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# Cardiorespiratory and Metabolic Responses to Hexagonal Barbell Deadlift Task Performed at an Intensity Corresponding to the Anaerobic Threshold

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**Cardiorespiratory and Metabolic Responses to Hexagonal Barbell Deadlift  
Task Performed at an Intensity Corresponding to the Anaerobic Threshold**

by

**Christopher C. Frankel**

Degrees

B.A. Sociology

Hiram College

1994

M.S. Exercise Science

University of New Mexico

2001

DISSERTATION

Submitted in Partial Fulfillment of the  
Requirements for the Degree of

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**Physical Education, Sports, and Exercise Science**

The University of New Mexico

Albuquerque, New Mexico

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## **DEDICATION**

This is dedicated to the memory of my parents, Raquel and Hy Frankel, who unfortunately were not able to share in many of my personal successes and I am sure were worried I would continue to make poor choices. Your love, support, and examples created a foundation I was finally able to use to help build amazing family. I think you would be happy and proud now.

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University of New Mexico. 2020

**ABSTRACT**

The objectives of this study were to identify the lactate threshold (LT) and the first ventilatory threshold (VT) during resistance exercise in a discontinuous incremental test, determine if both thresholds were observed at the same relative workload, and to analyze the acute cardiorespiratory and metabolic responses during a separate constant load resistance exercise protocol. Twelve healthy, trained women ( $n = 6$ ) and men ( $n = 6$ ) performed a maximal running test on a treadmill followed by three protocols using the hexagonal bar deadlift (HBDL) exercise. The treadmill test was performed to determine maximal oxygen consumption, peak heart rate, and lactate maximum. The HBDL protocols performed included a 1RM to determine maximal strength, an incremental test to

identify both thresholds, and a constant load session at the LT intensity to determine if selected physiological parameters demonstrated steady-state responses. The relative intensity of the LT and VT was  $31.67 \pm 6.15\%$  and  $29.71 \pm 3.49\%$  1RM respectively ( $p = .45$ ). During constant load exercise, no significant difference was observed in blood lactate from set 9 (S9) through S15 (end of exercise) ( $7.44 \pm 2.04$  and  $8.33 \pm 2.05$  mmol•L<sup>-1</sup>, respectively,  $p = .99$ ), in oxygen consumption from S3 through S15 ( $25.10 \pm 1.60$  and  $27.73 \pm 3.68$  ml•kg<sup>-1</sup>•min<sup>-1</sup>, respectively,  $p = 1.00$ ) or in heart rate from S9 through S15 ( $153.25 \pm 13.58$  and  $159.88 \pm 12.61$  beats•min<sup>-1</sup>, respectively,  $p = .19$ ). There were no statistically significant differences in physiological responses during either the incremental or constant load protocols between women and men, with the exception men had a lower HR during CL. This study demonstrated that using the HBDL exercise, both a lactate and ventilatory threshold can be identified at the same relative workload in trained women and men. Additionally, intensity equivalent to the lactate threshold can be maintained in an intermittent constant load exercise session to elicit steady state responses in blood lactate, oxygen consumption, and heart rate. Implications of these results indicate the HBDL exercise performed at the LT intensity may be effective for improving cardiorespiratory and muscular fitness for men and women.



## TABLE OF CONTENTS

<b>LIST OF FIGURES .....</b>	<b>xi</b>
<b>LIST OF TABLES .....</b>	<b>xii</b>
<b>SYMBOLS/ABBREVIATIONS .....</b>	<b>xiii</b>
<b>CHAPTER 1: INTRODUCTION.....</b>	<b>1</b>
Problem statement .....	7
Purpose of the study.....	8
Limitations .....	8
Assumptions .....	8
Hypotheses.....	9
Scope of the study.....	11
Significance of the study.....	12
Definition of terms.....	13
References .....	13
<b>CHAPTER 2: REVIEW OF THE LITERATURE .....</b>	<b>19</b>
Introduction.....	20
Methodology for the identification of the anaerobic threshold during resistance exercise and acute responses in subjects with known disease .....	22
Methodology for identification of the anaerobic threshold during resistance exercise in healthy populations and responses to constant load exercise at the lactate threshold intensity .....	30
Summary of findings.....	57
References .....	59

<b>CHAPTER 3: METHODS .....</b>	<b>64</b>
Experimental approach to the problem .....	65
Participants .....	67
Procedures .....	67
Data collection, exercise testing, screening .....	67
VO <sub>2</sub> max test .....	68
One-repetition maximum test .....	69
Discontinuous incremental test .....	70
Constant load session .....	71
Measurement and instrumentation .....	74
Anthropometric measurements .....	74
Metabolic gasses and heart rate .....	74
Blood lactate .....	75
Statistical analysis .....	75
References .....	77
<b>CHAPTER 4: RESULTS .....</b>	<b>80</b>
Descriptive statistics and comparison of relative intensity at LT and VT .....	80
DIT: Relative intensities, blood lactate, oxygen consumption, heart rate	
Responses and comparisons between women and men .....	81
Lactate and ventilatory thresholds .....	81
Metabolic and cardiorespiratory responses, and sex comparisons .....	84
Physiological responses during the constant load trial performed at the intensity equivalent to the LT .....	86

Physiological responses during the constant load trial: women versus men .....	90
<b>CHAPTER 5: DISCUSSION.....</b>	<b>94</b>
Lactate and ventilatory threshold identification.....	95
Physiological responses during constant load exercise at the intensity equivalent to the lactate threshold .....	100
Women compared to men during steady-state resistance exercise .....	103
Limitations .....	105
References .....	107
<b>CHAPTER 6: SUMMARY, CONCLUSIONS, FINDINGS, RECOMMENDATIONS .....</b>	<b>111</b>
Summary .....	111
Conclusions.....	112
Findings.....	114
Recommendations.....	114
<b>Appendices .....</b>	<b>116</b>
Appendix A. Informed Consent.....	117
Appendix B. Data Collection Sheets.....	123

## LIST OF FIGURES

### Chapter 4: Results

Figure 1. Identification of the lactate threshold using the visual inspection method on mean lactate values for all participants.....	82
Figure 2. Ventilatory threshold using the visual inspection method on mean ventilation values for all participants .....	82
Figure 3. Blood lactate concentrations during constant load resistance exercise .....	88
Figure 4. $\text{VO}_2$ during constant load resistance exercise .....	89
Figure 5. Heart rate during constant load resistance exercise.....	90

### Chapter 5: Discussion

Figure 6. Lactate threshold visual identification for participant #2 and participant #5 .....	96
Figure 7. Lactate threshold visual identification for participant #8 and participant #2 .....	97

## LIST OF TABLES

### Chapter 4: Results

Table 1. Descriptive statistics, TM-VO <sub>2max</sub> , and TBDL 1RM results.....	81
Table 2. Results from the discontinuous incremental resistance exercise test...	83
Table 3. Blood lactate and cardiorespiratory data from constant load exercise performed at the intensity equivalent to the lactate threshold.....	87
Table 4. Values from constant load exercise for lactate, oxygen consumption, and heart rate compared to maximal values from maximal treadmill test.....	90
Table 5. Blood lactate response comparison between women and men during constant load exercise .....	91
Table 6. Oxygen consumption response comparison between women and men during constant load exercise .....	92
Table 7. Heart rate response comparison between women and men during constant load exercise .....	93

**SYMBOLS / ABBREVIATIONS**

>: greater than

≥: greater than or equal to

<: less than

±: plus or minus

[BLa<sup>-</sup>]: blood lactate concentration

[Glu]: blood glucose concentration

%1RM: percentage of one-repetition maximum

1RM: one-repetition maximum

AP: average power

AT: anaerobic threshold

BE: base excess

BP: bench press

BP: blood pressure

CAD: coronary artery disease

CE: cycle ergometry

CG: control group

CL: constant load exercise

CMJ: counter movement jump

CPX: cardiopulmonary testing

DIT: discontinuous incremental test

DM-2: type 2 diabetes

GXT: graded exercise test

H: jump height

Hb: hemoglobin

HBDL: hexagonal bar deadlift

HR: heart rate

HR<sub>peak</sub>: heart rate peak

HR<sub>rest</sub>: resting heart rate

HRV: heart rate variability

HRV-T: heart rate variability threshold

HS: half squat

kg: kilogram

LP: leg press

LT: lactate threshold

min: minute

ml: milliliter

MLSS: maximal lactate steady state

pCO<sub>2</sub>: partial pressure of carbon dioxide

pO<sub>2</sub>: partial pressure of oxygen

PP: peak power

R-Ri: R to R interval

RE: resistance exercise

rMSSD: root mean square of successive RR interval differences

rMSSDT: root mean square of successive RR interval differences threshold

RPE: rating of perceived exertion

RT: resistance training

SBP: systolic blood pressure

SD1: Poincare plot standard deviation perpendicular the line of identity

SD1T: Poincare plot standard deviation perpendicular the line of identity  
threshold

SD2: Poincare plot standard deviation along the line of identity

SDNN: standard deviation of NN intervals

sO<sub>2</sub>: oxygen saturation

TM: treadmill

VCO<sub>2</sub>: volume of carbon dioxide

VE: pulmonary ventilation

VE•VCO<sub>2</sub>: ventilatory equivalents for carbon dioxide

VE•VO<sub>2</sub>: ventilatory equivalents for oxygen

VO<sub>2</sub>: oxygen consumption

VO<sub>2max</sub>: maximal oxygen consumption

VT: ventilatory threshold

VT1: first ventilatory threshold



## CHAPTER 1: INTRODUCTION

Resistance exercise (RE) is a popular fitness activity and is identified by the American College of Sports Medicine (2009) and the National Strength and Conditioning Association (2001, 2016) as an important component of fitness for healthy, and athletic populations to improve muscular strength, power, and endurance, and overall health. In addition, when properly prescribed, RE is considered a safe and effective way to improve and maintain health and quality of life for active elderly, and clinical populations (Williams et al., 2007). While RE is commonly used to improve a variety of neuromuscular and musculoskeletal aspects of health and performance, this form of exercise has also been shown to improve cardiorespiratory and cardiometabolic fitness (Garber et al., 2011). There are a wide range of exercise prescription variables for RE programs including exercise intensity prescribed relative to maximal strength, typically measured by repetition maximum efforts for a given exercise, volume prescribed as total number of lifts/repetitions performed in a set and/or in a workout session, load during a workout calculated as total repetitions multiplied by average weight lifted, as well as several other programming variables. While a significant amount of evidence exists describing the dose-response relationship between RE prescription variables and strength development (Peterson, Rhea, & Alvar, 2005), there is insufficient data on the dose-response relationship of RE and other health benefits (Garber et al., 2011), especially when considering the continuum of different intensity, volume, and load domains.

Resistance exercise is traditionally associated with anaerobic metabolic pathways. On the other hand, rhythmic, dynamic, lower load activities like running, cycling, rowing, and swimming are associated primarily with aerobic metabolism. During these types of aerobic exercise activities, the workload at which aerobic metabolism is increasingly supplemented with anaerobic mechanisms leading to an exponential increase in lactate production and metabolic acidosis is termed the anaerobic threshold (AT) (Wasserman, 1986). This intensity is related to endurance performance and therefore used as a marker of performance, as well as, to prescribe individualized exercise training workloads. Traditionally, the AT has been identified using graded exercise test (GXT) protocols, where the workload is systematically increased over time and physiological responses are measured, recorded, and analyzed. Ramp protocols for walking, running, cycling, rowing, and other rhythmic aerobic-type exercise modalities are commonplace in the literature. During RE, specifically for determination of a LT, an intermittent GXT is performed, starting with low percentages of one-repetition maximum (1RM) and increasing by 5% to 10% 1RM in successive stages until completion. The work stages range from 30-seconds up to three-minutes, but the majority of studies have used 60-second work stages, with two-minute passive rest inter-stage intervals (de Sousa et al., 2012; Garnacho-Castaño, Domínguez, Ruiz-Solano, & Maté-Muñoz, 2015; Maté-Muñoz et al., 2015; Simões et al., 2013). During RE, AT is often identified during a GXT measuring blood lactate concentration  $[BLa^-]$ , ventilatory, and cardiovascular responses. During a GXT an exponential increase in  $[BLa^-]$  is

termed the lactate threshold (LT). Similar changes in oxygen consumption ( $\text{VO}_2$ ) relative to ventilation (VE) and/or carbon dioxide production ( $\text{VCO}_2$ ) are termed the ventilatory threshold (VT), and certain changes in heart rate variability (HRV), the variation in the time between heart beats reflecting sympathetic/parasympathetic input, is termed heart rate variability threshold (HRV-T). Recently in the literature, studies examining RE performed at the intensity associated with the LT have demonstrated cardiovascular, respiratory, and metabolic responses typically associated with aerobic-type exercise, i.e. threshold responses during a GXT.

A 2006 study by Oliveira et al. identified both LT and blood glucose threshold (GT), the intensity at which blood glucose was at its nadir, during GXT protocols on both the leg press (LP) and bench press (BP) exercises in healthy subjects. When expressed relative to 1RM strength values, a nonsignificant difference between LP and BP intensity was observed for both LT ( $32.9 \pm 1.4\%1\text{RM}$ ,  $31.2 \pm 1.2\% 1\text{RM}$ , respectively) and GT ( $36.6 \pm 1.5\%1 \text{ RM}$ ,  $31.2 \pm 1.8\% 1\text{RM}$ , respectively). Strong correlations were reported between LT and GT for both exercise conditions (LP:  $r = 0.80$ , BP:  $r = 0.73$ ). This study demonstrated integrated metabolic adjustments during RE at low to moderate intensities for both lower body and upper body exercises. In both protocols, these healthy, younger, trained, male subjects exhibited LT and GT between 31% and 36% of 1RM.

Additional investigations over the last decade have demonstrated similar physiological responses to RE during GXT identifying AT using different

resistance exercise selection and different protocol design (de Sousa et al., 2012; de Sousa et al., 2011; Garnacho-Castaño, Domínguez, & Maté-Muñoz, 2015; Maté-Muñoz et al., 2015; Maté-Muñoz, Domínguez, Lougedo, & Garnacho-Castaño, 2017; Moreira et al., 2008; Simões et al., 2013; Simões et al., 2010). In these studies, AT was identified in different male populations (apparently healthy, with known disease, younger, and elderly) and was identified at workloads ~27-36% 1RM in the LP, ~30-32% 1RM in the BP, and ~23-25% 1RM in the half-squat (HS) exercise. The anaerobic threshold was identified using LT, VT, and HRV-T measures. Protocols were fairly consistent across investigations and included multiple testing sessions to first measure maximal strength (1RM) on the selected exercise and a subsequent visit for a GXT administered as a discontinuous incremental test (DIT) protocol during the RE. The DIT protocols initiated with low loads, 10% 1RM, and systematically increased intensity by 5-10% 1RM until exhaustion or volitional fatigue, while measuring different physiological variables including HR,  $[Bla^-]$ ,  $VO_2$ ,  $VCO_2$ , HRV, and perceived effort (RPE).

In addition to identification of the AT during a RE exercise test, some investigations have additionally demonstrated stabilization of physiological parameters during a constant load (CL) exercise session performed at the intensity equivalent to LT. For example, de Sousa et al. (2012) evaluated the acid-base status, as described below, during a CL session at the LT intensity using 12 healthy men ( $26.7 \pm 3.4$  years of age) with at least six months experience of hypertrophy type RE (6-12 RM intensity). The DIT and CL protocols used in

this study were similar to previous studies (Garnacho-Castaño et al., 2015; Maté-Muñoz et al., 2015). During three testing sessions separated by at least 48-hours, all subjects performed a 1RM, a DIT to determine LT intensity, and a CL session all using the LP exercise. In addition to blood lactate measurement, a metabolic cart was used for continuous determination of pulmonary gas and ventilation parameters. The DIT protocol was staged at 10-20-25-30-35-40% 1RM and then increased by 10% 1RM to exhaustion. Each stage was one-minute in duration with a repetition rhythm of approximately three-seconds (1.5-second concentric phase, 1.5-second eccentric phase) for a total of 20-repetitions per stage. Passive recovery of two-minutes between each stage was provided during which blood samples were collected via the earlobe 30-seconds post stage. Results from the DIT revealed that AT was identified for each subject with no significant difference in relative intensity observed between LT and VT (LT =  $27.1 \pm 3.7\%$  1RM; VT =  $30.3 \pm 7.9\%$  1RM).

