnTs) with measurements for [rΔBL] directly following each (1, 2, and 3). Peak Power (PP), relative peak power (rPP), average power (AP), relative average power (rAP), and fatigue index (FI) were also measured. Subjects were randomly assigned to either the LR or AR group; visits 3-10 involved IT as either LR or AR twice per week, for four weeks. Visits 11 and 12 involved retesting visits 1 and 2 in the same order. A 2x2 repeated measures mixed ANOVAs were used to analyze the data. **RESULTS:** There were no differences in LT between groups or from pre- to post-training (p > 0.05). There were no improvements in PP, rPP, AP, rAP, or FI following training in either group (p > 0.05). Lastly, there were no differences in [rΔBL] for either group after training (p > 0.05). **CONCLUSION:** Even though there were no significant differences, workload at LT for the LR group increased by 11.1 W (a 6.67% increase) while the AR group decreased by 0.7 W (a 0.4% decrease). Future research is warranted as this study had a low subject number and high variance in the data.
ACKNOWLEDGEMENTS

I would like to begin by acknowledging the excellent mentorship that I have received from Dr. Nicholas Hanson during the past two years. I could not have asked for a better mentor that has pushed me to grow immensely as a person, student, and professional. For his contributions I am extremely grateful.

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There are multiple others that have helped make this research possible. First, Henk Kraaijenhof and Cal Dietz for pioneering the idea of the lactate retention method. Regan Quaal and Mark Olson were also extremely helpful with helping me develop the training protocol and other methods within the protocol outlined. Rachel Dykstra and Collin Garner were also extremely supportive and helpful throughout data collection and writing of this thesis.

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Tyler M. Dundore
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LIST OF ABBREVIATIONS AND ACRONYMS

1. AR: Active recovery
2. LR: Lactate retention method
3. LT: Lactate threshold
4. IT: Interval training
5. MWR: Maximum work ate
6. ME: Mechanical efficiency
7. ME_{20}: Mechanical efficiency at 20% of workload at TTE
8. ME_{40}: Mechanical efficiency at 40% of workload at TTE
9. ME_{60}: Mechanical efficiency at 60% of workload at TTE
10. ME_{80}: Mechanical efficiency at 80% of workload at TTE
11. ME_{100}: Mechanical efficiency at 100% of workload at TTE
12. WAnT: Wingate Anaerobic Sprint Test
13. WAnT_1: first WAnT
14. WAnT_2: second WAnT
15. WAnT_3: third WAnT
16. WAnT_3i: 3 minutes after third WAnT
17. WAnT_3f: 15 minutes after third Win WAnT
18. PP: Peak power
19. rPP: Relative peak power
20. AP: Average power
21. rAP: Relative average power
22. FI: Fatigue index
23. T0: time zero
24. T3: three minutes
25. T15: fifteen minutes
26. T01: time zero after WAnT1
27. T02: time zero after WAnT2
28. T03: time zero after WAnT3
29. T31: three minutes after WAnT1
30. T32: three minutes after WAnT2
31. T33: three minutes after WAnT3
32. [BL]: blood lactate concentration
33. [ΔBL]: change in blood lactate concentration
34. [rΔBL]: rate of change of blood lactate concentration
35. [rΔBL]1: rate of change of blood lactate concentration after WAnT1
36. [rΔBL]2: rate of change of blood lactate concentration after WAnT2
37. [rΔBL]3i: rate of change of blood lactate concentration 3 minutes after WAnT3
38. [rΔBL]3f: rate of change of blood lactate concentration 15 minutes after WAnT3
39. L: Liter
40. VO2: Volume of oxygen consumption
41. VO2max: Maximum volume of oxygen consumption
42. bpm: beats per minute
43. min: minute
44. kg: kilograms
45. cm: centimeters
46. W: Watts

47. rpm: revolutions per minute

48. J: Joule

49. kcal: kilocalorie

50. RER: respiratory exchange ratio

51. IMP: Intramuscular pressure

52. MBF: Muscle blood flow

53. NAD+: Nicotine adenine dinucleotide

54. NADH: Reduced nicotine adenine dinucleotide

55. LDH: Lactate Dehydrogenase

56. GPP: General physical preparedness

57. GSP: General to specific preparedness

58. SPP: Specific performance preparedness

59. SD: Standard deviation

60. WMU: Western Michigan University

61. HPRL: Human Performance Research Lab
LIST OF EQUATIONS

Change in blood lactate concentration. \([\Delta BL]\) was calculated as follows:

1. \(\frac{([\text{Lactate T3}] - [\text{Lactate T0}])}{3 \text{ minutes}}\) (for all except WAnT3f)

2. \(\frac{([\text{Lactate T15}] - [\text{Lactate T0}])}{15 \text{ minutes}}\) (for WAnT3f)

Fatigue Index

\((\text{peak power} - \text{minimum power})/\text{peak power} \times 100\%\)

Mechanical Efficiency

1. Work Output = workload (W) of the stage

2. Work Input = Absolute VO2 (L/min) x caloric equivalent of average RER for last 2:00 of stage x 4184 J/kcal x (1 minute/60 seconds)

3. Mechanical Efficiency (ME) = Work Output / Work Input x 100\%
INTRODUCTION

Interval Training

Interval training (IT) is a method of training used to increase aerobic capacity and increase or maintain anaerobic capacity when performed at a supramaximal intensity. Both of these are adaptations of great value to athletes due to success in competition often relying on sustained aerobic performance, maintenance of anaerobic power, or a combination of both. Interval training is characterized by intense periods of exercise followed by a prescribed rest interval and is an alternative to monostructural endurance training (e.g., long-distance run, bike, etc.). It is also a method of training that allows for a greater amount of work to be done in a shorter amount of time. Since perceived lack of time is one of the most commonly cited reasons for not exercising, IT is a very popular form of training for coaches, athletes, and the general public. Interval training has a variety of performance benefits, such as increased 400-meter run time, improved neuromuscular power output, and maintenance of anaerobic capacity. Many studies on interval training focus primarily on active and/or passive recovery which have the objective of removing lactate and hydrogen ions from the working muscle in-between intervals.

Lactate

During exercise, lactate is produced in type-IIb fibers as exercise intensity increases and aerobic energy systems are used less as is the case in IT. Lactate is not a cause of fatigue, but rather a biomarker of intensity accompanied by increased hydrogen ions and other metabolites in the blood. Hydrogen ions can cause a decreased ability to contract the muscles due to decreased
pH of the muscles, which can cause decreased sensitivity to calcium in the myofibrils. This can result in a decline in power output and performance. Since lactate is also a marker of peripheral neuromuscular fatigue, the purpose of shuttling lactate and hydrogen ions is to maximize power output and overall athletic performance. This is the reason why AR has classically been used during the rest period of exercise.

An alternative method to AR during interval training is the lactate retention (LR) method, which involves trapping blood in the working muscles in an attempt to force the muscles to adapt to utilize lactate as a fuel source. This could be achieved by biking at a high intensity and then squatting to parallel and holding a high force isometric contraction for the entire rest interval. Endurance training is another form of exercise that also involves exercising at or above lactate threshold (LT) to induce the adaptations associated with IT. Since endurance training is typically not at a high intensity, anaerobic adaptations that may occur during IT may not occur during endurance training. This makes it a training type not suitable for some athletes or during different phases of training throughout the year.