In this same study, de Sousa et al. (2012) also had subjects perform a CL session with the load set at the LT intensity, for 30-minutes of local muscular endurance exercise using the same LP exercise. The CL session was divided into 15-sets, each one-minute in duration of 20-repetitions at the three-second cadence, with one-minute passive rest between each set. Blood samples for determination of  $[BLa^-]$  were taken at rest and 30-seconds post set for set 3 (S3), S6, S9, S12, and S15. Blood samples for determination of other metabolites and acid-base status including pH, base excess (BE), partial pressure of oxygen ( $pO_2$ ), partial pressure of carbon dioxide ( $pCO_2$ ), oxygen saturation ( $sO_2$ ),

concentration of glucose ([Glu]), bicarbonate, sodium, potassium, ionized calcium, hemoglobin (Hb), and hematocrit were collected at rest, after S10, and S15. Oxygen consumption,  $\text{VCO}_2$  and VE were continuously measured during the CL session using a metabolic gas analyzer. Results from the CL sessions revealed a significant change in  $[\text{BLa}^-]$ ,  $\text{VO}_2$ ,  $\text{VCO}_2$ , VE, and HR from rest ( $0.65 \pm 0.21 \text{ mmol}\cdot\text{L}^{-1}$ ,  $0.37 \pm 0.27 \text{ L}\cdot\text{min}^{-1}$ ,  $0.29 \pm 0.10 \text{ L}\cdot\text{min}^{-1}$ ,  $7.25 \pm 2.3 \text{ L}\cdot\text{min}^{-1}$ ,  $71.0 \pm 11.1 \text{ beats}\cdot\text{min}^{-1}$ , respectively) to S15 ( $4.58 \pm 1.96 \text{ mmol}\cdot\text{L}^{-1}$ ,  $1.02 \pm 0.33 \text{ L}\cdot\text{min}^{-1}$ ,  $1.20 \pm 0.49 \text{ L}\cdot\text{min}^{-1}$ ,  $33.5 \pm 18.6 \text{ L}\cdot\text{min}^{-1}$ ,  $137.7 \pm 29.7 \text{ beats}\cdot\text{min}^{-1}$ , respectively). However, there was no statistically significant difference in these parameters between S10 and S15. There were no statistically significant differences observed in pH values at rest, at S10 or S15 ( $7.472 \pm 0.058$ ,  $7.433 \pm 0.027$ ,  $7.413 \pm 0.053$ , respectively). There were significant reductions in bicarbonate and BE between rest ( $26.4 \pm 2.1 \text{ mmol}\cdot\text{L}^{-1}$ ,  $2.7 \pm 2.4$ , respectively) and S15 ( $19.6 \pm 4.3 \text{ mmol}\cdot\text{L}^{-1}$ ,  $-5.0 \pm 3.4$ , respectively). Values for  $\text{pO}_2$ ,  $\text{sO}_2$ , sodium, ionized calcium, potassium, Hb and hematocrit remained stable throughout the CL session. The blood [Glu] values were significantly lower after S15 ( $90 \pm 3.5 \text{ mg}\cdot\text{dL}^{-1}$ ) compared to rest ( $101.6 \pm 3.8 \text{ mg}\cdot\text{dL}^{-1}$ ). In summary, the results of this study demonstrated that during the CL sessions performed at LT intensity, while the acid-base status did not stabilize in all the measured parameters, pH did remain stable while  $\text{pCO}_2$ , bicarbonate and BE decreased from rest to S15. In addition, the ventilatory and HR parameters did stabilize between S10 and S15. The steady state characteristics of  $\text{VO}_2$ ,  $\text{VCO}_2$ , HR,  $[\text{BLa}^-]$  and RPE are consistent with other investigations (Garnacho-Castaño et al., 2015; Maté-Muñoz

et al., 2015). Taken together, the literature demonstrates the ability of using a DIT protocol for identification of LT during RE. Furthermore, during constant load sessions stabilization of physiological parameters was achieved as would be expected from workloads performed at the AT intensity during traditional aerobic or cardio activities. Recommendations for future research included expanding the types of exercises used with respect to muscle groups and actions.

The exercises examined in the RE at AT intensity literature have included the bench press, leg press, half squat, and biceps curl. To date, a full body exercise, combining upper- and lower-body engagement, has yet to be studied. The hexagonal bar deadlift (HBDL) exercise involves full body, upper- and lower-body musculature and has biomechanically transferable characteristics to sports and some duty/job-related tasks (Camara et al., 2016; Malyszek et al., 2017; Swinton, Stewart, Agouris, Keogh, & Lloyd, 2011). In the literature, only men have been used as participants in previous investigations and the inclusion of women is needed to identify, describe, and quantify similarities and/or differences in this area. Most studies attempted to standardize work volume, number of repetitions in a set and series of sets, and tempo for DIT and CL protocols to describe work rate and relate such changes to physiological responses.

## **Problem Statement**

Limited research exists on RE at the LT intensity, none exists on identification of AT using a full body RE such as the HBDL task. As a result, acute physiological responses including blood lactate concentration, oxygen

consumption, and heart rate during incremental and constant load exercise trials are lacking. In addition, no published study has yet described these responses in women or provided comparisons to male counterparts.

### **Purpose of the Study**

The purpose of the current study was to describe and quantify physiological responses (HR,  $\text{VO}_2$ ,  $[\text{BLa}^-]$ ) during a discontinuous incremental RE protocol and a separate discontinuous constant load session at the intensity equivalent to the lactate threshold using the hexagonal bar deadlift exercise.

### **Limitations**

The following limitations were identified in this study:

1. The study sample consisted of healthy, active men and women between the ages of 18-45 years who participate in regular resistance and cardiovascular exercise. Therefore, the results of this study may not be generalized to individuals who are sedentary, have chronic disease, or are outside of the age range studied.
2. All protocols in the current study were performed using the hexagonal bar deadlift exercise. Therefore, the results of this study may not be applicable to other modes of resistance exercise.

### **Assumptions**

The following assumptions were identified in this study:



1. Prior to each visit, the participant did not perform any exercise for 24 hours, did not ingest caffeine or alcohol for three hours, and consumed a small meal two to three hours prior to each exercise protocol.
2. Each participant performed the 1RM, DIT, and CL testing to the best of their ability to yield valid values for analyses.

## **Hypotheses**

The following hypotheses were tested in this study:

**Hypothesis 1:** A lactate threshold will be identified during the incremental RE protocol (DIT) using the HBDL exercise in all subjects.

*Due to the low initial starting intensity of the protocol (10% 1RM), small increments per stage (5-10% 1RM increases), stage durations (60-seconds work and 90- to 120-seconds rest) based on existing literature we expected to identify an exponential increase in blood lactate (de Sousa et al., 2012; de Sousa et al., 2011; Garnacho-Castaño et al., 2015; Garnacho-Castaño et al., 2015).*

**Hypothesis 2:** The first ventilatory threshold will be identified during the incremental RE protocol (DIT) using the HBDL exercise in all subjects.

*Due to the low initial starting intensity of the protocol (10% 1RM), small increments per stage (5-10% 1RM increases), stage durations (60-seconds work and 90- to 120-seconds rest) based on existing literature we expected to identify the start of an exponential increase in ventilation (de Sousa et al., 2012; Maté-Muñoz et al., 2015).*

**Hypothesis 3:** There will be no difference between LT and VT with respect to the relative intensity (%1RM) values from the DIT using the HBDL.

*Studies examining the relationship between LT and VT during incremental RE protocols have shown no significant differences in relative intensities between the two thresholds (de Sousa et al., 2012; Maté-Muñoz et al., 2015).*

**Hypothesis 4:** Blood lactate concentrations will stabilize during the constant load exercise session at the LT intensity.

*Based on existing literature when RE is performed in a discontinuous manner at the LT intensity, blood lactate concentration initially increases from resting values and then stabilizes (Garnacho-Castaño et al., 2015; Maté-Muñoz et al., 2015).*

**Hypothesis 5:** Oxygen consumption will stabilize during the constant load exercise session at the LT intensity.

*Based on existing literature when RE is performed in a discontinuous manner at the LT intensity, oxygen consumption initially increases from resting values and then stabilizes (Garnacho-Castaño et al., 2015; Maté-Muñoz et al., 2015).*

**Hypothesis 6:** Heart rate will stabilize during the constant load exercise session at the LT intensity.

*Based on existing literature when RE is performed in a discontinuous manner at the LT intensity, heart rate initially increases from resting value and then stabilizes (Garnacho-Castaño et al., 2015; Maté-Muñoz et al., 2015).*

**Hypothesis 7:** There will be no differences in physiological responses between males and females during the DIT protocol using the HBDL.

*This will be the first study examining gender differences during RE to identify LT, Equivocal findings have been reported on differences between men and women and RE (Gentil et al., 2016; Hunter, 2016; Mendonca et al., 2018) for this reason the null hypothesis is selected.*

**Hypothesis 8:** There will be no differences in physiological responses between males and females during the constant load protocol using the HBDL.

*This will be the first study examining gender differences during RE to identify LT and there is no evidence to support different responses, so the null hypothesis is selected.*

### **Scope of the Study**

Six healthy, active males and six healthy, active females between the ages of 18 and 45 who currently took part in resistance and cardiovascular exercise on a regular basis completed a graded running exercise test on a motorized treadmill for determination of maximum oxygen uptake ( $\text{VO}_{2\text{max}}$ ), peak HR, and mode specific maximum  $[\text{BLa}^-]$ . Each subject then completed three different RE protocols using the HBDL exercise in order to describe and quantify the physiological ( $[\text{BLa}^-]$ ,  $\text{VO}_2$ , HR) and perceptual (RPE) responses to 1RM, DIT, and CL conditions. Only participants with a 1RM value equal to or greater than 1.6 times body mass (men) or 1.4 times body mass (women), placing them in at least a “novice” level of strength (Strengthlevel.com) were included in the study.

Following a familiarization session on exercise technique, tempo, and wearing a facemask during exercise, the 1RM for the HBDL exercise, DIT, and CL sessions were performed, in this order on separate days. All pulmonary gas and heart rate measurements were collected continuously during the DIT and CL sessions using a metabolic analyzer and heart rate monitor. Blood samples were collected pre-exercise and within 30-40 seconds after each stage for the DIT and stages 3 (S3), S6, S9, S12, S15 for the CL trial. Bar velocity was measured continuously using a linear position transducer for each participant's 1RM, DIT, and CL sessions. Rating of perceived exertion (6-20 scale) was recorded after each stage of the DIT and stage 3 (S3), S6, S9, S12, S15 for the CL trial.

### **Significance of the Study**

This study described and quantified the physiological responses to a standing full body exercise performed in both incremental and constant load protocols by women and men. The use of RE at low to moderate intensities performed at higher volumes has been associated with acute neurological, metabolic, and cardiorespiratory responses which can be beneficial for improving and sustaining health and fitness when implemented into a training program. If a full body RE can be performed at an intensity which elicits stabilization of key physiological parameters, and if differences, or lack thereof, are identified in the responses between women and men, it will provide important information when prescribing exercise intensities and protocols in health, fitness and sports performance settings.

## Definitions

The terms in the study have been defined as follows:

Anaerobic threshold (AT): the workload at which aerobic metabolism is disproportionately supplemented with anaerobic mechanisms leading to a sustained increase in lactate and metabolic acidosis.

Blood lactate concentration ([BLa<sup>-</sup>]): the level of lactate in blood, a metabolic byproduct of phase I glycolysis. This measure is used as an indication of exercise intensity.

Carbon dioxide production (VCO<sub>2</sub>): The rate of carbon dioxide production measured at the lungs using a metabolic gas analyzer.

Constant load trial (CL): A discontinuous exercise session where fixed exercise stages are alternated with fixed rest intervals, using the same workload for the entire session.

Discontinuous incremental test (DIT): A graded exercise test where fixed exercise stages are alternated with fixed rest intervals and workloads are systematically increased each stage until predetermined intensity or volitional fatigue is reached.

Exercise heart rate (HR): Heart rate values associated with specific exercise mode and intensities.

Hexagonal bar deadlift (HBDL): A specific version of the deadlift exercise where the load is lifted from the ground in a continuous motion through extension of the lower back, hips, knees and ankle joints.

Lactate threshold (LT): The exercise intensity at which blood lactate starts to increase exponentially with increasing exercise intensity.

Maximal oxygen consumption ( $\text{VO}_{2\text{max}}$ ): The maximal rate at which oxygen is taken in, transported, and utilized, measured at the lungs using a metabolic gas analyzer.

One-repetition maximum (1RM): The maximum weight an individual can lift one time (but not more than one time consecutively in a set), used as a measure of absolute strength in a specific exercise/lift.

Oxygen consumption ( $\text{VO}_2$ ): The rate of oxygen uptake and utilization measured at the lungs using a metabolic gas analyzer.

Rating of perceived exertion (RPE): A subjective measurement to indicate individual level of perceived physical effort.

Ventilatory threshold (VT1): The exercise intensity at which pulmonary ventilation (VE) starts to increase exponentially with increasing exercise intensity.

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## **CHAPTER 2: REVIEW OF LITERATURE**

The review of literature of this study is presented in the following sections: a) introduction: a need for additional research on the metabolic and cardiorespiratory responses to resistance exercise, b) methodology for the identification of the anaerobic threshold during resistance exercise and acute responses in subjects with known disease, c) methodology for identification of the anaerobic threshold during resistance exercise in healthy populations and responses to constant load exercise at the lactate threshold intensity, d) summary of findings.

## 1. Introduction

Resistance exercise is used to improve overall fitness for the general population, sports performance in athletes, job/duty related performance in military and first responder personnel, and for individuals with known medical conditions to rehabilitate and improve quality of life. In addition to a wide range of musculoskeletal, neuromuscular and performance-related factors, healthy individuals and those with known disease can achieve additional positive outcomes from properly administered resistance training (RT) programs. These benefits include, but are not limited to, improvements in cardiorespiratory and metabolic fitness (Garber et al., 2011), reduced risk of all-cause mortality (Liu et al., 2019), reduced number of cardiovascular events (Liu et al., 2019), and reduced risk for developing functional limitations (von Bonsdorff & Rantanen, 2011). Currently, however, there is insufficient data to fully elucidate a comprehensive dose-response relationship between RT, muscular fitness, and other health benefits (Garber et al., 2011), especially when considering the wide range of intensity, duration, and volume recommendations available. The effects of low and moderate intensity, high repetition RE has been examined and recommended for apparently healthy older adults (Beneka et al., 2005) and cardiac patients (Ebben & Leigh, 2006), however the effect of these protocols on metabolic factors have not been fully described. The dose-response relationship of RT on strength, hypertrophy, and performance is more broadly examined and described (Rhea, Alvar, Burkett, & Ball, 2003). The dose-response relationship between lower-intensity rhythmic exercise (i.e., aerobic, endurance activities) on

health-related benefits and metabolic adaptations has also been extensively studied (Pinckard, Baskin, & Stanford, 2019).

One possible reason for a paucity of research on the cardiorespiratory and metabolic responses of acute RE and chronic adaptations to RT for healthy individuals may stem from the taxonomy and categorization of “strength versus endurance,” or even more suspect, “anaerobic versus aerobic” exercise interventions. It may be proposed there is a misapplication that strength training, resistance exercise, and weightlifting solely elicit anaerobic metabolic responses and adaptations. This constrained paradigm may contribute to an incomplete appreciation and application of training stimuli available and advisable for desired health, fitness, and performance outcomes. Resistance exercise intensity is often prescribed based on the measured or estimated percentage of an individual's maximal strength. Cardiovascular/aerobic exercise prescription is typically prescribed based upon percentage of maximal speed/power,  $VO_{2max}$ , and AT intensities. The most validated AT measures are identified using  $[BLa^-]$  and/or pulmonary gas analysis. Anaerobic threshold constructs represent the intensity at which there is a transition from predominantly aerobic energy pathways to an increasing contribution from anaerobic metabolism. For endurance/aerobic activities, this threshold represents the highest level of predominantly aerobic energy supply, above which metabolic by-products accumulate and fatigue ensues (Matsumoto, Ito, & Moritani, 1991). Applying the AT concept and measurement techniques established and accepted for endurance activities to RE has more recently appeared in the literature (de Sousa et al., 2012; de Sousa

et al., 2011; Garnacho-Castaño, Domínguez, & Maté-Muñoz, 2015; Maté-Muñoz et al., 2015; Oliveira et al., 2006). This methodological approach contributes to the mechanistic understanding and application of RE from a dose-response perspective, and can improve how fitness professionals, coaches, clinicians prescribe training loads based on mechanical stress, physiological strain, and probable metabolic adaptations.

The primary focus of this chapter is to provide an in-depth review of the metabolic and cardiorespiratory responses to constant-load RE performed at the lactate threshold intensity and the protocols used to identify AT markers such as lactate threshold, ventilatory threshold, and heart rate variability threshold using different strength training exercises, muscle groups, and protocols. This review will describe acute physiological responses to constant load and incremental RE to identify threshold parameters within the following populations: clinical, healthy young, and elderly adults.

## **2. Methodology for the Identification of the Anaerobic Threshold During Resistance Exercise and Acute Responses in Subjects with Known Disease**

Moreira et al. (2008) published one of the earliest studies describing the AT during a RE graded exercise test, using individuals with type 2 diabetes (DM-2), for both the leg press and bench press exercises. In addition to LT, the authors also examined the blood glucose threshold. Subjects for this study were nine men ( $47.2 \pm 12.4$  years of age) with diagnosed DM-2 (fasting blood glucose  $\geq 126 \text{ mg}\cdot\text{dl}^{-1}$  or glycosylated hemoglobin  $> 7\%$ ). At the time of the study all

participants were involved in an exercise program (aerobic and resistance exercise) for at least 12-months consisting of approximately 40-minutes of exercise per day, and at least three times per week. On different days participants performed a DIT on a cycle ergometer (CE) to determine LT and  $\text{VO}_{2\text{peak}}$ , a 1RM test on the LP and BP, and a DIT on both LP and BP. The selected intensities during the RE DIT for both the LP and BP were 10, 20, 25, 30, 35, 40, 50, 60, and continued to increase by 10% 1RM until fatigue, inability to maintain form or tempo. Each repetition lasted about two-seconds (one-second concentric phase, one-second eccentric phase), each stage lasted one-minute, consisting of 30 repetitions. Two-minutes of passive recovery were provided between stages, during which loads were increased, blood samples taken, and RPE recorded. Heart rate was continuously recorded throughout each DIT. The LT was identified using two methods, visual identification (VI) of an exponential increase in  $[\text{BLa}^-]$ , and QLac (LTp) method performed by plotting  $[\text{BLa}^-] / \%1\text{RM}$  against the relative intensity (%1RM) for each stage of the DIT. In the LTp method a second-order polynomial function was used to identify the intensity at which there was a disproportionate increase in  $[\text{BLa}^-]$ . GT was identified as the intensity at which blood glucose stopped decreasing and began to increase (i.e. glucose minimum/nadir).

A LT and GT were identified in both the LP and BP exercise protocols using each of the three detection methods. There were no significant differences in the relative intensity for LT, GT and LTp in the LP ( $31.0 \pm 5.3\%$  1RM,  $32.1 \pm 6.1\%$  1RM,  $36.7 \pm 5.6\%$  1RM, respectively) and the BP (LT=  $29.9 \pm 8.5\%$  1RM,

GT=  $32 \pm 8.5\%$  1RM, LTp=  $31.8 \pm 6.7\%$  1RM, respectively). When expressed as absolute [BLa<sup>-</sup>] there were also no significant differences between methods for the LP (LT=  $2.7 \pm 1.3$  mmol•L<sup>-1</sup>, GT=  $3.0 \pm 1.4$  mmol•L<sup>-1</sup>, LTp=  $3.7 \pm 1.5$  mmol•L<sup>-1</sup>) or for BP (LT=  $4.4 \pm 1.7$  mmol•L<sup>-1</sup>, GT=  $4.8 \pm 1.5$  mmol•L<sup>-1</sup>, LTp=  $4.9 \pm 2.0$  mmol•L<sup>-1</sup>). Bench press did show significantly greater absolute [BLa<sup>-</sup>] values compared to LP. Observed HR at the three thresholds were not significantly different between methods for LP (LT=  $103.9 \pm 7.9$  beats•min<sup>-1</sup>, GT=  $104.2 \pm 9.0$  beats•min<sup>-1</sup>, LTp=  $110.1 \pm 7.0$  beats•min<sup>-1</sup>) or between methods for BP (LT=  $106.9 \pm 15.7$  beats•min<sup>-1</sup>, GT=  $111.0 \pm 16.1$  beats•min<sup>-1</sup>, LTp=  $109.5 \pm 13.8$  beats•min<sup>-1</sup>). With respect to HR at the three thresholds, no significant differences were observed between LP and BP values. Ratings of perceived exertion showed no significant differences between methods for LP (LT=  $10.8 \pm 2.5$ , GT=  $11.1 \pm 3.2$ , LTp=  $12.8 \pm 3.0$ ) or for BP (LT=  $13.9 \pm 2.9$ , GT=  $14.6 \pm 2.9$ , LTp=  $14.7 \pm 2.4$ ). Bench Press did show significantly greater RPE values compared to LP. The authors concluded this type of incremental RE protocol was a valid method in the functional evaluation of individuals with DM-2. The value of identification of these thresholds is important to individuals with DM-2 because hyperglycemia is the main sign of this disease and incremental exercise performed at or below these thresholds result in a reduction of blood glucose concentration. This suggests acute exercise performed at the intensities related to LT and GT could contribute to better blood glucose control for this population. One limitation to this study was the absence of indirect calorimetry measurement to further validate attainment of AT.



Patients with known coronary artery disease (CAD) were investigated by Sperling et al. (2016) to describe the metabolic and cardiac autonomic responses during progressive resistance exercise and the associations AT. For this observational cross-sectional study, 20 males ( $63 \pm 7$  years of age) with CAD (left ventricular ejection fraction =  $60 \pm 10\%$ ) performed a DIT using the LP exercise to evaluate the response of HRV and  $[BLa^-]$ . A 1RM test was performed and then 72-hours later a DIT on the LP was administered. The initial load was 10% 1RM in the DIT with subsequent increases of 10% 1RM until exhaustion. Each stage was two-minutes in duration at a tempo of 12 repetitions per minute (total of 24 repetitions per stage). Five-minutes of passive recovery was provided between stages. Heart rate was continuously recorded for measurement of R-R intervals (R-Ri). For HRV analyses, the final/second minute of each stage was used because it was the most stable phase. Linear methods of rMSSD (parasympathetic heart modulation), RMSM (marker of total HRV), and nonlinear methods of SD1 (instantaneous beat-to-beat variability, parasympathetic marker), and SD2 (long term SD of continuous R-Ri as a parasympathetic and sympathetic marker) were used for HRV analyses. Visual identification of rMSSD and SD1 versus work graphs were used to identify the point at which there was initial decline in these indices during exercise, indicating vagal withdrawal. This HRV deflection point was used as HRV-T. Blood samples were taken via earlobe at rest and immediately after the final repetition of each stage. Visual inspection for the plot of  $[BLa^-]$  versus work was used to identify LT, defined as the intensity when lactate accumulation began to increase exponentially.

In this study during 1RM testing the reason for termination was muscle fatigue ( $RPE = 9.2 \pm 2.0$ ), with only one test terminated for chest pain. The average 1RM load was  $3.8 \pm 0.9$  body mass. During the DIT for LP the criterion for termination for almost all the subjects was muscle fatigue ( $RPE = 6.6 \pm 2.8$ ). The common maximal load achieved by all patients was 50% 1RM. During the DIT both rMSSD and SD1 indices, representative of cardiac parasympathetic modulation, demonstrated significant decreases at peak load compared to resting values, with a significant drop observed at about 30% 1RM. There was not a significant difference observed between methods for identifying AT between LT, rMSSD threshold (rMSSDT), or SD1 threshold (SD1T) either in absolute terms ( $81 \pm 19\text{kg}$ ,  $78 \pm 14\text{kg}$ ,  $79 \pm 13\text{kg}$ , respectively) or in relative value ( $29 \pm 5\%$  1RM,  $28 \pm 5\%$  1RM,  $29 \pm 5\%$  1RM, respectively). Using LT as the gold standard, Bland-Altman analyses demonstrated good agreement between threshold values. The Sperling et al. (2016) study provides additional support for the effectiveness of using a discontinuous resistance exercise protocol to identify the LT. The fall in parasympathetic indices associated with the onset of the exponential rise in  $[BLa^-]$  starting around 30% of 1RM in the leg press illustrates an integrated metabolic and autonomic response to incremental RE in CAD patients.

Simões et al. (2016) examined elderly CAD patients and also used a control group (CG) of age-matched apparently healthy males, to investigate LT and HRV-T using the LP exercise. The aims of this study were to identify LT and HRV-T, verify if HRV responses were consistent with blood lactate responses,

and to compare metabolic and cardiac autonomic modulation indices in elderly healthy versus individuals with known CAD. Twenty-two men, 12 with known CAD, defined as clinical diagnosis of CAD for at least one year, ( $65 \pm 7$  years of age) and 10 apparently healthy ( $64 \pm 4$  years of age), all with a history of aerobic activities but not RT experience completed the study. All subjects performed both a 1RM and DIT, separated by seven days. The DIT initiated with a load of 10% of their established 1RM and systematically increased by 10% 1RM until 30%, after which increments were 5% 1RM to exhaustion. The rationale for the 5% steps were for better visualization of physiological adjustments to increasing loads. Each stage was four minutes in duration at a tempo of 12 repetitions per minute, repetition cycle of two-seconds concentric and three-seconds eccentric. Fifteen minutes recovery between each stage was provided to allow HR and BP to return to baseline levels. Heart rate, R-Ri, and RPE were recorded throughout the protocol. Blood samples were taken from the earlobe at rest and immediately after each stage. Sections for HRV analyses were taken at rest and during the latter portion of each stage, between minute two and four where data was most stable. The initial phase of each stage was not used due to the abrupt vagal withdrawal. Heart rate variability data was analyzed using rMSSD, SDNN, SD1, and SD2 indices. Lactate threshold was determined using VI and identified as the first lactate turn point at which  $[BLa^-]$  began to increase exponentially. Thresholds for HRV, determined by VI, were determined with SD1T and rMSSDT.

Results demonstrated the CG had significantly higher 1RM values compared to CAD in absolute load ( $316 \pm 68\text{kg}$  vs  $253 \pm 59\text{kg}$ , respectively) and

also when expressed relative to body mass (load / BM ratio:  $4.5 \pm 0.9$  vs  $3.5 \pm 0.8$ , respectively). Results from the DIT showed all subjects presented with leg fatigue as the criterion for test termination (modified Borg: 9.3 for CAD, 9.1 for CG). No test was interrupted because of abnormal ECG, excessive rise in systolic blood pressure, or exceeding 85% of maximal heart rate. All subjects achieved at least 40% 1RM, which was the maximal load for three of the subjects in the CG and eight in the CAD group. Three from each group stopped at 45%; three in the CG and one in the CAD stopped at 50% 1RM; one in the CG stopped at 55% 1RM. There was a significant reduction in rMSSD and SD1 indices from 30% 1RM compared to rest for both groups. However, there was a significant reduction in SDNN from 30% 1RM versus rest for the CG only. In addition, there was a significant increase in  $[BLa^-]$  and delta HR for both groups from 35% 1RM. A significant increase in SD2 and SDNN from 30% 1RM versus rest was observed in CAD group only. Finally, when comparing HRV values between groups higher SD2 and SDNN at 30, 35, and 40% 1RM were observed in CAD only.

Anaerobic threshold was determined for all subjects by analysis of SD1, rMSSD, and  $[BLa^-]$ , expressed as absolute and relative resistance load values. No significant differences between methods and between groups were observed for absolute values (LT: CG =  $101 \pm 32$ kg, CAD =  $81 \pm 22$ kg; SD1T: CG =  $95 \pm 27$ kg, CAD  $74 \pm 28$ kg; rMSSDT: CG =  $96 \pm 21$ kg, CAD =  $75 \pm 21$ kg) or relative values (LT: CG =  $30 \pm 6\%$  1RM, CAD =  $32 \pm 5\%$  1RM; SD1T: CG =  $29 \pm 6\%$  1RM, CAD =  $29 \pm 5\%$  1RM; rMSSDT: CG =  $29 \pm 5\%$  1RM, CAD =  $30 \pm 6\%$

1RM). There was a significant correlation between LT and rMSSDT ( $r = 0.72$ ,  $p < 0.01$ ) and between LT and rMSSD ( $r = 0.75$ ,  $p < 0.01$ ).

The main findings from this Simões et al. (2016) study using both CAD patients and a healthy age-matched cohort was AT determined by HRV analysis was associated with [BLa<sup>-</sup>] responses and there was a pronounced reduction in vagal modulation verified at 30% 1RM intensity during LP in both groups. In addition, after the 30% 1RM workload the CAD group showed a more pronounced sympathetic cardiac modulation compared to the CG. Delta HR ( $HR_{peak}$  in a stage -  $HR_{rest}$ ) demonstrated a marked change from 35% 1RM in both groups. This difference would not be observed in conventional HR analysis which only shows gradient increases in HR with increasing loads. These findings, in conjunction with Sperling et al. (2016) and results for individuals with DM2 in the Moreira et al. (2008) study, support using a progressive RE protocol to identify AT in these clinical populations. The practical value of identifying these parameters may be inferred to enhance safety and effectiveness when prescribing RE for individuals at higher health risks. Understanding program design variables, specifically intensity and volume, can inform strategies to optimize outcomes and mitigate potential risks associated with exercising at too high an intensity, which could exacerbate blood glucose levels in DM2 patients and cardiac stress in CAD patients. These findings represent an important step forward for clinicians when prescribing and evaluating exercise interventions.

### **3. Identification of the Anaerobic Threshold During Resistance Exercise in Healthy Populations and Responses to Constant Load Exercise at the Lactate Threshold Intensity**

Oliveira et al. (2006) published an early study describing metabolic thresholds during RE. Investigating the GT and LT during RE in healthy subjects they demonstrated both these thresholds were detected during DIT protocols on the LP and BP exercises. Twelve healthy male volunteers ( $24.4 \pm 1.2$  years of age), having at least two years of RT experience, underwent two sessions of testing which included 1RM and DIT protocols on the LP and BP. Intensities selected during the DIT for both exercises were 10, 20, 25, 30, 35, 40, 50, 60, 70, 80, and 90% 1RM. Lifting tempo was three-seconds per repetition, each stage was 60-seconds/20 repetitions in duration, with two-minutes passive recovery between stages. Blood samples were collected from the earlobe during the first minute of recovery after each stage for determination of blood lactate and blood glucose values. Lactate threshold was determined using VI, as a sudden exponential increase in  $[BLa^-]$ . Glucose threshold was identified using VI as the lowest observed value in blood glucose concentration. Results demonstrated a significant difference in absolute loads between LP and BP for LT ( $115.9 \pm 13.2$ kg,  $29.9 \pm 2.4$ kg, respectively) and GT ( $132.8 \pm 15.5$ kg,  $30.3 \pm 3.4$ kg, respectively). However, when expressed relative to 1RM, a nonsignificant difference between LP and BP intensity was observed for both LT ( $32.9 \pm 1.4\%$  1RM,  $31.2 \pm 1.2\%$  1RM, respectively) and GT ( $36.6 \pm 1.5\%$  1RM,  $31.2 \pm 1.8\%$  1RM, respectively). In addition, there were high correlations reported between LT

and GT for both exercise conditions (LP:  $r = 0.80$ , BP:  $r = 0.73$ ). This study highlighted integrated metabolic adjustments during RE at low to moderate intensities for both lower-body and upper-body exercises. It is relevant to note, in both protocols subjects exhibited LT and GT between 31% and 36% of 1RM.