**Maintenance of Power**

Variables such as absolute and relative peak power (PP and rPP), absolute and relative average power (AP and rAP), and fatigue index (FI) (respectively) can show how well a participant is able to maintain a high power output across repeated bouts of high intensity exercise. If these variables were measured alone during repeated sprint performance to quantify fatigue and showed a reduction in fatigue, the results would not explain why these changes occurred. To further understand this, it is important to discuss qualities of different muscle fibers. There are two main types of skeletal muscle fibers: type-I muscle fibers are slow twitch, rely on
oxidative-phosphorylation energy production, and have low power output; type-IIb muscle fibers are fast twitch, rely on glycolysis for energy (producing lactate), and have high power output. After performing IT, muscles can adapt to shuttle lactate from type-IIb fibers to type-I fibers, the heart, or the liver quicker. Once the lactate is delivered to type-I fibers, energy generation can occur via hydrogen oxidation from lactate. Increased amounts of NAD+ and rate of turnover of NADH to NAD+ are also beneficial adaptations to IT. In addition, increased amounts of lactate dehydrogenase would be stored in the cytosol of slow twitch fibers and inside of the mitochondria to catalyze the rate of conversion of lactate to pyruvate. Since pyruvate can form glucose through gluconeogenesis in the heart and liver, LR may also lead to increased glucose production.

Measuring [rΔBL] can show that lactate is being removed from the blood to go through either gluconeogenesis or aerobic metabolism and can also show how hydrogen ions are moving with lactate which are associated with fatigue. For example, increased [rΔBL] (more negative) would be a marker of recovery during repeated Wingate Anaerobic Sprint Tests (WAnTs). If a marker of recovery ([rΔBL]) was better and AP, rAP, and FI improved following training, the improved performance could potentially be correlated to [rΔBL]. This would mainly be due to improved oxidative metabolism of lactate in the mitochondrias and removal of hydrogen ions from the muscle, the combination of which allows for maintenance of a higher power output over subsequent sprint efforts. Blood lactate concentration was also measured during the LT test to help determine if LT increased following the training protocol. If an increase in LT was observed following training, an individual could perform at a higher intensity for longer during endurance exercise than before training. Measuring LT also allows for more valid quantification of
endurance performance than VO2max, allowing for a better exercise prescription and practical application.

**Statement of the Problem**

Very little research has been conducted on LR outside of a study that focused on anaerobic power output alone but not the glycolytic-oxidative energy system or lactate accumulation and clearance. This is one of the only studies on LR, popularized by Cal Dietz (a strength and conditioning coach at the University of Minnesota) and Henk Kraaijenhof (a consultant and educator for high performance). Each of these individuals have anecdotally found this training strategy to be very beneficial. This method of retaining lactate in the muscles during glycolytic-oxidative IT could lead to more significant adaptations of this energy system. In addition, it could allow strength and conditioning professionals to enhance performance/fitness to a greater magnitude with their athletes/clients during the time available with them.

The purpose of this study was to determine if after 4 weeks of IT, LR would (1) elicit a greater increase in LT and (2) have greater improvements in blood lactate clearance rate compared to IT that uses active recovery (AR). It was hypothesized that LT and ME would increase more in the LR group after training compared to the AR group. In addition, it was hypothesized that neither PP nor rPP would change for either group when compared to pre-training values. However, AP and rAP would have a greater increase while FI values would be smaller in the LR group compared to pre-training. Lastly, the LR group would have a faster [rΔBL] than the AR group following training and when compared to pre-training values.
METHODS

Participant Recruitment

Participants were recruited through flyers placed in WMU’s student recreation center (Appendix A). In addition, the researchers sent the recruitment information to several gyms in the Kalamazoo area in an email and asked for them to post them or mention the study to their members. In addition, local activity groups (triathlon, cycling, club sports, and intramural sports) were contacted and given the recruitment materials. If participants indicated interest in learning more about this study, the researchers provided further information by sending informed consent documents (Appendix B) to them. Participants were informed of the inclusionary and exclusionary criteria so that they could self-select to participate.

Informed Consent Process

After participants indicated interest in participating in the study, the informed consent document was emailed (or a paper copy was given) to the participant so that they could review the study and decide if they wanted to participate. After reviewing the document on their own, participants decided if they wanted to participate in the study. Upon arrival to the Human Performance Research Lab (HPRL), the informed consent document was explained in detail to the participant. During this explanation, participants were encouraged to ask any questions pertaining to the study. Upon completion of reviewing the procedures, participants verbally acknowledged their understanding and acceptance of the procedures. Participants were then given detailed explanations of all risks and benefits associated with participating in the study. Participants then verbally acknowledged that they understood all the risks and benefits associated
with the study. Following this, the participants signed and dated the document. Participants could decide not to participate at any time and could also decide not to have their data used for research purposes. All participation in this study was voluntary. If a participant decided not to participate in this study, they still had access to all personal physiological data that was collected regardless of if they decided to complete all training and testing sessions. Ten of eleven participants completed every session. One participant withdrew from the study due to injury that occurred outside of the study.

Study Design

This study used a repeated measures experimental design. All participants completed the standardized pre-testing outlined in the sections below. Following testing, each participant was assigned to either the AR or LR training group based on workload at LT to match group characteristics. All participants performed IT twice per week for four weeks. Following training, participants performed the same standardized tests as those that were done in pre-testing and results were compared. The general timeline of the study is presented in figure 1 below.

![Timeline for participants to complete the study.](image)

Participants were asked not to engage in any lower body resistance training or high intensity aerobic/anaerobic exercise for at least 48 hours before each test. Only participants that
consented to participate in this research study completed testing and training in the HPRL. This study was approved by Western Michigan University’s Human Subjects Institutional Review Board (Appendix C).

**Pre-Training Testing**

*Session 1.* After obtaining written informed consent, participants filled out a demographic questionnaire to confirm inclusion criteria. These criteria included being 18 to 36 years old and being cross-trained (defined as participating in strength training activities at least once per week and interval and/or endurance training at least twice per week for a total of at least 150 minutes per week one year prior to beginning the study). Participants were excluded if they had any musculoskeletal injury that prevented them from biking or squatting. After this information was collected, anthropometric measurements were obtained (height and body mass) using a wall-mounted stadiometer and electronic scale.

Next, participants performed a test to measure LT. Before the test, participants were given a general overview of how the cycle ergometer works as well as all metabolic testing equipment as well as an overview of the protocol. The LT test involved an increasing workload every 4 minutes while riding on an electromagnetically braked cycle ergometer (Lode, Netherlands) until the participant could no longer pedal at the given power of the stage. All participants started pedaling at a workload of 60 Watts for the first 4 minutes. In each 4-minute stage following, the workload was increased by 25W. Therefore, from 0-4 minutes, participants biked at 60W, from 4-8 minutes participants biked at 85W, 8-12 minutes 110W, 12-16 minutes 135W, 16-20 minutes 160W, and so on until the participant failed to continue pedaling or the participant terminated the test, which was deemed the maximum work rate (MWR). During the
last 30 seconds of each 4-minute stage, ratings of perceived exertion (RPE) were assessed using the Borg 15-point scales and blood lactate concentration ([BL]) was measured from a finger prick using a Unistik 3 Lancet, Lactate Scout lactate monitor and Lactate-Scout test strips (Sports Resource Group, Inc., Hawthorne, NY). After every minute, heart rate was measured using a Polar FT1 heart rate monitor (Polar Electro Oy, Finland). Following the test, participants had a 5-minute cooldown period where they were encouraged to walk around the laboratory under the supervision of the researcher. Appendix D gives a visual overview of the protocol.