Simões et al. (2010) using a cohort of 10 apparently healthy, older men ( $64 \pm 4$  years of age,  $BMI = 25 \pm 3$ ,  $VO_{2peak} = 29.7 \pm 7 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ), examined the relationship between the responses of cardiac autonomic nervous system parameters and blood lactate accumulation during an incremental LP protocol. All subjects performed a 1RM test and a subsequent DIT test over two days, separated by one week. The incremental RE test started at an intensity of 10% 1RM and increased by 10% 1RM until 30% 1RM was reached, subsequent increases were 5% 1RM until exhaustion. Each stage was four-minutes in duration at a tempo of 12 repetitions per minute; two-second concentric phase (hip/knee extension), three-second eccentric phase (hip/knee flexion). A 15-minute passive recovery period was provided between each stage. Rating of perceived exertion was recorded at the end of each stage. Heart rate was continuously recorded, as were R-R intervals. Blood samples were collected at rest and immediately after each stage via earlobe. Cardiac autonomic nervous system regulation, HRV, was measured and evaluated using rMSSD, RMSM, SD1, SD2, and SD1/SD2 ratio (indicator of an increase in sympathetic modulation). For HRV measurement, sections analyzed at rest and within each stage were the four-minute periods containing sufficient data, subtracting the initial 40-seconds, during which a rapid withdrawal of vagal activity occurred, and

the last 30-seconds during which blood pressure was taken. Anaerobic thresholds were identified using HRV and  $[BLa^-]$  accumulation. Heart rate variability thresholds were identified by VI using SD1T (the stage at which there was a difference of less than 1-ms between two consecutive stages) and rMSSDT (the point at which the index stabilized between two stages). Lactate threshold was identified using VI by plotting  $[BLa^-]$  versus work and identifying the intensity at which there was an initial exponential increase.

Observed results from 1RM testing were RPE  $9.8 \pm 0.5$  (modified Borg Scale 1-10), peak absolute loads were  $316 \pm 68\text{lbs.}$ , and relative loads (lbs. / BM) were  $4.5 \pm 0.9$ . All HRV measures were significantly lower immediately after 1RM compared to resting values. Results from the DIT testing revealed all 10 subjects achieved at least 40% 1RM intensity (for three subjects that was the maximal stage achieved), seven achieved 45%, four achieved 50%, and one achieved 55%. There was a significant reduction in SD1, rMSSD, RMSM indices, and R-Ri from rest to 30% 1RM. The SD1/SD2 ratio significantly increased at 35% 1RM versus rest. In addition, there were significant increases in  $[BLa^-]$  at 35% 1RM versus rest. There were no significant differences observed for AT measured in absolute load between LT, SD1T, and rMSSDT methods ( $101 \pm 32.5\text{kg}$ ,  $95.7 \pm 27.8\text{kg}$ ,  $96.7 \pm 21.3\text{kg}$ , respectively) or in relative load ( $30 \pm 6.2\%$  1RM,  $29 \pm 6.5\%$  1RM,  $29.5 \pm 5.5\%$  1RM, respectively). Significant correlations were found between LT and SD1T ( $r = 0.82$ ,  $p < 0.01$ ), and between LT and rMSSDT ( $r = 0.78$ ,  $p < 0.01$ ).



The main findings of this Simões et al. (2010) investigation included LT observed at 30% 1RM in the LP exercise, consistent with previous literature, and AT obtained using HRV measures were coincident with LT, also in agreement with the literature. In this sample of healthy older men, R-Ri decreased progressively with increasing intensity, and resulted in a significant reduction at 30% 1RM. This coincided with a significant increase in HR, indicating significant augmentation in sympathetic activity around 30% 1RM. The authors proposed the increase in muscular tension (peripheral resistance) associated with RE, particularly during the concentric phase, imposing a mechanical compressive force on the peripheral arterial system leading to occlusion in blood flow, as described by Petrofsky et al. (1981). Restriction in blood flow results in the stimulation of type III and IV afferents (metaboreceptors and mechanoreceptors) in skeletal muscle (Mitchell, 1990). This change in blood flow also results in perturbations of the metabolic environment including reduced pH and stimulation of afferents that transmit information to the ventrolateral medullary region, triggering increased sympathetic discharge to the cardiovascular system (Iwamoto & Kaufman, 1987). The resulting increase in HR and arterial pressure is an attempt to restore muscle blood flow. The magnitude of these HR and BP adjustments are related to the exercise intensity and amount of exercising muscle mass. These findings suggest at around 30% 1RM in the LP exercise, there is sufficient afferent stimulation to drive the observed physiological responses. This is an important finding, especially for populations with known cardiac disease, or at higher risk during exercise, when excessive sympathetic

activity may be of concern or contraindicated. With respect to  $[BLa^-]$  accumulation during the incremental test, the authors suggested the early increase in resistive load initially stimulating greater recruitment of oxidative fibers until eventual exhaustion or inability of aerobic metabolism to meet energy demands, after which there is a greater recruitment of type IIx fibers. This increased activation of glycolytic fibers results in increased glycogenolysis and production of lactate via the lactate dehydrogenase (LDH) reaction. Thus, the combination of hemodynamic and cellular bioenergetic factors contribute to parallel metabolic and autonomic changes which appear to occur at intensities above 30% 1RM for the LP exercise in this population. The authors identified study limitations including lack of expired gas analysis to support identification of AT, and the incremental RE protocol used had a relatively long duration (four-minute stages), which may have induced subjects to reach peak load at a lower intensity. The stage duration for this study was selected to better capture valid HR signal data for HRV analysis. However, despite these limitations, the identification of the AT using LT and/or HRV thresholds may be advantageous in prescribing safe and tolerable exercise intensities.

de Sousa et al. (2011), to address emerging research investigating AT during RE, compared four methodological procedures, two of which were previously described in the literature and two traditionally used in aerobic-type exercise research. The visual identification method ( $LT_{VI}$ ), originally proposed by Wasserman et al. (1973), was performed by plotting  $[BLa^-]$  and workload, followed by experienced investigators determining the onset of a systematic

increase in  $[BLa^-]$ . This method was previously used by Moreira et al. (2008) for RE. The QLac method ( $LT_{QLac}$ ), also used by Moreira et al. (2008), uses a polynomial function applied to the QLac ( $[BLa^-] / \%1RM$ ) plotted against the relative intensity ( $\%1RM$ ) for each stage of the DIT. The algorithmic adjustment method ( $LT_{AA}$ ), based on the work of Orr et al. (1982), uses a double linear regression model where a computerized 2-segment regression analysis (one for the lower component and one for the upper component) to locate the intersection of the  $[BLa^-]$  versus workload. The best-fit regression model is selected by minimizing the pooled residual sum of squares. Finally, the log-log transformation method ( $LT_{LL}$ ), based on the research of Beaver et al. (1985), performed by transforming  $[BLa^-]$  and exercise intensity data to their logarithmic values and then dividing the log-log data into two segments with a common data point identified by iterative process to minimize residual sum of squares was used. The intersection point of the two lines represents the log work rate and its antilog is the work rate at the  $LT_{LL}$ .

For this study, de Sousa and colleagues (2011) used 12 healthy males ( $26.0 \pm 2.9$  years of age) with a minimum of six months of RT experience. Subjects completed two sessions, 1RM and DIT, using a 45-degree LP machine. The first testing session was 1RM determination. The DIT protocol used a three-second repetition tempo (1.5 seconds eccentric phase, 1.5 seconds concentric phase), a one-minute duration for a total of 20 repetitions per stage. Selected intensities for the DIT were 10, 20, 30, 35, 40, 45, 50, 70, 80, and 90  $\%1RM$ . Two-minute passive rest periods between sets were used to adjust load and

collect blood samples from an earlobe 30-seconds post set, for lactate analysis. Motion angle of the knee was kept between 90 and 180 degrees with the use of an electrogoniometer. The average maximum intensity achieved in the DIT was  $68.5 \pm 9.9\%$  1RM. Mean  $[BLa^-]$  at rest and at maximum intensity were  $1.01 \pm 0.5 \text{ mmol} \cdot \text{L}^{-1}$  and  $8.52 \pm 2.27 \text{ mmol} \cdot \text{L}^{-1}$ , respectively. Lactate threshold was successfully identified using all four methods:  $LT_{VI} = 26.9 \pm 5.2\%$  1RM,  $1.91 \pm 0.78 \text{ mmol} \cdot \text{L}^{-1}$ ,  $LT_{AA} = 27.8 \pm 3.6\%$  1RM,  $1.84 \pm 0.61 \text{ mmol} \cdot \text{L}^{-1}$ ,  $LT_{LL} = 23.3 \pm 3.5\%$  1RM,  $1.58 \pm 0.63 \text{ mmol} \cdot \text{L}^{-1}$ ,  $LT_{QLac} = 31.6 \pm 9.8\%$  1RM,  $2.6 \pm 1.4 \text{ mmol} \cdot \text{L}^{-1}$ . Only the  $LT_{LL}$  was significantly different from  $LT_{QLac}$  ( $p < 0.05$ ). This study demonstrated the ability to identify LT using different methods during a DIT for RE in this cohort of healthy male subjects. Lactate threshold using the LP occurred around 30% 1RM, similar to previous studies. The authors suggested that  $LT_{AA}$  showed more “quality and precision” for LT identification. However, the authors additionally noted there exists some uncertainty in this method, citing previous studies where the algorithmic adjustment method produced significantly greater values compared to the log-log method and the fit was not as good. The QLac method calculated the LT at a higher intensity than the other methods and was unable to identify an LT in 25% of the subjects (three individuals).

In a 2012 follow up study, de Sousa et al. replicated the incremental exercise test on the LP to identify LT, the VT, and also examined physiological responses to a separate RE session performed with a constant load equivalent to the LT intensity for multiple sets. Subjects were 10 healthy males ( $25 \pm 3$  years of age) with at least six months experience of hypertrophy-type RT (loads

corresponding to 6-12 RM). Three testing protocols were performed on different days, with 48-hours between visits. The first session was 1RM testing. The second session was DIT to determine LT, with intensity stages of 10, 20, 25, 30, 35, and 40% 1RM, followed by increases of 10% of the subject's 1RM until exhaustion or volitional fatigue. This loading scheme was designed for better visualization of physiological responses to increasing loads, based on previous studies demonstrating LT occurs around 30% of 1RM (Moreira et al. 2008, Simões et al. 2010). Repetition cycles lasted three-seconds, each stage lasted one-minute (20 repetitions per stage). During two-minute passive rest between stages the load was increased and blood samples via earlobe were collected 30-seconds after each stage. Tests were terminated either by the subject's inability to perform the movement with proper biomechanics or to perform required repetitions a stage. Lactate threshold was identified as the intensity where  $[BLa^-]$  increased in an exponential manner using the  $LT_{AA}$  method. During the DIT,  $VO_2$ ,  $VCO_2$ , and  $VE$  were continuously measured. The VT (VT1) was defined as the intensity where  $VE$  began to increase in an exponential manner with the same algorithm adjustment method used for LT determination. During the third session, subjects performed 30-minutes of discontinuous LP exercise at the LT intensity, divided into 15 sets. Each set lasted one-minute, and subjects performed 20 repetitions at a three-second tempo controlled by visual and verbal commands. Passive rest between sets for the CL protocol was one-minute during which blood samples were collected from an earlobe 30-seconds after the end of set 3 (S3), S6, S9, S12, and S15. During the CL session  $VO_2$ ,  $VCO_2$ , and  $VE$  were

continuously measured. The average of one-minute rest and S1, S3, S6, S9, S12, and S15 were used for ventilatory parameter analysis. Heart rate was measured at rest and in the 18<sup>th</sup> repetition of S1, S3, S6, S9, S12, and S15. Two separate RPE scales were reported immediately after S1, S3, S6, S9, S12, and S15, using Borg Perceived Exertion Scale (overall body) and the OMNI Resistance Exercise Scale (active muscles).

Results demonstrated LT and VT were identified for all subjects during the DIT. The mean intensity for LT and VT were  $27.1 \pm 3.7\%$  1RM and  $30.3 \pm 7.9\%$  1RM respectively, with no statistically significant differences observed between the methods. A significant positive correlation was found between LT and VT ( $r = 0.64$ ;  $p = 0.049$ ). ANOVA results from the CL session revealed significant differences in  $[BLa^-]$  between the time points rest and S9 ( $0.8 \pm 0.3 \text{ mmol} \cdot \text{L}^{-1}$  vs.  $3.3 \pm 0.09 \text{ mmol} \cdot \text{L}^{-1}$ , respectively). However,  $[BLa^-]$  values between S9 and S15 ( $4.1 \pm 1.4 \text{ mmol} \cdot \text{L}^{-1}$  at S15) were not statically significant ( $p = 0.166$ ). Heart rate significantly increased from rest to S6 ( $71.4 \pm 13 \text{ beats} \cdot \text{min}^{-1}$  vs.  $114.9 \pm 13.9 \text{ beats} \cdot \text{min}^{-1}$ ) but stabilized with no significant difference observed ( $p = 0.181$ ) between S6 and S15 ( $124.5 \pm 14.0 \text{ beats} \cdot \text{min}^{-1}$  at S15). Ventilatory parameters differed significantly between time points. Oxygen consumption and  $\text{VCO}_2$  increased ( $p = 0.0005$ ) from rest ( $0.29 \pm 0.09 \text{ L} \cdot \text{min}^{-1}$  and  $0.33 \pm 0.01 \text{ L} \cdot \text{min}^{-1}$ , respectively) to S3 ( $0.77 \pm 0.18 \text{ L} \cdot \text{min}^{-1}$  and  $0.84 \pm 0.20 \text{ L} \cdot \text{min}^{-1}$ , respectively). However, from S3 to S15 both  $\text{VO}_2$  and  $\text{VCO}_2$  stabilized and were not significantly different ( $0.83 \pm 0.16 \text{ L} \cdot \text{min}^{-1}$  and  $0.95 \pm 0.21 \text{ L} \cdot \text{min}^{-1}$ , respectively). Minute ventilation was also significantly different between time points, increasing

from rest to S6 ( $8.9 \pm 2.8 \text{ L} \cdot \text{min}^{-1}$  and  $19.4 \pm 4.9 \text{ L} \cdot \text{min}^{-1}$ , respectively), but was not significantly different between S6 and S15 ( $22.4 \pm 5.5 \text{ L} \cdot \text{min}^{-1}$ ). Perceived exertion demonstrated similar results, with significant differences from S1 (Borg:  $7.8 \pm 1.8$ , OMNI:  $1.5 \pm 1.2$ ) and S9 (Borg:  $11.5 \pm 2.9$ , OMNI:  $4.2 \pm 2.3$ ), but no significant difference from S9 to S15 (Borg:  $13.0 \pm 3.5$ , OMNI:  $5.2 \pm 2.6$ ). The main findings of this study were identification of both LT and VT during the DIT and stabilization of physiological parameters during the CL session. Taken together these results were novel findings because the construct of anaerobic threshold in general, LT and VT specifically, are typically applied to endurance or aerobic activities. However, the authors demonstrated that during a discontinuous RE test an intensity associated with an AT is evident. In addition, performing RE for a longer duration at the intensity associated with LT, there was a stabilization of blood lactate appearance/clearance. In addition, stabilization of the parameters  $\text{VO}_2$ ,  $\text{VCO}_2$ , VE, HR, and RPE was achieved, reflecting a predominance of aerobic metabolism during strength training.

de Sousa et al. (2013) published another investigation, this time evaluating the acid-base status during a CL LP exercise session at the LT intensity. Subjects were 12 healthy men ( $26.7 \pm 3.4$  years of age) with at least six months experience of hypertrophy type RE (6-12 RM intensity). During three testing sessions separated by 48-hours, each subject performed a 1RM, an incremental RE test to determine LT intensity (DIT), and a CL session all on a LP machine. The loading protocol used to determine LT was 10-20-25-30-35-40% 1RM and then increases of 10% 1RM to exhaustion. Each stage was one-minute

in duration at a repetition tempo of approximately three seconds (1.5 second concentric phase, 1.5 second eccentric phase) for a total of 20 repetitions per stage. Motion angle of the knees was between 90 and 108 degrees monitored with an electrogoniometer. Passive recovery of two-minutes between each stage was provided during which blood samples were collected via earlobe 30-seconds post set. Lactate threshold was identified using visual identification of the intensity at which  $[BLa^-]$  started to exponentially increase. During the CL session the load was set to the LT intensity derived from the DIT and each participant performed 30-minutes of local muscular endurance exercise on the LP. The session was divided into 15 sets, each one-minute in duration, of 20 repetitions at the three-second tempo. There was one-minute of passive recovery between each set. Blood samples for determination of  $[BLa^-]$  were taken at rest and 30-seconds post set for set S3, S6, S9, S12, and S15. Blood samples for determination of other metabolites and acid-base status including pH, base excess, partial pressure of oxygen, partial pressure of carbon dioxide, oxygen saturation, concentration of glucose, bicarbonate, sodium, potassium, ionized calcium, hemoglobin, and hematocrit were collected at rest, after S10, and S15. Oxygen consumption,  $VCO_2$  and VE were continuously measured during the CL session using a metabolic gas analyzer. This data was smoothed using one-minute average at rest, S10, and S15 for ventilatory parameter analysis. Heart rate was measured at rest and in the 18<sup>th</sup> repetition of S10 and S15. Results from the DIT revealed the average maximum intensity achieved was  $66 \pm 8.3\%$  1RM. The average LT intensity used for the CL sessions was  $29.2 \pm 3.8\%$  1RM.



Results from the CL session demonstrated a significant change in  $[BLa^-]$ ,  $VO_2$ ,  $VCO_2$ ,  $VE$ , and  $HR$  from rest ( $0.65 \pm 0.21 \text{ mmol}\cdot\text{L}^{-1}$ ,  $0.37 \pm 0.27 \text{ L}\cdot\text{min}^{-1}$ ,  $0.29 \pm 0.10 \text{ L}\cdot\text{min}^{-1}$ ,  $7.25 \pm 2.3 \text{ L}\cdot\text{min}^{-1}$ ,  $71.0 \pm 11.1 \text{ beats}\cdot\text{min}^{-1}$ , respectively) to S15 ( $4.58 \pm 1.96 \text{ mmol}\cdot\text{L}^{-1}$ ,  $1.02 \pm 0.33 \text{ L}\cdot\text{min}^{-1}$ ,  $1.20 \pm 0.49 \text{ L}\cdot\text{min}^{-1}$ ,  $33.5 \pm 18.6 \text{ L}\cdot\text{min}^{-1}$ ,  $137.7 \pm 29.7 \text{ beats}\cdot\text{min}^{-1}$ , respectively). However, there was not a statistically significant difference in these parameters between S10 and S15. The  $pCO_2$  was  $36.0 \pm 2.7 \text{ mmHg}$  at rest,  $32.3 \pm 1.3 \text{ mmHg}$  at S10, and  $30.2 \pm 0.4 \text{ mmHg}$  at S15, demonstrating significantly higher values at rest than at S15 ( $p = 0.012$ ). There were no statistically significant differences observed in pH values at rest, at S10 or S15 ( $7.472 \pm 0.058$ ,  $7.433 \pm 0.027$ ,  $7.413 \pm 0.053$ , respectively). There were significant reductions in bicarbonate and BE between rest ( $26.4 \pm 2.1 \text{ mmol}\cdot\text{L}^{-1}$ ,  $2.7 \pm 2.4$ , respectively) and S15 ( $19.6 \pm 4.3 \text{ mmol}\cdot\text{L}^{-1}$ ,  $-5.0 \pm 3.4$ , respectively). Values for  $pO_2$ ,  $sO_2$ , sodium, ionized calcium, potassium, Hb and hematocrit remained stable throughout the CL session. The blood  $[Glu]$  values were significantly lower after S15 ( $90 \pm 3.5 \text{ mg}\cdot\text{dL}^{-1}$ ) compared to rest ( $101.6 \pm 3.8 \text{ mg}\cdot\text{dL}^{-1}$ ).

In summary, the results of this de Sousa et al. (2013) study demonstrated that during the CL session at LT intensity, while the acid-base status did not stabilize in all the measured parameters, pH did remain stable while  $pCO_2$ , bicarbonate and BE decreased from rest to S15. In addition, the ventilatory and HR parameters did stabilize between S10 and S15. The authors proposed the stabilization of pH was mediated by ventilatory compensation mechanisms for a mild exercise induced acidosis environment as a result of the protocol. In

addition, even though blood lactate accumulated, compensatory mechanisms including consumption of bicarbonate to buffer protons in the plasma decreasing BE and reductions in  $p\text{CO}_2$  from hyperventilation, were likely contributors to maintenance of blood pH. The arterial pH at the end of exercise was much higher than values considered to induce fatigue. Comparing their results to Baron (2003) who reported stable pH between the 10th and 30th minute of CE exercise performed at the maximal lactate steady state (MLSS), the authors noted more of a reduction in bicarbonate and BE during the RE protocol comparatively. They therefore proposed, based on their results, RE at the LT intensity demonstrates a greater magnitude of metabolic perturbation compared to dynamic exercise (CE) performed at a similar relative intensity. They went on to point out this was contrary to maximal exercise where the metabolic response is greater in dynamic exercise and can reduce peak power by a greater magnitude. Evidence used to support this position is based on research by MacDougall et al. (1999) where it was demonstrated maximal force was reduced in RE by 20% at momentary muscle failure (inability to complete further repetitions with 80% 1RM load) compared to data from McCartney et al. (1986) which showed during a 30-second all-out effort on a CE there was a 50% drop in power.

To investigate and describe the potential effects of aging on identifying the AT during RE, Simões et al. (2013) compared a group of young men (YG) ( $n = 14$ ,  $23 \pm 3$  years of age) and elderly men (EG) ( $70 \pm 4$  years of age) on the LP exercise. In addition, cardiopulmonary (CPX) testing using a ramp protocol on a CE was also performed. Similar to their previous study using older men (Simões

et al., 2010), both HRV and  $[BLa^-]$  were used to identify AT. A 1RM test was performed and followed after at least 48 hours by a DIT. The protocol for the DIT started with an initial 10-minute rest on the LP machine and the first load was 10% 1RM with subsequent stages increasing by 10% 1RM to exhaustion. Each stage was two-minutes in duration at a rhythm of five-seconds per repetition (two-second concentric phase, three-second eccentric phase), 12 repetitions per minute with a five-minute passive recovery between stages. Modified Borg Scale was collected at the end of each stage along with blood samples taken at rest via earlobe and immediately after each set. Heart rate for the purposes of R-Ri, was continuously recorded throughout the DIT. Heart rate variability was analyzed during the initial rest period for baseline and during the last portion of all stages for rMSSD, RMSM, and SD1 and HRV thresholds of rMSSDT and SD1T were identified as previously described (Simões, 2010). Lactate threshold was identified as an exponential increase of  $[BLa^-]$  versus intensity plots as previously described using visual identification.

Results from CPX testing revealed the EG had significantly lower peak values compared to the YG, except for RER values (max power: EG =  $152 \pm 27$ W, YG =  $242 \pm 57$ W; HR: EG =  $138 \pm 25$  beats $\cdot$ min $^{-1}$ , YG =  $169 \pm 25$  beats $\cdot$ min $^{-1}$ ; VE: EG =  $70 \pm 14$  L $\cdot$ min $^{-1}$ , YG =  $103 \pm 27$  L $\cdot$ min $^{-1}$ ; VO $_2$ : EG =  $1757 \pm 389$  ml $\cdot$ min $^{-1}$ , YG =  $2852 \pm 462$  ml $\cdot$ min $^{-1}$ ; VCO $_2$ : EG =  $2191 \pm 415$  ml $\cdot$ min $^{-1}$ , YG =  $3568 \pm 616$  ml $\cdot$ min $^{-1}$ ; RER: EG =  $1.25 \pm 1$ , YG =  $1.23 \pm 1$ ). Results from 1RM testing revealed the YG was significantly stronger when expressed as absolute load (YG =  $358 \pm 57$ kg vs EG =  $306 \pm 75$ kg) but when expressed relative to body

mass (load / BM) there was no statistically significant difference (YG =  $4.52 \pm 0.87$  vs EG =  $4.23 \pm 1.2$ ). Results from DIT showed all subjects reached at least 50% 1RM intensity. There was a progressive decrease in rMSSD, SD1, and RMSM from 10% to 30% 1RM, with subsequent stabilization observed in both groups. The EG showed lower HRV values for loads below 30% 1RM compared to YG. Blood lactate concentrations were lower for EG at 40% and 50% compared to YG. Within both groups delta HR was significantly higher at intensities above 30% 1RM compared to those below. Between groups, the delta HR was lower compared to YG for all intensities, starting at 30% 1RM. There was a progressive decrease in R-Ri in both groups, but it was more pronounced in the YG. With respect to AT determination, there was no significant difference observed between groups expressed as absolute or relative values for LT (YG =  $92 \pm 32\text{kg}$ ,  $29 \pm 6\%$  1RM, EG =  $96 \pm 25\text{kg}$ ,  $28 \pm 4\%$  1RM), rMSSDT (YG =  $98 \pm 28\text{kg}$ ,  $29 \pm 5\%$  1RM, EG =  $94 \pm 23\text{kg}$ ,  $28 \pm 7\%$  1RM), or SD1T (YG =  $96 \pm 32\text{kg}$ ,  $29 \pm 6\%$  1RM, EG =  $95 \pm 25\text{kg}$ ,  $28 \pm 5\%$  1RM). Significant correlations were observed between LT and rMSSDT ( $r = 0.60$ ,  $p < 0.01$ ) and LT and SD1T ( $r = 0.56$ ,  $p < 0.01$ ) for both groups. These results, in agreement with previous studies, demonstrated parasympathetic cardiac modulation was lower in the EG at rest and at loads below the AT.

Simões et al. (2014), using older males only, compared exercise on a cycle ergometer with RE on a LP for determination of AT using blood lactate and HRV analyses. A group of 14 older males ( $70 \pm 4$  years of age) performed a max GXT on a CE for determination of maximal power (MP), 1RM on a LP machine, a

DIT on the CE (DIT-C), and a DIT on the LP (DIT-L). This was a unique approach because different exercise modes were compared in this elderly sample assessing metabolic, cardiovascular, and cardiac autonomic variables at similar relative intensities. The author's hypothesized a relationship existed between cardiovascular and metabolic adjustments during both dynamic and resistance modes of exercises, it was possible to determine AT using both HRV and blood lactate measurements, and the cardiovascular, metabolic blood lactate, and HRV responses would differ between dynamic and resistance exercise modes.

To ensure normal physiological responses to exertion and determine individual MP (at  $\text{VO}_{2\text{peak}}$ ) for the DIT-C, all subjects performed a GXT on the CE while gas exchange and ventilatory variables were continuously measured with a breath-by-breath system. An eight to 12-minute maximal ramp protocol was used, HR and R-Ri were recorded, BP measured every three-minutes along with RPE using a modified Borg scale. The DIT-C consisted of three-minute stages, starting with 10% MP, pedaling at 60 rpm, and five-minute recovery between stages. Intensity increased 10% MP each stage with BP and RPE recorded at the end of each stage, blood samples from earlobe collected immediately after each stage, HR, R-Ri, VE and gas exchange were measured continuously. Leg press 1RM testing included a familiarization period for form and technique on a 45 degree LP. The DIT-L protocol started with 10% 1RM and systematically increased 10% 1RM each stage. Each stage was two-minutes in duration using a 12 repetition per set tempo (two-second concentric/three-second eccentric) and five-minute recovery between each stage. Heart rate and R-Ri were continuously

recorded, blood samples were collected before exercise for baseline and immediately after each stage, along with RPE. Gas exchange data was not collected during LP protocols. Anaerobic threshold was identified using VI for ventilatory anaerobic threshold, LT, and HRV parameters including SD1T and rMSSDT.

Results from the maximal CE test showed the cardiovascular parameters, systolic blood pressure (SBP) and HR, were significantly elevated from rest to peak conditions ( $130 \pm 11$  mmHg vs  $176 \pm 3$  mmHg;  $85 \pm 13$  vs  $138 \pm 25$  beats•min<sup>-1</sup>). Additional data from CE included MP =  $152 \pm 27$  W, power at AT =  $74 \pm 13$  W, delta HR =  $53 \pm 25$  beats•min<sup>-1</sup>, and  $VO_{2peak} = 24 \pm 5$  ml•kg<sup>-1</sup>•min<sup>-1</sup>. Similar to CE max test results, 1RM LP testing revealed significant increases in cardiovascular parameters from rest to peak for SBP ( $138 \pm 12$  vs  $144 \pm 20$  mmHg), and HR ( $75 \pm 13$  vs  $93 \pm 14$  beats•min<sup>-1</sup>). The mean 1RM value for the LP was  $306 \pm 75$  kg and delta HR =  $19 \pm 7$  beats•min<sup>-1</sup>.

Results from DIT protocols revealed rest versus peak values were greatest for SBP and HR and lowest for HRV variables in both CE and LP. Percentage of maximal load, HR<sub>peak</sub> and VO<sub>2</sub> at AT were all higher for DIT-C versus DIT-L. In both DIT-C and DIT-L all subjects achieved at least 50% maximal intensity which was the highest intensity for one subject on CE and for eight subjects on LP. Sixty percent of maximal intensity was the highest stage reached for 10 subjects on CE and five subjects for LP. One subject achieved 70% of maximal intensity each for CE and LP. Two subjects achieved 80% of MP on CE. Peak absolute and relative power achieved during DIT-C were  $95 \pm 21$  W

and  $63 \pm 8\%$ , respectively. Maximal absolute and relative loads achieved during DIT-L were  $170 \pm 53\text{kg}$  and  $55 \pm 6\%$  respectively. The average peak intensity achieved during the DIT-L was significantly lower than that achieved during DIT-C ( $55 \pm 6\%$  vs  $63 \pm 8\%$  1RM, respectively). Systolic blood pressure significantly increased from rest to peak in both CE and LP ( $126 \pm 15$  to  $182 \pm 22$  mmHg and  $125 \pm 11$  to  $181 \pm 29$  mmHg, respectively) but were not significantly different between modes. Diastolic blood pressure also significantly increased from rest to peak in both CE and LP ( $81 \pm 8$  to  $90 \pm 11$  mmHg and  $72 \pm 11$  to  $114 \pm 20$  mmHg, respectively) which were statistically significantly different between modes of exercise. Neither HR at AT (DIT-C =  $98 \pm 12$  beats $\cdot\text{min}^{-1}$ ; DIT-L =  $90 \pm 15$  beats $\cdot\text{min}^{-1}$ ) nor delta HR (DIT-C =  $49 \pm 14$  beats $\cdot\text{min}^{-1}$ ; DIT-L =  $41 \pm 15$  beats $\cdot\text{min}^{-1}$ ) were significantly different between modes. Oxygen consumption at peak was significantly different between modes (CE =  $21 \pm 4$  ml $\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ; LP =  $15 \pm 5$  ml $\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ). However,  $\text{VO}_2$  at AT was not significantly different between CE ( $13 \pm 2$  ml $\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ) and LP ( $9 \pm 2$  ml $\cdot\text{kg}^{-1}\cdot\text{min}^{-1}$ ). With respect to heart rate variability, indices from rest to 50% maximal power (CE) and 50% 1RM (LP), which were the highest common loads for all subjects, both rMSSD and SD1 demonstrated a progressive decrease in with increasing loads for both modes of exercise. Significant decreases in these variables were observed at 10% MP vs rest and 20% MP vs 10% during DIT-C. During DIT-L, significant decreases in these indices were observed at 20% 1RM vs rest and at 30% 1RM vs rest. Both rMSSD and SD1 stabilized from 30% maximal intensity and no significant difference between CE and LP. A decrease in RMSM occurred from rest to 30%

with no further changes during both CE and LP protocols. There was an increase in delta HR from 30% maximal intensity in both protocols as well.