Session 2. Participants performed three WAnTs during their second session which occurred no less than 48 hours and no more than 96 hours after session 1 at approximately the same time of day. Participants were asked to consume meals similar to those that they ate prior to Session 1. Prior to performing any activity in the HPRL, participants were weighed so that their warm-up and testing weights could be calculated for their body weight on that day. Participants performed a 5-minute warm-up on the Monark cycle ergometer (Monark, Sweden). This warm-up involved light cycling against no resistance for 55 seconds then sprinting against 20% of the test’s resistance for 5 seconds. This was repeated for 40%, 60%, 80%, and 100% of the test weight. The participant then had a 3-minute break where no cycling took place. The resistance for the WAnT was set at 10% of the participant’s body weight. Participants were instructed to reach a maximum pedaling rate of at least 110 rpm, and then to hit the button on the handle of the cycle ergometer to drop the weight at that point. The participant then continued to cycle as fast as possible for 30 seconds, after which the first WAnT (WAnT1) was finished. Capillary blood lactate concentration ([BL]) was measured directly at the end of WAnT1 (T01). Each participant then performed three minutes of AR at a pace of 50-70 rpm with no resistance.
During the last 30 seconds of this 3-minute period (T31), [BL] was measured again to determine the [rΔBL] during the recovery period37.

Each WAnT and the subsequent lactate measurements then took place two more times10. After the third WAnT (WAnT3), the same 3-minute active recovery and lactate measurements took place at T03 and T33. After the T33 measurement, participants passively recovered for an additional 12 minutes by sitting in a chair, after which [BL] was measured again (T15). During each WAnT, peak power (PP), relative peak power (rPP), average power (AP), relative average power (rAP), and fatigue index (FI) were recorded (also labeled by a subscript 1, 2, or 3). The second WAnT (WAnT2) also had [BL] measured at T02 and T32.

Following Session 2, participants were assigned two days that they would come to the lab for training for the next four weeks. Participants were assigned to training groups by the researchers which were determined by matching subjects based on workload at LT to obtain group averages for LT as close as possible between AR and LR. Examples of data sheets and the demographic questionnaire can be found in Appendix D.

Training

Sessions 3-10. During the next four weeks of the study, all study participants performed IT twice per week. Previous research showed that as little as 2 to 4 weeks11,18,32,33,36 of IT twice per week17,32,33 increased aerobic and anaerobic performance variables in trained athletes. Each session was separated by at least 48 hours. Participants were allowed five minutes of self-selected warm-up and four minutes of self-paced biking followed by a 2-minute break before beginning training10. During IT, each participant biked at the workload directly above where the LT test was terminated. This means that if a participant stopped their LT test at a workload of
210W, their training workload would be 235W to ensure lactate accumulation. All training utilized the Lode bike and initially started as a work period of 20 seconds followed by a rest period of 40 seconds\textsuperscript{36}. Participants in the AR group biked at 70\% of the work rate at LT for the 40 second rest period\textsuperscript{7}. Participants in the LR group got off the bike and sat in the bottom of the squat as shown in figure 2 in order to trap the accumulated lactate in the active muscles (mainly quadriceps and hamstrings).

![Figure 2: Blood flow occlusion during the lactate retention method of recovery during training.](image)

The lactate retention method is performed by sitting in the bottom of a squat position to trap lactate in the quadriceps (the primary working muscles while biking). This limits the ability of blood to move out of the quadriceps, potentially leading to the muscles utilizing lactate as a fuel source better than other recovery methods.

This program utilized undulating periodization with the number of intervals increasing during the second week, followed by a decline in intervals during the third week (with an increase in the amount of time working to 30 seconds). The fourth week featured an increase in the number of intervals at the same new work to rest ratio (:30 work/:40 rest). The training program can be seen in table 1. Participants were also engaged in resistance training once per
week and endurance or interval training (cross-training) at least twice per week throughout this study which was not under the control of the researchers. The IT in this study could serve as the two days of interval training stated as a requirement in the inclusionary criteria, but participants could also perform other interval and/or endurance training outside of the training protocol for the study (and all did).

*Table 1*: Training protocol for interval training.

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intervals</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Work</td>
<td>:20</td>
<td>:20</td>
<td>:30</td>
<td>:30</td>
</tr>
<tr>
<td>Rest</td>
<td>:40</td>
<td>:40</td>
<td>:40</td>
<td>:40</td>
</tr>
</tbody>
</table>

**Post-Training Testing**

*Session 11*. Participants had their second LT testing session no less than 48 hours after session 10 at approximately the same time of day. Participants were reminded after session 10 to consume a similar meal as their initial testing. Participants performed the same LT test with the same warm-up and testing procedure as outlined in the pre-testing.

*Session 12*. Participants had their second WAnT testing session no less than 48 hours after session 11 at approximately the same time of day. Participants were reminded after their LT testing session to consume a similar meal as their initial testing. Participants performed 3 WAnTs with the same warm-up and testing procedure as outlined in the pre-testing.

The researchers decided that participants could not miss a training session during training since there were only eight training sessions. Therefore, participants had to complete all eight training sessions and all pre- and post-testing in order to have data included in the final analyses.
Analysis

Calculations

Lactate Threshold. LT was defined as the work rate at which there was an exponential rise in blood lactate concentration (lactate accumulation > lactate removal)\(^9\). LT was determined after completion of the LT test using a two-line regression model also termed the “V-Slope Method”\(^22\). This involves inserting a regression line through all of the data points before the exponential rise occurred (which was approximately around 5 mmol/L for the subjects in this study), and then a second regression line through all of the data points after the exponential rise occurred. The regression equations were set equal to each other and solved for x to determine where the lines crossed. This is where LT occurred.

Rate of Change in Blood Lactate Concentration. \([\Delta \text{BL}]\) was calculated as follows:

- \(
\frac{([\text{Lactate } T_3] - [\text{Lactate } T_0])}{3 \text{ minutes}} \) for all except WAnT\(_3f\)
- \(
\frac{([\text{Lactate } T_{15}] - [\text{Lactate } T_0])}{15 \text{ minutes}} \) for WAnT\(_3f\)

Statistical Analyses

All data were analyzed using IBM SPSS Version 25 (IBM, Armonk, NY). All values are listed as average ± SD. Independent samples t-tests were used to determine if there were group differences between height, body mass, age, cross-training experience, and training intensity before training. 2x2 repeated measures mixed ANOVAs were used to compare the following variables pre- and post-training and between AR and LR training groups: workload at LT, relative VO\(_2\) at LT, heart rate (HR) at LT, \([\Delta \text{BL}]_1\), \([\Delta \text{BL}]_2\), \([\Delta \text{BL}]_3i\), \([\Delta \text{BL}]_3f\), and AP, rAP, PP, rPP, and FI for each WAnT respectively. If sphericity was violated, Greenhouse-Geiser corrections were used to determine p-values. Significance was set a priori at \(p < 0.05\).
RESULTS

Descriptive Data and Group Comparisons Pre-training

Table 2: Participant Descriptives.