Anaerobic threshold was determined in each subject during both protocols by analysis of  $[BLa^-]$ , rMSSD, and SD1 expressed in relative and absolute values. There were no significant differences observed between methods to identify AT. In addition, for CE there were significant correlations between LT and rMSSDT ( $r = 0.55$ ,  $p < 0.05$ ) and LT and SD1T ( $r = 0.58$ ,  $p < 0.05$ ) and also for LP between LT and rMSSDT ( $r = 0.58$ ,  $p < 0.05$ ) and LT and SD1T ( $r = 0.59$ ,  $p < 0.05$ ). Anaerobic threshold occurred at approximately 30% maximal intensity for LP and CE. Identifying AT using HRV was feasible and associated with  $[BLa^-]$  in both protocols. In addition, subjects showed similarity in HRV indices with increasing intensities during both protocols. Leg press produced greater increases in SBP and  $[BLa^-]$  from AT on, compared to CE. The authors speculated the larger values of  $[BLa^-]$  during LP beyond the AT could be related to different hemodynamic changes induced by the two modes of exercise. Leg press elicits an isometric contraction component previously described by Simões and colleagues. The more pronounced accumulation of  $[BLa^-]$  above 30% 1RM during LP compared to CE may have resulted in greater fatigue and earlier cessation of exercise, demonstrated by the lower average maximal intensity achieved in LP ( $55 \pm 6\%$  1RM) compared to CE ( $63 \pm 8\%$  MP). This study represented a unique approach to AT identification during RE and the similarities to rhythmic dynamic/cardio exercise.



Garnacho-Castano et al. (2015) introduced two new variables to the body of research on RE at the LT. Similar to previous studies, they examined the acute metabolic and cardiac responses during a DIT during RE, however, they were the first to use a standing exercise, the barbell half squat (HS), and also examined the changes in lower body power measured by a countermovement vertical jump (CMJ) test. Thirteen male subjects ( $21.23 \pm 1.83$  years of age) each completed a 1RM test and a DIT. Stages for the DIT were one-minute in duration with two-minutes passive recovery between each stage. Lifting tempo was two seconds per repetition (one-second eccentric/one-second concentric) and 30 repetitions per stage. Incremental loads for the DIT were 10, 20, 25, 30, 35, and 40% 1RM. Blood samples were collected 30-seconds after each stage from a finger. Lactate threshold was identified using the algorithm adjustment method as the work intensity at which  $[BLa^-]$  started to increase in an exponential manner. Subjects also completed a 31-minute CL session at the LT load/intensity. Total volume was 21 sets, each set 30-seconds in duration (15 repetitions per set, one-second eccentric/one-second concentric tempo) and one-minute passive rest between sets. Rating of perceived exertion and blood samples were collected 30-seconds after S3, S6, S9, S12, S15, S18, and S21. Heart rate was recorded throughout the CL session. In addition, muscle fatigue was assessed in the lower limbs with the CMJ performed on a force plate. Jump testing took place before and after the CL protocol and consisted of three maximal jumps separated by 30-seconds. Mean values for jump height (H), average power (AP), and peak power (PP) were calculated.

The mean value for the HS 1RM for the group was  $188.78 \pm 35.64\text{kg}$ . Lactate threshold was identified for each subject and the mean absolute load at LT was  $43.72 \pm 11.87\text{kg}$ . The average relative intensity for LT was  $22 \pm 3.54\%$  1RM. This relative mean value was lower than previously reported for LP and BP exercises. If the difference in results was due to the nature of the exercise (standing versus sitting or supine) or different stage duration (30-seconds versus 60-seconds) is unknown. During the CL protocol HR stabilized from S6 until the end of the test. Blood lactate concentration stabilized from S3 until the end of the test. There were no significant differences in RPE throughout the test. Results of the CMJ tests showed significant power losses in all three variables of H, AP, and PP. The correlations between losses in power and  $[\text{BLa}^-]$  for H ( $r = 0.028$ ,  $p = 0.587$ ), AP ( $r = 0.072$ ,  $p = 0.504$ ), and PP ( $r = 0.359$ ,  $p = 0.076$ ) indicated no likely effects of lactate levels on CMJ decrements. The main finding of this investigation was prolonged HS exercise at the LT load lead to significant reduction in jump power despite stable HR, RPE, and  $[\text{BLa}^-]$ . This was the first study to examine neuromuscular fatigue associated with CL RE exercise which was predominantly aerobic in nature.

In a follow up study, Garnacho-Castano et al. (2015) compared acute metabolic, cardiorespiratory, and RPE responses to two prolonged exercise sessions of CE and HS (smith machine) executed at a constant load equivalent to the LT. In addition, they examined which of these two protocols induced greater muscle fatigue, measured by changes in CMJ power. A smith machine half squat 1RM test was performed and the subsequent DIT protocol used 10,

10, 25, 30, 35, and 40% 1RM incremental stages. Each stage was one-minute in duration (30 repetitions at a two-second tempo), with two-minute passive rest during which load was changed and fingertip blood sampling was taken. Lactate threshold for HS was identified using the algorithm adjustment method. The CE test started with 50W resistance and 70 to 80 RPM, stage increments were 25W. Lactate threshold for CE was identified as the greatest load with a  $0.5 \text{ mmol}\cdot\text{L}^{-1}$  increase over baseline observed in at least two instances. Constant load test at LT intensity on the CE was 31-minutes in duration. The HS CL protocol consisted of 21 sets of 15 repetitions at a one-second eccentric/one-second concentric tempo (30-second set durations) for a session duration of 31 minutes. Blood sampling and RPE data for HS and CE protocols were matched by collecting at the end of set/minute (S/M) S3/M4, S6/M8.5, S9/M13, S12/M17.5, S15/M22, S18/M25.5, S21/M31 (end of test). During both CL tests HR was continuously recorded and breath-by-breath gas measurements we recorded for VE,  $\text{VO}_2$ ,  $\text{VCO}_2$ , and RER. To evaluate mechanical fatigue a force plate was used to measure H and MP before and after both CL tests with the same protocol of three maximal jumps separated by 30-seconds.

Results from 1RM testing revealed maximum values for HS of  $188.78 \pm 35.64\text{kg}$ . The absolute load at LT was  $43.72 \pm 11.87\text{kg}$  and the relative load at LT was  $23.35 \pm 4.32\%$  1RM. The mean power at LT from CE GXT was  $126.94 \pm 22.83 \text{ W}$ . Results from the CL tests revealed cardiorespiratory and RPE values ( $\text{VO}_2$ , HR, VE,  $\text{RPE}_{\text{legs}}$ , and  $\text{RPE}_{\text{overall}}$ ) were significantly greater for CE versus HS. Conversely, values for RER were significantly greater for HS compared to

CE. Countermovement jump data showed a significant decrease pre- to post CL for HS, but not for CE. There was a nonsignificant correlation between  $[BLa^-]$  and decrements in CMJ power.

Similar to the authors' previous 2015 study, a stabilization of metabolic, cardiorespiratory, and RPE measures for the CL HS session performed at the LT was observed. The CE CL session performed at the same relative intensity (LT) also resulted in stabilization of the same variables. Blood lactate concentration increased from rest to S3/M4 during HS and from rest to M13 during CE, and then stabilized to the end of testing for both conditions. The 2013 de Sousa et al. study demonstrated a plateau of variables between minutes 10 and 15 during CL protocols on CE and LP. The authors suggested these observed discrepancies may be attributed to different protocols, selected exercises, muscle groups used, and blood sampling procedures. With the exception of RER, the cardiorespiratory responses were significantly greater for CE compared to HS during CL protocols. Heart rate initially increased to minute four during HS and minute 8.5 during CE, then stabilized until end of the CL protocols. Heart rate was significantly greater during CE compared to HS and the authors suggested the two-minute rest intervals in the HS protocol could account for this difference. The nature of the RE and the previously described hemodynamic effect of resistance exercise makes continuous HS unviable. The authors concluded different exercise modes such as HS and CE provoke different physiological and mechanical responses despite a similar intensity of exercise equivalent to the mode specific LT. The mechanical fatigue induced by the HS serve as an interesting concept for future

research to better describe and understand the potential benefits of lighter RE protocols designed to induce a predominantly aerobic metabolic response.

Mate-Munoz et al. (2015) used the HS exercise to examine the cardiorespiratory and metabolic responses to CL at LT intensity. This research team included members of the Garnacho-Castano et al. (2015) group and the protocols were similar, however, additional respiratory variables were examined. Twenty-four healthy males ( $21.5 \pm 1.8$  years of age) performed 1RM, DIT, and CL protocols as previously described by Garnacho-Castano et al. (2015). In addition to  $[BLa^-]$ , HR, RPE, RER, VE,  $VO_2$ ,  $VCO_2$ , the ventilatory equivalent for  $VO_2$  ( $VE \cdot VO_2^{-1}$ ) and  $VCO_2$  ( $VE \cdot VCO_2^{-1}$ ) were also analyzed. Results from 1RM testing showed maximum values of HS at  $203.7 \pm 42.2$  kg. Lactate threshold was detected in all subjects at an absolute load of  $49.9 \pm 16.15$  kg and relative load of  $24.8 \pm 4.8\%$  1RM. During the CL session,  $[BLa^-]$  remained stable from S3 to S21, the end of the test ( $3.07 \pm 1.0$ ,  $3.37 \pm 0.7$  mmol $\cdot$ L $^{-1}$ , respectively). Heart rate stabilized from S3 to end of the test, although a slight increase (nonsignificant) was observed. Ventilatory responses revealed initial significant increases in  $VO_2$  and  $VCO_2$  from rest to S3, but then both measures showed no further statistically significant increases from S3 to end of test. Pulmonary ventilation differed significantly between S3 and S18 or S21, but there were no significant differences between S3 and other sets. Values for  $VE \cdot VO_2^{-1}$  stabilized from S6 to S21 ( $27.3 \pm 1.9$ ,  $28.0 \pm 2.1$  L $\cdot$ min $^{-1}$ , respectively). Values for  $VE \cdot VCO_2^{-1}$  showed significant differences only between rest ( $27.3 \pm 2.4$  L $\cdot$ min $^{-1}$ ), S15 ( $29.7 \pm 1.8$

L•min<sup>-1</sup>), S18 ( $29.8 \pm 1.9$  L•min<sup>-1</sup>), and S21 ( $30.0 \pm 2.0$  L•min<sup>-1</sup>). There were no significant differences in RER values observed across all sets.

In agreement with previous studies, LT was successfully identified in all subjects using a DIT. The intensity associated with the LT was  $24.8 \pm 4.8\%$  1RM, similar to the HS results from Garnacho-Castano et al. (2015) ( $23.35 \pm 4.32\%$  1RM). This relative intensity is lower than results from LP and BP studies where LT was identified closer to 30% 1RM. Mate-Munoz et al. (2015) in this study suggested this difference is due to the nature of the HS exercise, a standing task which elicits greater muscle mass involvement compared to LP and BP. The authors also compared the LT parameters from the DIT to the mean and maximum values from the CL protocol. With the exception of HR,  $VE \cdot VO_2^{-1}$ , and  $VE \cdot VCO_2^{-1}$  all the other variables were significantly higher measured at LT in the DIT compared to CL. The authors suggested this could be a result of differences between protocol stage and rest durations. The DIT was one minute of work versus 30 seconds in the CL along with two versus one-minute rest period, respectively. Discrepancies in protocols between this and previous studies were identified as a potential limitation to fully address the adaptations and interpretation for general recommendations for RE and the LT intensity. However, this study provided additional information that a standing exercise such as the HS provides different relative intensities for RE at the LT compared to exercises where body mass is supported by external structures (leg press and bench press equipment design).

Mate-Munoz and colleagues (2017) published a related study using the same 24 male subjects ( $21.5 \pm 1.8$  years of age) sample (Mate-Munoz et al., 2015). However, this time the HS DIT data analyses included calculation and evaluation of the VT from pulmonary gas analysis in addition to LT to determine if both thresholds were produced at the same workload. In addition, two methods for detecting LT and VT (VI versus AA) were compared. Ventilatory threshold was calculated using breath-by-breath data in three ways; the workload at which VE started to rise exponentially (VT-VE); the workload which corresponded to the first increase in  $VE \cdot VO_2^{-1}$  absent a concomitant increase in  $VE \cdot VCO_2^{-1}$  (VT- $VE \cdot VO_2^{-1}$ ); the first increase in end tidal partial pressure of oxygen (VT-PetO<sub>2</sub>). Results from the AA method revealed there was not a significant difference between LT and VT-VE and there was a strong positive correlation between the values ( $r = 0.761$ ,  $p < 0.001$ ). There was also not a significant difference between LT and VT- $VE \cdot VO_2^{-1}$  and there was also a strong positive correlation between these two values ( $r = 0.768$ ,  $p < 0.001$ ). When comparing the LT and VT values derived from the two methods, AA and VI, no significant differences were observed.

The main findings from these additional analyses were LT and VT (calculated from three different methods) were identified at the same intensity during the DIT using the HS exercise. The results for VI and AA methods to detect LT and VT were not statistically different from each other and relationship between these AT thresholds were significant and positively correlated. Breakpoints in [BLa<sup>-</sup>] and VE occurred at a similar intensity (LT = 24.8% 1RM, VT

= ~23.5 %1RM). These data were consistent with values of LT ( $27.1 \pm 3.7\%$  1RM) and VT ( $30.3 \pm 7.9\%$  1RM) obtained by de Sousa et al. (2012).

In a more recent study by Campos et al. (2017) investigated the relationship between LT identified using  $[BLa^-]$  during a GXT on a treadmill (TM) and a DIT on the LP exercise. Twelve male subjects ( $29.27 \pm 3.24$  years of age), all runners with three to five years' experience competitive running was the subject cohort. Their 5000-meter run performance data was 20-minutes: 37.8-seconds  $\pm$  2-minutes: 21-seconds. Each subject performed, in a randomized order, incremental protocols on both TM and LP. After completing 1RM testing on LP the DIT protocol was one-minute stages, two-minute recovery between stages, three second per repetition tempo (two-seconds eccentric/one-second concentric), initiating at 10% 1RM followed by 20, 25, 30, 35, 40 %1RM, with subsequent increases of 10% 1RM to exhaustion. The TM GXT was three-minute stages (with 30-second pauses for blood sampling from earlobe), initiating at  $8.0 \text{ km} \cdot \text{hr}^{-1}$  with 1% slope and subsequent  $1.2 \text{ km} \cdot \text{hr}^{-1}$  increments to maximal exertion. Blood lactate analysis demonstrated no significant difference between TM and LP at AT ( $4.80 \pm 1.27 \text{ mmol} \cdot \text{L}^{-1}$ ,  $5.30 \pm 1.33 \text{ mmol} \cdot \text{L}^{-1}$ , respectively). This data is consistent with Simões et al. (2014) where a nonsignificant difference was observed between CE and LP for apparently healthy, elderly men. It is noteworthy that detection of LT is repeatedly demonstrated to be reliable using different modes of dynamic (TM and CE) and RE in different populations.



#### **4. Summary of Findings**

In summary, the published research up to this point, provides compelling evidence that discontinuous graded exercise tests provide a valid and reliable method to identify the AT during RE measured by blood lactate accumulation, pulmonary ventilatory parameters, and HRV. In addition, once the intensity corresponding to LT and/or VT is identified, a prolonged discontinuous session, for durations of about 30-minutes, at AT intensity, have resulted in steady-state type cardiorespiratory and metabolic responses. These responses are similar to those seen in dynamic/cardio exercise performance such as running, cycling, and swimming. This point is further supported by data demonstrating dynamic exercise modes, including CE and running, elicit similar AT values compared to RE. This aerobic profile of RE may provide useful application to clinical, apparently healthy, and sports performance populations. For individuals with known disease, specifically diabetes and coronary artery disease, the LT exercise intensity domain may impart both positive muscular strength and metabolic outcomes, in addition to, cardiovascular benefits with lower risks compared to higher intensities. For general and athletic populations RE prescription at this intensity may be an effective way to stimulate improvements in local muscular endurance, central and peripheral cardiorespiratory fitness without the musculoskeletal impact associated with higher impact activities such as running. In addition, possible underlying mechanisms related to motor unit recruitment and hemodynamic characteristics of discontinuous RE protocols described may provide unique chronic training adaptations. Subsequent studies

should investigate other exercise modes which include combined upper- and lower-body movements, include women participants, and address longer term training studies to examine the physiological and performance adaptations.