<table>
<thead>
<tr>
<th>Variable</th>
<th>All Participants (N= 10)</th>
<th>LR Group (N = 6)</th>
<th>AR Group (N = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>23.3 ± 4.7</td>
<td>24.2 ± 5.1</td>
<td>22.00 ± 4.3</td>
</tr>
<tr>
<td>Cross-training Experience (years)</td>
<td>6.9 ± 3.6</td>
<td>8.0 ± 3.6</td>
<td>5.2 ± 2.5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>166.5 ± 7.1</td>
<td>175.5 ± 6.8</td>
<td>175.6 ± 8.6</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>77.0 ± 12.5</td>
<td>79.7 ± 10.1</td>
<td>72.9 ± 16.2</td>
</tr>
<tr>
<td>Training Intensity (W)</td>
<td>262.5 ± 27.5</td>
<td>264.2 ± 33.2</td>
<td>260.0 ± 20.4</td>
</tr>
</tbody>
</table>

Table 2 shows the characteristics of the two groups and all participants. There were no group differences (p > 0.05) for age, cross-training experience, height, body mass, or training intensity. All values are listed as mean ± SD.
Lactate Threshold

Figure 3: VO₂ at LT. Figure 3 shows the effect of the training protocol on VO₂ at LT in AR and LR groups. Prior to training, LR had a LT of 29.4 ± 6.0 mL/kg/min while AR had a LT of 31.5 ± 5.2 mL/kg/min. Following training, LR had a LT of 30.0 ± 5.1 mL/kg/min while AR had a LT of 32.8 ± 3.4 mL/kg/min. There were no differences in lactate threshold between pre- and post-training or between groups. There also was no interaction between group and pre- and post-training values of LT. All results presented are mean ± standard deviation.
Figure 4: Power Output at LT. Figure 4 shows the effect of the training protocol on power output at LT in AR and LR groups. Prior to training, LR had a LT of 155 ± 45.6 W while AR had a LT of 157 ± 22.7 W. Following training, LR had a LT of 166 ± 32.4 W while AR had a LT of 157 ± 15.8 W. There were no differences in lactate threshold between pre- and post-training or between groups. There also was no interaction between group and pre- and post-training values of LT. All results presented are mean ± standard deviation.
Figure 5: Heart Rate at LT. Figure 5 shows the effect of the training protocol on heart rate at LT in AR and LR groups. Prior to training, LR had a LT of 157 ± 18.3 bpm while AR had a LT of 147 ± 17.3 bpm. Following training, LR had a LT of 166 ± 3.6 bpm while AR had a LT of 153 ± 13.5 bpm. There were no differences in lactate threshold between pre- and post-training or between groups. There also was no interaction between group and pre- and post-training values of LT. All results presented are mean ± standard deviation.
Figure 6: Peak power during the repeated WAnTs. Figure 6 shows peak power across all three WAnTs for LR and AR both pre- and post-training. There was a within-subjects effect of time for PP (p = 0.025) as PP decreased from WAnT1 to WAnT2 to WAnT3 for LR Pre (1017 ± 194, 991 ± 172, 842 ± 380), LR Post (985 ± 181, 938 ± 180, 846 ± 127), AR Pre (805 ± 238, 805 ± 299, 736 ± 265), and AR Post (775 ± 217, 763 ± 285, 712 ± 266). There were no other significant differences or interactions between time, pre- and post-training, and group. All results presented are mean ± standard deviation.
Figure 7: Relative peak power during the repeated WAnTs. Figure 7 shows relative peak power across all three WAnTs for LR and AR both pre- and post-training. There was a within-subjects effect of time for rPP (p = 0.043) as rPP decreased from WAnT1 to WAnT2 to WAnT3 for LR Pre (12.7 ± 1.5, 12.4 ± 1.1, 10.2 ± 4.31), LR Post (12.4 ± 1.6, 11.8 ± 1.3, 10.7 ± 1.2), AR Pre (11.0 ± 1.6, 10.8 ± 1.8, 9.9 ± 1.4), and AR Post (10.5 ± 1.6, 10.2 ± 1.8, 9.5 ± 1.7). There were no other significant differences or interactions between time, pre- and post-training, and group. All results presented are mean ± standard deviation.
**Figure 8: Average power during the repeated WAnTs.** Figure 8 shows average power across all three WAnTs for LR and AR both pre- and post-training. There was a within-subjects effect of time for AP (p = 0.010) as AP decreased from WAnT₁ to WAnT₂ to WAnT₃ for LR Pre (678 ± 141, 637 ± 124, 543 ± 240), LR Post (692 ± 108, 647 ± 93, 580 ± 80), AR Pre (598 ± 125, 580 ± 169, 537 ± 163), and AR Post (592 ± 134, 542 ± 140, 517 ± 118). There were no other significant differences or interactions between time, pre- and post-training, and group. All results presented are mean ± standard deviation.
Figure 9: Relative average power during the repeated WAnTs. Figure 9 shows relative average power across all three WAnTs for LR and AR both pre- and post-training. There was a within-subjects effect of time for rAP ($p = 0.021$) as rAP decreased from WAnT1 to WAnT2 to WAnT3 for LR Pre (8.4 ± 1.2, 7.9 ± 0.9, 6.6 ± 2.7), LR Post (8.7 ± 1.0, 8.2 ± 0.5, 7.3 ± 0.5), AR Pre (8.3 ± 1.0, 7.9 ± 0.8, 7.3 ± 0.60), and AR Post (8.1 ± 1.2, 7.4 ± 0.5, 7.0 ± 0.2). There were no other significant differences or interactions between time, pre- and post-training, and group. All results presented are mean ± standard deviation.
Figure 10: Fatigue index during the repeated WAnTs. Figure 10 shows fatigue index across all three WAnTs for LR and AR both pre- and post-training. There was a group effect for FI (p = 0.043) as FI was higher in LR than AR for WAnT1, WAnT2, and WAnT3 for LR Pre (74.7 ± 13.1, 73.2 ± 6.6, 77.9 ± 12.8) vs. AR Pre (52.8 ± 14.5, 52.7 ± 13.4, 55.3 ± 11.3), and LR Post (64.2 ± 12.2, 65.7 ± 12.1, 69.5 ± 11.1) versus AR Post (52.7 ± 12.5, 54.0 ± 16.2, 55.2 ± 19.47). There were no other significant differences or interactions between time, pre- and post-training, and group. All results presented are mean ± standard deviation.
Rate of Change in Blood Lactate Concentration

Table 3. [rΔBL] – LR vs. AR.

<table>
<thead>
<tr>
<th>Variable</th>
<th>LR Pre</th>
<th>LR Post</th>
<th>AR Pre</th>
<th>AR Post</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAnT1 [rΔBL] (mmol/L/min)</td>
<td>0.32 ± 0.87</td>
<td>0.91 ± 0.52</td>
<td>0.78 ± 0.76</td>
<td>1.42 ± 0.40</td>
</tr>
<tr>
<td>WAnT2 [rΔBL] (mmol/L/min)</td>
<td>-0.03 ± 1.36</td>
<td>1.04 ± 0.44</td>
<td>0.57 ± 1.26</td>
<td>0.60 ± 0.84</td>
</tr>
<tr>
<td>WAnT3i [rΔBL] (mmol/L/min)</td>
<td>-0.58 ± 0.71</td>
<td>-0.68 ± 1.25</td>
<td>-0.68 ± 1.65</td>
<td>0.27 ± 1.03</td>
</tr>
<tr>
<td>WAnT3f [rΔBL] (mmol/L/min)</td>
<td>-0.30 ± 0.07</td>
<td>-0.48 ± 0.49</td>
<td>-0.39 ± 0.35</td>
<td>-0.22 ± 0.21</td>
</tr>
</tbody>
</table>

Table 3 shows the rate of change in blood lactate 3 minutes after each WAnT as well as 15 minutes after the final WAnT (WAnT3f) before and after training in both groups. There was a significant effect of time (p = 0.002) for [rΔBL] following each subsequent WAnT. As time went on, participants metabolized lactate faster. There was also a trend of significant effect for pre- to post-training on [rΔBL]. There were no other effects or interactions of time, training, or group. All results presented are mean ± standard deviation.
DISCUSSION

Study Summary

While there was a limited number of participants, the main finding of this study was that there was not a significant difference in adaptation to a 4-week IT protocol between AR and LR groups.

Lactate Threshold

Lactate is a naturally occurring product of both glycolysis and is removed through oxidative metabolisms. For this reason, lactate is a very important substrate for both anabolic and catabolic reactions, as it is a link between two energy systems. The intention of the LR bike interval training protocol used in this study was to trap lactate in the lower body through active muscular contraction of the quads and glutes. This would occur by an increase in intramuscular pressure (IMP) \(^2\). LR involves a sustained isometric contraction (maintaining a squat position) which should increase IMP and therefore decrease muscle blood flow (MBF) which has been shown to have a negative correlation with IMP\(^2\). If this contraction is large enough to occlude blood flow, over a chronic training period, the lactate shuttle could increase lactate’s flux rate to increase oxidative metabolism of lactate\(^5\). If this happened, the lactate threshold of the subjects in the LR group would have significantly increased.

A recent study\(^2\) examined the effect of sustained isometric dorsiflexion contractions at varying intensities on MBF and found that blood flow is not linearly graded with contraction intensity but rather changes throughout the muscular contraction. They looked at 3 different contraction intensities and all had similar results. This evidence contends that a long duration
isometric contraction may have too much variability in IMP and MBF to occlude blood consistently. Participants in the current study were only instructed to “hold” a squat position during their rest period. In addition, past research has also shown that a minimum of 60% of limb occlusion pressure is required to fatigue the muscle and decrease tissue oxygenation\textsuperscript{14}. Another study found that certain parts of the quadriceps muscle obtain different levels of IMP and can vary from person to person\textsuperscript{28}. Differing IMPs could cause different amounts of blood lactate to be trapped for individuals causing a different training response and the results seen in this data set. The current study sought to make this protocol generalizable to a team setting where expensive blood flow restriction equipment is often unavailable for an entire team utilize during a training session. When looking at just the mean power generated at LT, the LR group increased this value by 11.1 W (a 6.67% increase) while the AR group decreased by 0.7 W (a 0.4% decrease).

The results presented here do not mean that this should be dismissed as a viable training technique. The AR group was treated somewhat as a control group to LR since there are many studies that have concluded that IT done with AR is an effective means to increase LT and fitness as a whole.\textsuperscript{18,27,30,36} Neither training protocol was seen to have a significant effect of LT or most other variables. This could mean that the training intensity was not high enough to produce results over 4 weeks. Future studies should measure the amount of blood flow occluded during a maximal isometric contraction of the quadriceps, hamstrings, and glutei during a body weight squat. This could help determine if a high enough IMP can be achieved to trap blood lactate in the upper leg and drive conversion to pyruvate. If this cannot be achieved, this pressure may have to be regulated closer and even increased above the level that an individual can achieve actively to get the results hypothesized. In addition, both LR and AR are typically part of
a much larger training program that is overseen by a strength and conditioning professional. Within this program, strength, endurance, and power would all be controlled and periodized to complement the goal of the training cycle and work towards preparing an athlete for their season. This could help with preparing an athlete to perform LR by increasing mitochondrial size and efficiency as well as general strength qualities. This in turn would help athletes produce more power during the testing and training as well as drive the conversion of lactate to pyruvate that can be used in aerobic metabolism. An optimal training program that incorporates LR will be included later in the discussion.

**Power**

During the repeated WAnTs, the relative and absolute peak and average power were gathered. During both pre and post-testing, there was a time effect for all of the variables mentioned above. As can be seen in figures 6-10 in the results section (all of which show a time effect), PP, rPP, AP, and rAP all declined during subsequent bouts of exercise (WAnTs). This was expected since individuals were told to cycle as fast as they could for the 30 seconds of each test, which would (and did) result in fatigue.

Interestingly, a group effect for fatigue index was also found between LR and AR. Fatigue index is calculated using the following procedure: (peak power – minimum power)/peak power x 100%. This shows that the LR group had a greater difference between their peak and minimum power, showing that they were unable to maintain a high power output for long. Interestingly, this difference did decrease after training showing that the LR group was able to maintain a higher power output for longer or that they did not reach as high of a power output.
Based on PP data, the latter was not a contributing factor, so minimum power was higher than before training, just not to a significant level.

If an effect of training type was seen on these variables, average power would have decreased less over each subsequent WAnT. In addition, FI would have increased less due to an ability to maintain a higher power output. This would have occurred because the muscles would be better trained to metabolize lactate for energy and NAD+ would pick up its extra hydrogen in this oxidation/reduction reaction that can occur in several places within/around the mitochondrial membrane. Excess hydrogen ions would also be buffered more efficiently by the bicarbonate buffer system, decreasing muscle acidosis and fatigue.

Peak power likely would not have been affected by this specific training protocol because subjects did not train anywhere near an intensity close to their peak power. Future studies that also train other aspects of the power curve, especially through the utilization of high-power output lower body/full body movements could improve PP. These movements could include the Olympic lifts, jumping variations, and very short bike sprints (such as a protocol by Tanisho & Hirakawa31) targeting the phosphagen energy system. In addition, a peaking/supercompensation phase should be implemented to ensure the participants have gained maximal adaptations from the training program. This could be as simple as a reduction in intensity and volume for one week before testing.

**Rate of Change in Blood Lactate Concentration**

Blood lactate metabolism ([rΔBL]) was a variable that showed a trend of significance for a training effect in all participants. Since IT creates an excess amount of lactate due to the high rate of glycolysis23,35,37, the body will have the option to use lactate to fuel oxidative metabolism
during recovery and in the process reduce excess hydrogen ions in the blood. When these conditions are created, Mitochondrial MCT1 (a lactate/pyruvate transporter) is bound to a chaperone protein CD147 and works in conjunction with lactate dehydrogenase (LDH) and cytochrome oxidase to form a mitochondrial lactate oxidation complex. If efficiency of this complex improves then arterial lactate concentration will decrease quicker, as will the acidity of the bloods. This allows for more lactate to be metabolized for future energy use as acetyl-CoA or glucose (the latter via gluconeogenesis).

Chronic IT/high intensity exercise that causes lactate buildup can increase expression of sarcolemmal MCT1 and mitochondrial proteins, including the lactate oxidation complex, to improve lactate metabolism during exercises. When training in this type of environment for a prolonged period of time (such as a mesocycle or macrocycle of training) performance adaptations such as increased LT and aerobic performance should result. The blood lactate response shown here is promising; this physiological result in combination with all of the other performance results can allow for a few different conclusions. The first that comes to mind is that physiological adaptations to this type of training may precede others. Even if lactate is converted to acetyl CoA or glucose quickly, glycolysis or oxidative metabolism still have to have time to generate energy. In addition, improvement in lactate metabolism is not the only factor that affects performance in a TTE or repeated WAnT test. Strength, power, and muscular endurance also play into these tests significantly. For this reason, this type of training should be done in complement with other types of training to maximize performance.

Another important finding from this study is that there was a significant effect of time (p = 0.002) for [rΔBL] following each subsequent WAnT. This means that as time went on, the rate of lactate clearance was faster (see table 3). Lactate concentration did increase after each WAnT
as well so this does leave more lactate to metabolize. When lactate exceeds cytosolic pyruvate concentration, it becomes the predominant monocarboxylate oxidized by mitochondria, therefore, an increased rate of metabolism is what should happen. If muscle biopsies would have been taken on the participants, it could have allowed insight into the fiber-type distribution of their muscles (likely taking a sample from the vastus lateralis). If some subjects had an increased number of type-I fibers or more developed type-I fibers, they could adapt faster to utilize lactate due to the lactate shuttle from type-II glycolytic muscle cells to type-I oxidative muscle cells.