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### CHAPTER 3: METHODS

The primary objective of this study was to describe and quantify the cardiorespiratory and metabolic responses during while performing a discontinuous incremental resistance exercise test and a subsequent constant load protocol performed at an intensity equivalent to the lactate threshold. The specific aims of this study were the following: 1) ascertain if an anaerobic threshold would be identified by analyzing both the LT and VT during the DIT using the hexagonal bar deadlift; 2) calculate the relative load (percentage of maximum) corresponding to LT and VT identified from the DIT and determine if there was a significant difference between the two values; 3) describe and quantify the HR, pulmonary ( $\text{VO}_2$ ,  $\text{VE}$ ), and  $[\text{BLa}^-]$  responses during the CL exercise session to determine if these physiological parameters stabilized; and 4) describe and quantify differences in physiological parameters between women and men participants, if any. We hypothesized, using the visual identification method (de Sousa et al., 2011; Moreira et al., 2008; Oliveira et al., 2006; Simões et al., 2016, 2010; Sperling et al., 2016) to determine both LT and VT, that there would be no statistically significant difference in the relative workloads between the two thresholds and these parameters. We also hypothesized that during the CL protocol these physiological parameters ( $[\text{BLa}^-]$ ,  $\text{VO}_2$ , HR) would stabilize in the latter stages. We further hypothesized that there would be no statistically significant differences in responses between women and men during the DIT or CL protocols.

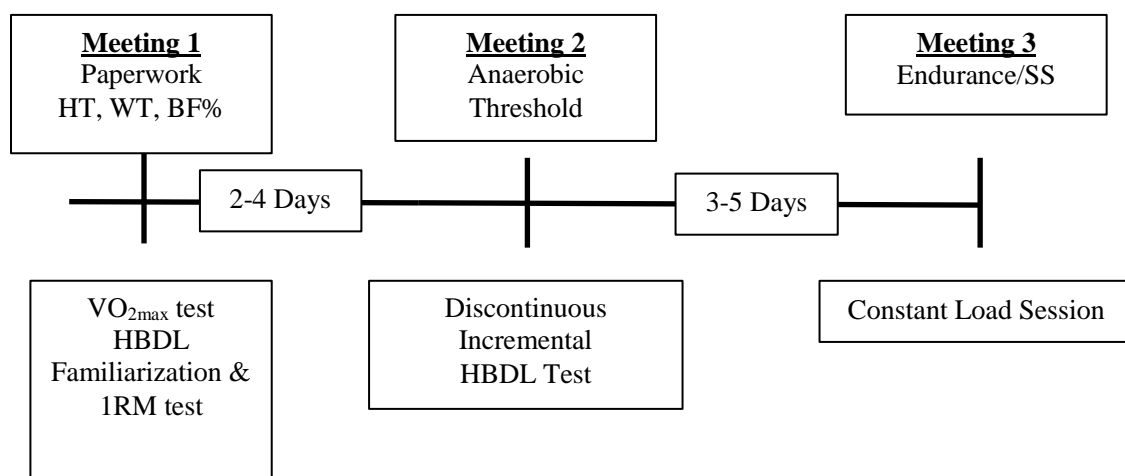


## EXPERIMENTAL APPROACH TO THE PROBLEM

This study examined the relationships between acute cardiorespiratory and metabolic responses during incremental and constant load resistance exercise protocols in women and men. All trials were performed in the same exercise laboratory. Trials were performed at a similar time of day ( $\pm 2$  hours) and separated by at least 48-hours but no more than five days. Participants were instructed to refrain from vigorous exercise for 24-hours, alcohol and caffeine for 3-hours prior to all testing sessions. In addition, participants were instructed to consume the same small meal, drink adequate fluids/water two- to three-hours prior to each trial, and to refrain from any strenuous resistance or aerobic exercise throughout the duration of their participation in the study. Each participant performed four exercise trials during three separate visits to the lab. All subjects performed a standardized warm-up plus a self-selected stretching/mobility routine before each session and were provided a familiarization session in form on the HBDL exercise supervised by an experienced, certified strength and conditioning professional.

The order of the tests was the following: 1) an incremental maximal running test on a motorized treadmill (TM); 2) a one-repetition maximum (1RM) hexagonal barbell deadlift test; 3) a discontinuous maximal incremental test for the HBDL; and 4) a constant load HBDL test at the LT intensity. Both the  $VO_{2max}$  TM and 1RM HBDL tests were performed during the first visit, with the DIT and CL tests performed on visits two and three respectively.

The goal of the TM max test was to establish  $VO_{2max}$ , peak heart rate, and mode specific maximal lactate. After a 30-minute rest following the  $VO_{2max}$  test, each participant completed the 1RM test to meet inclusion criteria and to establish the loading scheme for the subsequent DIT. During the second visit, the DIT was performed to determine LT, VT, and identify the load equivalent to LT for the CL protocol. During the third session, participants performed the CL intermittent resistance exercise protocol at the predetermined LT intensity to collect cardiorespiratory and metabolic data. All RE tests were performed using the hexagonal bar deadlift task. For the DIT and CL sessions each repetition cycle was three-seconds in duration, with participants instructed to perform the ascent (concentric) phase “fast” using proper form, the lowering (eccentric) phase at a comfortable speed, and not to begin the subsequent repetition until they heard and/or saw the visual and audible cue from a digital timer (Interval Timer Pro, Deltaworks).



## **PARTICIPANTS**

Following an estimation of the sample size required for the primary comparisons, six healthy men (age  $28.67 \pm 5.99$  years; height  $177.6 \pm 6.73$  cm; body mass  $81.58 \pm 7.98$  kg; %BF  $14.23 \pm 3.28$ ;  $\text{VO}_{2\text{max}}$   $45.58 \pm 4.28$  ml•kg<sup>-1</sup>•min<sup>-1</sup>; 1RM  $177.36 \pm 16.23$  kg) and six healthy women (age  $25.17 \pm 3.87$  years; height  $162.3 \pm 6.6$  cm; body mass  $60.30 \pm 8.30$  kg; %BF  $20.15 \pm 5.93$ ;  $\text{VO}_{2\text{max}}$   $43.17 \pm 2.54$  ml•kg<sup>-1</sup>•min<sup>-1</sup>; 1RM  $108.57 \pm 14.81$  kg) were recruited from the University of New Mexico, Albuquerque area and participated in the study. All subjects had deadlift exercise experience and a minimum of six months strength training, aerobic type training, and high intensity interval training.

## **PROCEDURES**

### **Data Collection, Exercise Testing, Screening**

#### *Health History and Anthropometrics*

Prior to any testing, all participants completed a health history questionnaire to identify risks associated with maximal exercise testing, and to ensure they were free of known cardiovascular, metabolic, renal disease, orthopedic limitations, anabolic steroid use, or any other condition that would contraindicate safe maximal exercise testing. The research team reviewed forms to ensure potential subjects had no excluding conditions. Women were provided a pregnancy test. None of the women participants tested positive for pregnancy which was an exclusion criterion. An additional exclusion criterion was a maximal strength level (1RM) on the HBDL of at least 1.4 times body mass for women or

1.6 times body mass for men at the time of the study. All participants provided written informed consent prior to participating in the study and signed Institutional Review Board approved informed consent forms.

After completion of paperwork each participant had her/his height and weight measured, followed by body composition assessment using skinfold calipers (Lange, Beta Technologies, Cambridge Maryland). Body fat was calculated using a three-site formula; chest, abdomen, thigh for males, and triceps, suprailium, thigh for females (Jackson & Pollock, 1978).

### **VO<sub>2max</sub> Test**

After anthropometric data was collected participants completed a maximal effort TM (Quintin Q-Stress TM55, Quinton Cardiology Systems, Bothell, WA, USA) protocol for VO<sub>2max</sub> determination. Each participant had the TM protocol explained, then was fitted with a chest strap for continuous heart rate measurement (Polar Electro, Finland), headgear and facemask for continuous measurement of oxygen consumption, carbon dioxide production, and ventilation (VE) using a metabolic analyzer (TrueOne 2400, Parvomedics, Sandy, UT, USA). After a five-minute easy jog as a warmup, an individualized treadmill ramp protocol started at a self-selected comfortable running speed at an incline of 3% and then increased by 0.4 miles per hour each minute/stage until volitional fatigue. At the end of each stage participants indicated their perception of effort using the 6-20 Borg Scale of Perceived Exertion (Borg, 1982). Immediately after

the test an earlobe blood sample was collected for determination of blood lactate concentration.

### **One-Repetition Maximum Test**

After at least 30-minutes of passive rest, subjects performed the 1RM HBDL protocol. Participants were familiarized and instructed on how to perform proper biomechanics of the HBDL task prior to the 1RM testing, and then again before each subsequent HBDL session. Performance of the HBDL consisted of the following; Set Up using a conventional stance about shoulder width or slightly wider; slight external rotation in the hips; feet slightly turned out; feet remaining flat throughout the movement; braced neutral spine; shoulders higher than hips; shoulders down; and back with chest lifted (depression and retraction of shoulder girdle). The point of separation/start of ascent/concentric phase included the following directions: shoulders and hips move together at the same speed; and stiff spine/torso to maintain neutral spine. For the top position/end of the ascent/concentric phase instructions were as follows: stand with upright torso; hips fully extended; knees extended; and shoulder girdle depressed and retracted.

The 1RM test followed a standardized protocol (Seo et al., 2012). Initially, participants performed 8-10 repetitions of a light load (~50% of their anticipated 1RM) through full range of motion with proper form. After one- to two-minutes of passive rest, subjects performed a second set with a moderately heavy load (~80% of their anticipated 1RM). Subsequently, up to six maximal single

repetition attempts with five-minute inter-set passive rest periods were completed. After each successful attempt, the load was increased based on the participant's self-perceived capacity until a failed attempt occurred or the participant identified maximal effort and requested to terminate the test. The maximal load successfully completed was recorded as the 1RM. Participants received strong verbal encouragement throughout the test and were reminded they could end the test whenever desired.

Each participant's 1RM results were used to determine eligibility for participation in the remainder of the study. Strength specific exclusion criterium was established as a 1RM less than 1.4 times body mass for women or less than 1.6 times body mass for men (retrieved from <https://strengthlevel.com/strength-standards/hex-bar-deadlift>). For participants meeting inclusion criteria, 1RM results were used to determine the starting and incremental loading stages for the subsequent DIT. All 1RM HBDL tests were performed using a standard 22.68 kg (50 pound) hexagonal bar (CAP Barbell, Houston Texas). Exercise form and range of motion was monitored for all attempts by a qualified member of the research team. A general warm-up and familiarization period preceded the 1RM test. Coaching points for correct performance technique were reinforced during the warm-up of all subsequent testing sessions as described above.

### **Discontinuous Incremental Test**

Participants returned to the exercise laboratory for the DIT (Visit 2) a minimum of 48 hours, but not more than five days following the 1RM test.

Participants were instructed to consume a small meal two to three hours before arriving, and to arrive at the lab two-hours postprandial. Participants were instructed to consume at least a pint of water 2-3 hours prior to each session, and to refrain from exercise and alcohol for 24-hours, and caffeine for four-hours prior to the visit. Participants completed the DIT with the HBDL in order to identify their individual LT and VT workloads. The participants performed a general warm-up consisting of treadmill jogging for five minutes and a self-selected stretching/mobility exercise sequence before the test. Throughout the DIT participants wore headgear and facemask connected to a metabolic analyzer for continuous measurement of  $\text{VO}_2$  and VE. In addition, a heart rate monitor was worn throughout the test to measure cardiac responses. Lifting straps were not used during the DIT as pilot testing demonstrated grip was not a limiting factor during the DIT. One-minute of quiet seated pulmonary gas and HR data, as well as a capillary blood sample (0.5 to 0.7 microliters) from an earlobe in duplicate for [BLa-] determination (Lactate Plus, Nova Biomedical, MA) was also collected before trials to establish baseline measures.

The multiple stage discontinuous resistance exercise protocol used in this study has been validated in previous investigations (de Sousa et al., 2012; Garnacho-Castaño, Domínguez, Ruiz-Solano, & Maté-Muñoz, 2015; Maté-Muñoz et al., 2015; Simões et al., 2013) and shown to be effective for identifying the physiological thresholds considered here. Stages were one minute in duration with a 90-second seated passive recovery between stages, during which the bar load was increased, RPE recorded, and earlobe blood samples were

collected in duplicate. The selected stage intensities were 10, 20, 25, 30, 35, 40, 45, 50, 55, 60% 1RM. The division of intensities was chosen based on previous findings demonstrating the anaerobic threshold intensity during RE occurs around 30% 1RM during a DIT (de Sousa et al., 2012; Garnacho-Castaño, Domínguez, Ruiz-Solano, & Maté-Muñoz, 2015; Maté-Muñoz et al., 2015; Simões et al., 2013). During each stage subjects performed 20 repetitions at a tempo of three-seconds per repetition. Tempo was controlled through an audible and visual cue from an electronic metronome. Participants were instructed and encouraged to lift (concentric phase) at a “fast” tempo to full extension and to return the bar to the ground (eccentric phase) at a comfortable tempo and not to initiate the next repetition until the cue from the metronome. This strategy provided a brief moment (approximately 1 to 1.5 seconds) to reset and re-grip as needed before initiating the next repetition and to remove bouncing of the weight, eliminating momentum for the subsequent repetition. This also promoted a positional reset and re-gripping of the bar as needed for proper lifting biomechanics. Lifting chalk (magnesium carbonate) was used for grip as needed/preferred by each subject. Participants were encouraged to complete as many stages as possible but were reminded they were free to stop the test at any time.

### **Constant Load Session**

A minimum of 48-hours, but not more than five days following the DIT, subjects returned to the exercise laboratory for the CL trial (Visit 3). Participants



were instructed to consume a small meal 2-3 hours before arriving, and to arrive at the lab two-hours postprandial. Participants were instructed to consume at least a pint of water two- to three-hours prior to the visit, and to refrain from exercise and alcohol for 24-hours, and caffeine for four-hours prior to the visit. Participants completed the HBDL exercise session at a constant load equivalent to their individual LT intensity, determined from the DIT session (Visit 2) and VI analysis of load by  $[BLa^-]$ . Prior to activity, resting HR and resting  $[BLa^-]$  were recorded. A similar warm-up protocol as used for the DIT was performed prior to the CL session. The CL session was approximately 36-minutes in duration, divided into 15 one-minute stages, with 90-second passive rest intervals between each stage.

Participants wore a HR monitor and were connected to the metabolic cart as described for the DIT. One-minute of resting pulmonary gas and HR data, as well as, a blood sample (0.5 to 0.7 microliters) from an earlobe in duplicate for  $[BLa^-]$  determination was collected before the trial to establish baseline measures. Participants performed 20 repetitions at the three-second tempo in the same manner used for the DIT. Participants were again instructed and encouraged to perform the ascent phase at a fast tempo, to lower the weight at a comfortable speed, and re-set before the subsequent repetition. During the 90-second rest interval after stage 3 (S3), S6, S9, S12, and S15 RPE was recorded immediately and blood samples were collected within 30- to 40-seconds for determination of  $[BLa^-]$ . Exercise form and range of motion were continuously

monitored. Repetition initiation and duration were cued with audible and visual signals using the electronic metronome.