**Psychological Factors**

In this study, no data was collected on how participants mentally approached training and testing. The following commentary is not based off of any statistics but was notable feedback that I received from participants throughout the study. For the majority of participants, this was their first time doing a LT test or repeated WAnTs. Following LT testing (which ended when participants could not cycle anymore) participants were extremely fatigued and everyone commented on how their legs were “dead”. In addition, after the repeated WAnTs some people could barely walk and felt sick after the first trial, and one subject vomited after the test. Some of the participants reported that they were not looking forward to post-testing and just wanted to get through it. Having knowledge of how these tests would feel could have caused some participants not to give maximal effort during post-testing even with verbal encouragement from the researcher. In addition, all participants knew which stage that they reached in their initial LT test. This could have motivated some participants to beat the number of stages they got through in their pre-test during their post-training testing. For this reason, future studies should try to blind participants how far they progressed in the protocol by not revealing their results until all testing
was done. This could be difficult because even without visual evidence of where a participant is in the test, it is relatively easy to tell when resistance is added during the LT test, allowing participants to track which stage they are in (as would the finger pricks and RPE measurements). Having individuals on each end of this spectrum (trying to beat a previous best versus just getting through the test) could add variability to the data set, especially with this small subject number.

Future studies should have participants fill out a questionnaire after each testing session to collect data on attentional focus, anticipation of doing the test, and their thought process on getting through the test versus beating their pre-testing values. Past studies on attentional focus during exercise with an unknown endpoint (such as the initial LT test) have shown that attentional focus is higher in conditions with known endpoints. Since individuals had better knowledge of an endpoint during the second LT test, their attentional focus likely was higher. This could have helped some individuals go further in the test and improve their LT. Collecting the aforementioned data could allow for another way to group participants and potentially determine if mental processes can affect training responses.

Case study

There were a few variables within this study that would be beneficial to closely monitor more than what the current study did. The main factor that could have contributed to variability in the results obtained when sample size is disregarded is training outside of the study. All participants in this study performed interval training twice a week and strength trained at least once per week throughout this study. Based on dialogue with the participants, a mixture of strength, interval, and endurance training was performed outside of the lab, typically 4-6 days
per week for the subjects. Since none of this was controlled, and it was the majority of the training that participants were doing, this probably impacted the results. In addition, very few of these individuals were following the same type of program and were training for a variety of goals.

There were two interesting participants within the LR group. One (LR A) had cross-trained for 7 years and competed in CrossFit®-style competitions. The other (LR B) had cross-trained for 15 years and played hockey at an elite (juniors, college, and professional) level for 18 years. In addition to being very well trained, these two participants had done LR before and were doing a very similar style of training to each other at the time that had a “triphasic” approach. This approach targets eccentric, isometric, and concentric movements in different blocks and also has the goal to improve complimentary energy systems such as the glycolytic system simultaneously. This qualitative data may suggest that complementary resistance exercise and pre-exposure to this type of training (or a longer training block) may be needed to improve LT and power.

The raw data for these two participants shows several trends that follow what was hypothesized to happen following LR. All LT, AP, and rAP values improved as hypothesized for both subjects. In addition, the majority of FI values were lower (less fatigue) following training. Most PP and rPP values did not improve after training for both participants likely due to specificity of training. It is interesting to note that PP and rPP was higher on the final WAnT following training suggesting that these participants were better able to maintain higher power outputs after training. Also intriguing is the contrast between [rΔBL] improving for LR A while not improving for LR B while mechanical efficiency (ME) improved for LR B but not LR
A. Although not mentioned in the methods section, ME data was collected and analyzed during this test. The procedure for ME data collection is given in appendix E.

These results could show that different individuals may physiologically adapt to training differently while still improving their own performance. To help explain this, it is important to examine the following equation to calculate ME:

1. Mechanical Efficiency = Work Output / Work Input x 100%
2. Work Output = workload (W) of exercise
3. Work Input = Absolute VO\(_2\) (L/min) x caloric equivalent of average RER for last 2:00 of stage x 4184 J/kcal x (1 minute/60 seconds)

These equations show that ME can improve by having a higher work output, and/or by having a lower absolute VO\(_2\) or lower RER (lower corresponding caloric equivalent). ME should increase in almost every stage due to an increase in power output in each stage, which was shown by the time effect for this variable mentioned above. However, since the same workloads were repeated in post-testing, work output is not a factor in explaining the changes in ME within subjects. Also, in LR B, absolute VO\(_2\) only increased by 0.08 L/min at LT. Thus, absolute VO\(_2\) is also not a major factor for the improvements seen in LR B. This leaves only a lower RER (and its caloric equivalent) as a factor that impacted LR B’s ME improving.

A lower RER corresponds to an increased percentage of fats being burned to fuel exercise\(^{20,26,34}\). This data for LR B shows that during his LT test, his performance was likely improved due in part to a higher percentage of fats being metabolized throughout. This is beneficial for two reasons; first, there is only a limited store of carbohydrates in the body. Humans only store 300-700 grams (1200-2800 kilocalories) of carbohydrates in the body which varies by body size\(^{24}\) compared to 30,000 kcal of fat in lean (7-14% body fat) individuals\(^{34}\).
During prolonged exercise (e.g. a marathon, ironman, and ultra-endurance events), athletes would be able to work at higher power outputs while burning more fats and fewer carbohydrates. This would delay the onset of fatigue associated with carbohydrate depletion. Burning more fats for fuel also has the benefit of lowering H+ concentrations in the blood, decreasing fatigue related to muscle acidosis. This also increases the availability of enzymes necessary for other metabolic processes in the body that could be inhibited by acidic conditions.

When [rΔBL] is examined closer, it is interesting to see that LR A improved rate of blood lactate metabolism in the majority of time points while LR B did not (opposite of ME). This could mean that instead of improving ME to improve performance, LR A may have adapted to LR by becoming more efficient at shuttling lactate and using it for fuel. This could also be a reason why LR A’s ME could go down since LR A would be utilizing more carbohydrates, raising the RER.

When examining the physiological variables of interest (ME and [rΔBL]) the above evidence supports that different athletes may adapt to a training protocol differently and still improve performance. If information like ME and [rΔBL] is known, different training protocols could be developed to improve performance in different ways. First, if an athlete is screened as improving performance following training due to having better [rΔBL], this could prompt a strength and conditioning professional to prescribe them more intense interval training with LR to have more lactate accumulate. This may improve performance to a point, but eventually, ME would likely need to be addressed with a greater number of lower intensity intervals or even long duration endurance training without LR. These two approaches could also work for someone who has better ME initially. This athlete may be given more lower intensity intervals and/or long duration endurance training. Again, this athlete may respond well to this type of training for a
while but likely changing to higher intensity intervals with LR to address this shortcoming that an athlete may have.

**Practical Applications**

Given the variability in the data, it is important to examine characteristics of participants who responded well such as LR A and LR B until more data can be collected on this method of training. LR A and LR B were both performing cross-training that was complementary to this protocol outside of visits to the lab. This demonstrates that LR might have to be used within an exercise program that directly supports the goals of LR (such as improved LT and maintenance of a higher power output).

To give readers an idea of what this may look like, a 16-week training design has been included that details ideas on how to utilize LR within a training program.
This table shows an example of a 16-week training program that incorporates LR and is similar to what LR A and LR B were doing for training outside of the study.

Table 4: 16-week training design.
Limitations

Sample size was a limitation in this study. Originally, this study was targeting elite hockey players as the sample population, with the goal of testing 24 participants. However, due to scheduling conflicts that would have caused inconsistencies in training, this population was redefined to include cross-trained individuals. Even with the broadening of the sample population available, the main barrier to participation in this study was having individuals complete two extra workouts per week. These workouts had to occur in the HPRL, outside of the gym that they already go to.

All of the measures taken in this study can be altered by nutrition, stress, previous workouts, and more which can change the effects of what was measured. Participants were asked to not participate in lower body or endurance/interval exercise 48 hours before testing and to also consume a similar meal. This may have been too small of a time window of time because some studies have shown that muscle fatigue can impact performance for up to 24-72 hours. This can vary even more when nutrition habits, sleep, alcohol consumption, and other stressors are not ideal. The researcher asked about these variables before testing (and prior training) and moved post-testing sessions accordingly. However, not all of these variables could be controlled and could have played a role in the results obtained.

Muscle blood flow was also not controlled in this study and could have varied between subjects. Future studies on this training should use doppler ultrasound to monitor blood flow through the quads during LR to see if there is differential MBF. In addition, future studies could also use aneroid sphygmomanometers and other blood flow restriction equipment to more closely control MBF. If this is performed, limb occlusion pressure of the quad during an isometric bodyweight squat should be examined. From there, a protocol could be established to
manage MBF and remove variability. If this equipment is not available but a near infrared spectroscopy device that can monitor tissue oxygenation is, this could be a valuable measurement tool to see if tissue oxygenation decreases significantly during a maximal isometric contraction. All of these measurements are important because under these conditions is when the lactate shuttle would work the most and drive creation of pyruvate and NADH.

**Conclusion**

With the limited subject number and high variance in the data (both within and between groups), there were no key findings of statistical significance showing merit to LR training. Only \( r\Delta BL \) showed a trend of significant effect of training with no significant effect of group to make a distinction that AR is better than LR or vice versa. Looking at raw data for a few of the subjects that were training within the suggested design given, there is promise that LR can improve performance. Future studies should increase sample size and try to control outside training variables more closely. This could be accomplished by testing a team that is undergoing the same training before and after the LR block of training. Although there is overlap with other energy systems being trained and stress on the nervous system that could still affect results, these factors could be better controlled when the participant is only performing the training program given.
REFERENCES


For more information, contact Tyler Dundore:

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Total of 7 hours

Total of at least 72 laboratory visits over 6 weeks.

Participation involves 12 laboratory visits over 6 months.

The study must also be injury-free for the past 6 months.

Endurance training at least twice per week.

Activities at least once per week and interval and/or

To be eligible, you must participate in strength training.

Structured time to interval train for 4 weeks of the study.

To maximize your performance:

Determine what your lactate threshold is and how to use it.

Research study looking for participants.

Attention fitness enthusiasts!
Appendix B: Informed Consent

Principal Investigator: Nicholas J. Hanson
Student Investigator: Tyler Dundore, Rachel Dykstra, Collin Garner
Co-Investigators: Michael Miller, Timothy Michael

Title of Study: The Effect of 4 Weeks of Bike Interval Training Using the Lactate Retention Method on Lactate Threshold and Repeated Sprint Performance

STUDY SUMMARY: This consent form is part of an informed consent process for a research study and it will provide information that will help you decide whether you want to take part in this study. Participation in this study is completely voluntary. The purpose of this research is to determine if the lactate retention method can increase lactate threshold and repeated sprint performance following interval training more than active recovery. This research project will serve as Tyler Dundore’s thesis for the requirements of the Master of Science in Exercise Physiology at Western Michigan University. If you take part in this research, you will be asked to do two separate lactate threshold tests, two separate repeated Wingate tests, and 4 weeks of bike interval training. Your time in the study will take approximately 12 hours over 6 weeks. Possible risks and costs to you for taking part in this study may be muscular discomfort, dehydration, and musculoskeletal injuries (none of which are greater than participating in normal exercise) as well as discomfort from finger prints. Potential benefits may be increased aerobic and anaerobic fitness and increased physical and emotional health. An alternative to taking part in this research study is to not participate in it.

You are invited to participate in this research project titled “The Effect of 4 Weeks of Bike Interval Training Using the Lactate Retention Method on Lactate Threshold and Repeated Sprint Performance” and the following information in this consent form will provide more detail about the research study. Please ask any questions if you need more clarification and to assist you in deciding if you wish to participate in the research study. You are not giving up any of your legal rights by agreeing to take part in this research or by signing this consent form. After all of your questions have been answered and the consent document reviewed, if you decide to participate in this study, you will be asked to sign this consent form.

What are we trying to find out in this study?
The main purpose of this study is to determine if the lactate retention method can increase lactate threshold and repeated sprint performance following interval training more than active recovery.

Who can participate in this study?
Twenty-four adults between the ages of 18 and 36 will be recruited to participate in this study. In addition, you must be a resistance and interval and/or endurance trained individual (defined as participating in strength training activities at least once per week and interval and/or endurance training at least twice per week for a total of at least 150 minutes per week one year prior to beginning the study).
You will be excluded if you have any musculoskeletal injury that prevents you from biking or squatting, or any history of cardiopulmonary contraindications or have sustained any of these injuries within the past 6 months.

**Where will this study take place?**
Data collection will take place in the Human Performance Research Laboratory (HPRL) located on the first floor of Western Michigan University’s student recreation center (SRC).

**What is the time commitment for participating in this study?**
Your time in the study will take a maximum of 7 hours total over 6 weeks. This is broken down to 1.5 hours for the first session, 1 hour for the second session, 20 minutes for sessions 3-10, 1 hour for session 11 and 1 hour for session 12.

**What will you be asked to do if you choose to participate in this study?**

**Pre-Training Sessions (2 visits for all participants):**

*Session 1.* During session one, you will be asked to complete the informed consent and we will verify that you meet all requirements to participate in this study. If you are able to participate, you will be taken through an overview of the lactate threshold (LT) and mechanical efficiency test including the protocol and all equipment being used. You will then be put through a warm-up and start the LT test which involves cycling for 4-minute stages with the workload increasing by 25 Watts (starting from 60W) until failure after each 4-minute stage. Blood samples will be collected via a finger prick at the end of each stage to get a drop of blood on a strip that can read the amount of lactate in your blood. There is a video available for you to watch this process if you would like to. Breath samples will also be collected to determine your mechanical efficiency. This will be done using a two-way non-rebreathing valve and metabolic cart. The two-way non-rebreathing valve allows you to inhale room air through a one-way valve and exhale freely through another one-way valve so the air expired can exit into the metabolic cart. Following a cooldown period after this test, you will perform a familiarization test for the Wingate Anaerobic Sprint Test (Wingate or WAnT).

*Session 2.* During session 2 you will perform a warm-up followed by three repeated Wingates. This is a 30 second sprint on a cycle ergometer against a resistance based off of your body weight (10% of body weight) to measure anaerobic power output and fatigue. Blood samples will also be taken directly after subjects stop cycling and again 30 seconds before the next Wingate (3 minutes after the last Wingate) as well as 15 minutes after the subject’s third Wingate using a finger prick. These tests will be repeated following 4 weeks of interval training.

After session 2, you will be assigned to either the active recovery or lactate retention method training group and schedule times to come in for training.
Training Sessions (4 weeks, sessions 3-10):
You will go through 4 weeks of interval training at the intensity/workload above which you stopped pedaling at during the LT test (done during the work period). Training will take place twice per week separated by at least 48 hours. These training sessions will be approximately 20 minutes long. Over the four weeks, your training will progress from 20 seconds of work with 40 seconds of rest to 30 seconds of work with 40 seconds of rest. The progression of your training is shown in the table below.

<table>
<thead>
<tr>
<th></th>
<th>Week 1</th>
<th>Week 2</th>
<th>Week 3</th>
<th>Week 4</th>
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<td>Rest</td>
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Active recovery group: During the rest period of interval training, you will pedal at 70% of the workload of your lactate threshold.

Lactate retention method group: During the rest period of interval training you will sit in the bottom of a squat and be instructed not to move until getting back on the bike.

Post-Training Sessions (2 visits for all participants)
Post-testing will include 2 visits to the lab to repeat both the LT and repeated Wingate tests described during the pre-training section.

What information is being measured during the study?
Pre- and Post-testing:
During session 1 and 11 we will measure your lactate threshold and mechanical efficiency. Lactate threshold is measured by taking measurements of blood lactate concentration during the graded LT test described above. LT is the point during exercise when the rate of lactate removal is less than the rate of lactate build-up. Mechanical efficiency will be calculated from the amount of oxygen you inhale, and the amount of carbon dioxide exhaled. Your heart rate will also be measured every minute throughout the LT test.

During session 2 and 12, your relative average power, relative maximum power, and fatigue index will be measured from your performance during the Wingate cycle test. In addition, rate of decline in blood lactate will be measured between each Wingate by taking samples of blood lactate concentration.

What are the risks of participating in this study and how will these risks be minimized?
As in all research, there may be unforeseen risks to the subject. If an accidental injury does occur, appropriate emergency measures will be taken; however, no compensation or additional treatment will be made available to you except otherwise stated in this consent form. The risks in this study are considered minimal. These include musculoskeletal injuries, general muscle soreness and discomfort, and dehydration. We will provide individuals with water if needed. A proper warm-up and cool down will be implemented to reduce the risk of musculoskeletal injury and soreness. The lactate retention method could involve muscular discomfort in the quads and
glutes while holding a sustained squat which is not different than other muscular discomforts experienced in typical interval training. The only foreseeable risks in this study are with measuring blood lactate concentration. There is possibility of discomfort from finger pricks required for measurements. Ice will be provided if needed to help with any pain experienced. In addition, there is risk of exposure to blood borne pathogens. Exposure will be limited by handling all biohazard materials with nitrile gloves and disposing of all materials in contact with blood into a biohazard waste disposal bin. Before any samples are taken, the finger being pricked will be cleaned with alcohol. Following measurement, gauze will be applied to stop any bleeding.

What are the benefits of participating in this study?
You may receive health and performance benefits from participating in this program. A plethora of research studies have concluded that exercise provides a wide range of benefits to an individual’s physical and emotional health and longevity. This study will teach you a new form of exercise/training that could increase your anaerobic and aerobic fitness. This may allow you to be more functional in your activities of daily living and increase performance in physical activities that you participate in. This study will provide you a structured time to exercise twice per week, possibly benefitting both emotional and physical health. Lastly, you will receive an exercise program tailored custom to your physiologic training needs which should maximize benefits of exercise and minimize risk of injury.

Are there any costs associated with participating in this study?
There are no costs associated with this study besides the time required to participate. Free parking is available off campus and is a 5- to 10-minute walk away from the HPRL.

Is there any compensation for participating in this study?
No compensation will be provided for participating in this study.

Who will have access to the information collected during this study?
During the study, only the student investigator and faculty mentor will have access to information collected. All personal data will be kept locked up separate from any data sheets (which will not have your name on them). All data will be stored in the principal investigator’s office in the department of HPHE for three years. The results of this study will be published in a peer reviewed journal and potentially presented at a conference. Your identity will be kept confidential in both of these mediums of communication as the data from your results will be compiled as an average with everyone else in your training group and compared to the other group. Your name and personal information will not be mentioned at any time.

What will happen to my information or biospecimens collected for this research after the study is over?
All biospecimens collected will be discarded in a biohazard removal bin following analysis with the lactate monitor. Biospecimens and/or data collected about participants for this research will not be used by or distributed to investigators for other research.
What if you want to stop participating in this study?

You can choose to stop participating in the study at any time for any reason. You will not suffer any prejudice or penalty by your decision to stop your participation. You will experience NO consequences either academically, athletically, or personally if you choose to withdraw from this study.

The investigator can also decide to stop your participation in the study without your consent.

As in all research, there may be unforeseen risks to the participant. If an accidental injury occurs, appropriate emergency measures will be taken; however, no compensation or additional treatment will be made available to you except as otherwise stated in this consent form.

Should you have any questions prior to or during the study, you can contact the student investigator, Tyler Dundore by email at tyler.m.dundore@wmich.edu or the primary investigator, Nicholas Hanson at nicholas.hanson@wmich.edu. You may also contact the Chair, Institutional Review Board at 269-387-8293 or the Vice President for Research at 269-387-8298 if questions arise during the course of the study.

This consent document has been approved for use for one year by the Western Michigan University Institutional Review Board (WMU IRB) as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is older than one year.

I have read this informed consent document. The risks and benefits have been explained to me. I agree to take part in this study.

Please Print Your Name

Participant’s signature ___________________ Date ___________________
Date: August 16, 2019

To: Nicholas Hanson, Principal Investigator
    Tyler Dundore, Student Investigator for thesis
    Rachel Dykstra, Student Investigator
    Michael Miller, Co-Principal Investigator
    Timothy Michael, Co-Principal Investigator

From: Amy Naugle, Ph.D., Chair

Re: IRB Project Number 19-05-04

This letter will serve as confirmation that the changes to your research project titled “The Effect of 4 Weeks of Bike Interval Training Using the Lactate Retention Method on Lactate Threshold and Repeated Sprint Performance” requested in your memo received August 16, 2019 (to add student investigator Collin Garner) has been approved by the WMU Institutional Review Board.

The conditions and the duration of this approval are specified in the Policies of Western Michigan University.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the IRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: July 2, 2020
## Appendix D: Data Sheets and Demographic Questionnaire

Subject Number: ____________  Training Group: LR or AR  Sex: ______
Date of Birth: ______  Height: _____ cm  Mass: _____ kg

Training History: Is the subject a resistance and interval and/or endurance trained individual (defined as participating in strength training activities at least once per week and interval and/or endurance training at least twice per week for a total of at least 150 minutes per week one year prior to beginning the study)?  Yes / No  Approximate number of years: ______

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<thead>
<tr>
<th>Pre-Training Results:</th>
<th>Post-Training Results:</th>
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<tr>
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Training Intensity: _______ W  
Active Recovery Intensity: _______ W
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### Wingate Data Sheet (Pre-Training)

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<th>Relative Average Power (Watts)</th>
<th>Fatigue Index (%)</th>
<th>Lactate Concentration T0</th>
<th>Lactate Concentration T3</th>
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<th>Resistance (kg) 10% BM</th>
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<th>HR (bpm)</th>
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### Wingate Data Sheet (Post-Training)

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<th>Wingate</th>
<th>Relative Max Power (Watts)</th>
<th>Relative Average Power (Watts)</th>
<th>Fatigue Index (%)</th>
<th>Lactate Concentration T0</th>
<th>Lactate Concentration T3</th>
<th>Lactate Concentration T15</th>
<th>Resistance (kg) 10% BM</th>
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Appendix E: Mechanical Efficiency Procedure

Gas exchange was collected using a two-way non-rebreathing valve (Hans Rudolf, Shawnee, KS) and a Parvo Medics TrueOne 2400 metabolic measurement system (Sandy, UT). This data was used to calculate ME. A 3L syringe (Hans Rudolf, Shawnee, KS) was used to calibrate the metabolic cart before each test. During the last two minutes of each stage (2:00-4:00 of a stage when the subject reached steady state), \( \text{VO}_2 \) (L/min), \( \text{VO}_2 \) (mL/kg/min), and respiratory exchange ratio (RER) were measured every 15 seconds. This data was used in conjunction with workload and a caloric equivalent conversion table to measure gross energy output, gross energy input, and ME of cycling at each workload as calculated below.

1. Mechanical Efficiency = Work Output / Work Input x 100%

2. Work Output = workload (W) of exercise

3. Work Input = Absolute \( \text{VO}_2 \) (L/min) x caloric equivalent of average RER for last 2:00 of stage x 4184 J/kcal x (1 minute/60 seconds)