## **MEASUREMENT AND INSTRUMENTATION**

### **Anthropometric Measurements**

Height was measured during the first visit and weight was measured at the beginning of each session to capture for possible changes in body mass. Upon arrival for the first exercise testing trial, body density was estimated using a standardized three-site skinfold (Lange, Beta Technology, Cambridge, MD) measured in duplicate. Each participant had their skinfold measurements taken by the same technician. Body density was estimated according to Jackson and Pollock's equation (1978) and converted to body fat percentage using Siri's equation (1956).

### **Metabolic Gases and Heart Rate**

During TM, DIT and CL exercise trials, expired gases were continuously measured using breath-by-breath sampling to obtain metabolic variables ( $\dot{V}E$  and  $\dot{V}O_2$ ). The metabolic gas analyzer was calibrated prior to each exercise session in accordance with manufacturer guidelines. Heart rate was monitored continuously using a heart rate monitor and chest strap.

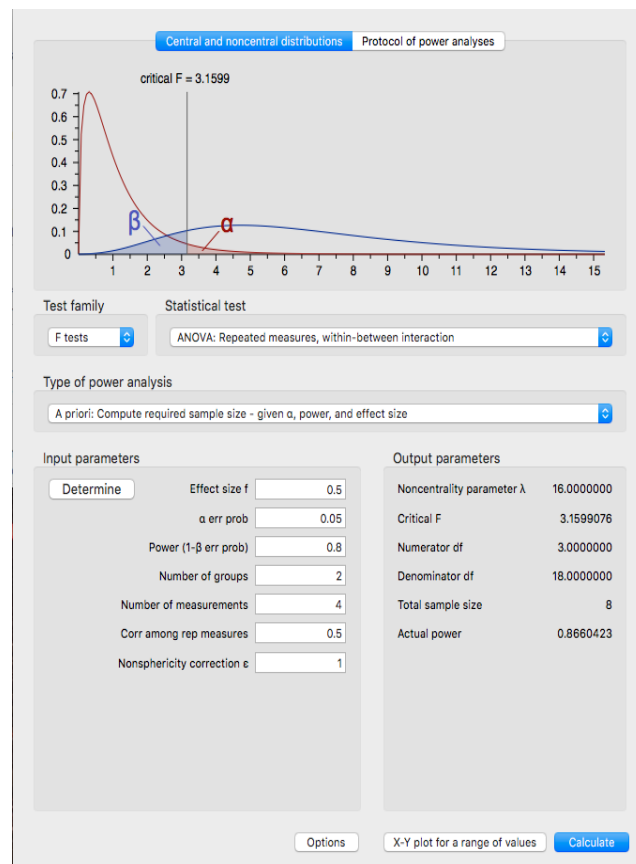
## **Blood Lactate**

Arterialized capillary blood samples for determination of  $[BLa^-]$  were collected pre- and immediately post exercise (IPE) for the max TM test, pre- and 30- to 40-seconds after each stage for the DIT. For the CL session  $[BLa^-]$  was measured pre- and post-stages 3, 6, 9, 12, and 15. All  $[BLa^-]$  samples throughout the study were collected at the earlobe. Blood samples were collected and analyzed in duplicate to measure capillary lactate concentration using a lactate meter (Lactate Plus, Nova Biomedical, Waltham, MA, USA).

## **Statistical Analysis**

Sample size was determined a priori using SPSS Software (Somers, NY, USA) with level of significance set at  $p = 0.05$  and power  $(1-\beta) = 0.80$  in order to detect a large effect. The normal distribution of the data was checked using Shapiro-Wilk's test ( $p > .05$ ). All variables analyzed produced normal distribution. A paired t-test was used to compare the intensity (workload) at LT versus VT. Lactate threshold was identified as the intensity at which there is a non-linear increase in blood lactate versus workload identified with the visual identification method (de Sousa et al., 2011; Moreira et al., 2008; Oliveira et al., 2006; Simões et al., 2016, 2010; Sperling et al., 2016). Using the visual identification method (Maté-Muñoz, Domínguez, Lougedo, & Garnacho-Castaño, 2017), the ventilatory threshold (VT1) was identified when VE began to increase in an exponential manner versus workload. One-way repeated measures ANOVA analyses were conducted to determine whether there were statistically significant differences in

the selected parameters [BLa<sup>-</sup>], VO<sub>2</sub>, and HR compared across different time points (S3, S6, S9, S12, S15) during the CL trial. Assumption of sphericity was verified by the Mauchley test. If the assumption of sphericity was not met, the significance of the F-ratios was adjusted according to the Greenhouse-Geisser procedure. Post-hoc tests with Bonferroni adjustment was applied in the event of a significant difference. The level of significance was  $p < .05$  and SPSS version 26.0 (Somers, NY, USA) was used. Independent samples t-test was used to determine if there were statistically significant differences in responses between women and men from the DIT. Two-way mixed ANOVA analyses were conducted to determine whether there were statistically significant differences between women and men during the CL trial.



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## CHAPTER IV: RESULTS

The results of this study are presented in the following sections: a) descriptive statistics and comparison of relative intensity at LT and VT from the discontinuous incremental test (DIT), b) relative intensities, blood lactate, oxygen consumption, heart rate responses, and gender comparisons from the DIT, c) physiological responses during the constant load (CL) trial performed at the intensity equivalent to the LT, d) gender comparisons in physiological responses during the CL trial.

### DESCRIPTIVE STATISTICS AND COMPARISON OF LT VERSUS VT

Descriptive data, results from maximal treadmill (TM), and HBDL 1RM tests for all participants are provided in Table 1. Independent samples t-tests were conducted to determine if there were statistically significant differences between women and men. The men were significantly taller ( $p = .03$ ), heavier ( $p = .001$ ), and stronger (1RM) ( $p < .0005$ ) than the women. However, with respect to strength, when adjusted for body weight (1RM / BW) there was not a statistically significant difference in strength ( $p = .07$ ) between women and men.



**Table 1:** Descriptive statistics, TM-VO<sub>2max</sub>, and HBDL 1RM results.

	Pooled	Women	Men
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
Participants	n=12	n=6	n=6
Age (y)	26.92 $\pm$ 5.14	25.17 $\pm$ 3.87	28.67 $\pm$ 5.99
Height (cm)	169.95 $\pm$ 10.19	162.34 $\pm$ 6.59	177.60 $\pm$ 6.73*
Weight (KG)	70.94 $\pm$ 13.56	60.30 $\pm$ 8.30	81.58 $\pm$ 7.98*
Body Fat (%)	17.19 $\pm$ 5.51	20.15 $\pm$ 5.93	14.23 $\pm$ 3.28
VO <sub>2max</sub> -TM (ml•kg <sup>-1</sup> •min <sup>-1</sup> )	44.38 $\pm$ 3.59	43.17 $\pm$ 2.54	45.58 $\pm$ 4.28
HR Max-TM (beats•min <sup>-1</sup> )	188.50 $\pm$ 15.26	188.5 $\pm$ 7.77	188.5 $\pm$ 21.26
La <sup>-</sup> Max-TM (mmol•L <sup>-1</sup> )	7.96 $\pm$ 1.99	7.52 $\pm$ 1.89	8.49 $\pm$ 2.17
1RM-HBDL (kg.)	142.96 $\pm$ 38.86	108.57 $\pm$ 14.81	177.36 $\pm$ 16.23*
Relative Strength (1RM/Body Weight)	2.01 $\pm$ 0.35	1.82 $\pm$ 0.36	2.19 $\pm$ 0.25

HR = Heart rate; TM = treadmill; 1RM = one-repetition maximum; HBDL = hexagonal bar deadlift.

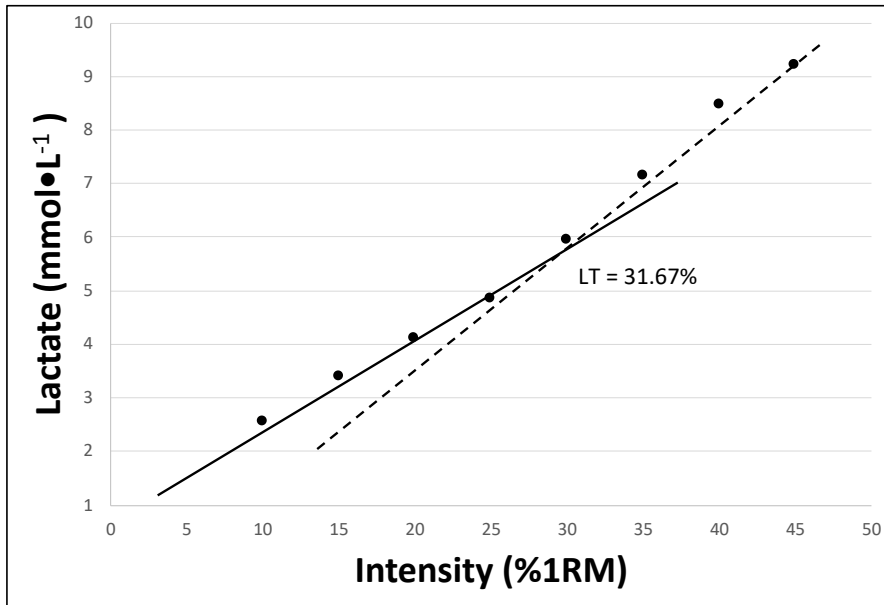
\* Differs significantly versus women ( $p < 0.05$ ).

## **DIT: RELATIVE INTENSITIES, BLOOD LACTATE, OXYGEN CONSUMPTION, HEART RATE RESPONSES AND COMPARISONS BETWEEN WOMEN AND MEN**

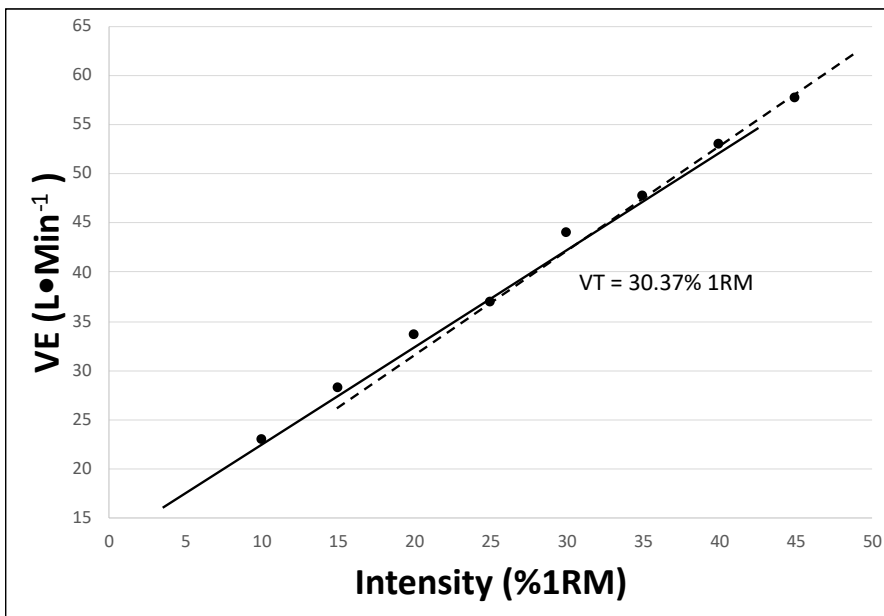
### **Lactate and Ventilatory Thresholds**

During the DIT, LT was identified in all participants by the VI method. The mean relative intensity corresponding to LT for all participants was 31.67  $\pm$  6.15% 1RM (Figure 1). The VT was identified in all participants using the VI

method. The mean relative intensity corresponding to VT for all participants was  $30.37 \pm 4.03\%$  1RM (Figure 2).



**Figure 1:** Identification of the lactate threshold (LT) using the visual inspection method on mean lactate values for all participants. RM = repetition max (n=12).



**Figure 2:** Ventilatory threshold using the visual inspection method on mean ventilation values for all participants. VE = ventilation, RM = repetition max (n=12).

A paired-samples t-test was used to determine whether there was a statistically significant mean difference between relative intensity (%1RM) at LT compared to VT. Two outliers were detected that were more than 1.5 box-lengths from the edge of the box in a box plot. Inspection of their values did not reveal them to be extreme and they were kept in the analysis. The assumption of normality was met, as assessed by Shapiro-Wilk's test ( $p > .05$ ). Participants' relative intensity was greater at LT ( $M = 31.67$ ,  $SD = 6.15\%$  1RM) compared to VT ( $M = 30.37$ ,  $SD = 4.03\%$  1RM), which was not a statistically significant difference of  $1.30\%$  1RM,  $95\%$  CI  $[-3.78, 5.78]$ ,  $t(11) = 0.461$ ,  $p = .65$ ,  $d = .13$ . The selected variables examined at the LT intensity during the DIT are provided in Table 2.

**Table 2:** Results from the discontinuous incremental resistance exercise test.

	Pooled (n = 12)	Women (n = 6)	Men (n = 6)
	Mean $\pm$ SD	Mean $\pm$ SD	Mean $\pm$ SD
LT intensity-HBDL (%1RM)	31.67 $\pm$ 6.15	35.00 $\pm$ 5.48	28.33 $\pm$ 5.16
VT intensity-HBDL (%1RM)	30.37 $\pm$ 4.03	32.17 $\pm$ 2.48	29.17 $\pm$ 4.92
[BLa <sup>-</sup> ]@LT-HBDL (mmol•L <sup>-1</sup> )	6.32 $\pm$ 1.49	6.25 $\pm$ 1.48	6.39 $\pm$ 1.66
VO <sub>2</sub> @LT (ml•kg <sup>-1</sup> •min <sup>-1</sup> )	26.02 $\pm$ 3.03	25.72 $\pm$ 2.83	26.31 $\pm$ 3.45
HR@LT (beats•min <sup>-1</sup> )	158.33 $\pm$ 15.82	157.00 $\pm$ 12.57	159.67 $\pm$ 19.71

LT = Lactate threshold HBDL = hexagonal bar deadlift; %1RM = percentage of one-repetition maximum; VT = ventilatory threshold; [BLa<sup>-</sup>]@LT = blood lactate concentration at LT; VO<sub>2</sub>@LT = oxygen consumption at LT; HR@LT = heart rate at LT. No statistically significant differences observed between women and men ( $p > 0.05$ ).

## Metabolic and Cardiorespiratory Responses, and Sex Comparisons

Independent samples t-tests were run to determine if there were statistically significant differences between women ( $n = 6$ ) and men ( $n = 6$ ) on the selected variables from the DIT; relative intensity at LT, relative intensity at VT, blood lactate ([BLa<sup>-</sup>]) at LT, oxygen consumption ( $\text{VO}_2$ ) at LT, and heart rate (HR) at LT. Data are mean  $\pm$  standard deviation, unless otherwise stated.

*Relative intensity at LT:* The mean relative intensity at LT for all participants was  $31.67 \pm 6.15\%$  1RM. There was one outlier that was more than 1.5 box-lengths from the edge in a box plot. Inspection of the value did not reveal it to be extreme and it was kept in for the analysis. Relative intensity at LT was normally distributed, as assessed by Shapiro-Wilk's test ( $p > .05$ ), and there was homogeneity of variances, as assessed by Levene's test for equality of variances ( $p = .79$ ). Relative intensity at LT was higher for women ( $M = 35.00$ ,  $SD = 5.48\%$  1RM) than men ( $M = 28.33$ ,  $SD = 5.16\%$  1RM), which was not a statistically significant difference,  $M = 6.67$ , 95% CI [-0.18, 13.51],  $t(10) = 2.17$ ,  $p = .055$ ,  $d = 1.25$ .

*Relative intensity at VT:* The mean relative intensity at VT for all participants was  $30.37 \pm 4.03\%$  1RM. There were no outliers in the data, as assessed by inspection of a boxplot. The assumption of normal distribution of scores was violated as assessed by Shapiro-Wilk's test for women ( $p = .03$ ) and for men ( $p = .04$ ). The t-test is robust to violations of the assumption of normality. The assumption of homogeneity of variances was violated, as assessed by Levene's test for equality of variances ( $p = .03$ ), as a result an alternative

analysis was conducted. A Welch t-test, which adjusts for unequal variances, was performed to determine if there were statistically significant differences in the relative intensity at VT between women and men. The relative intensity was higher for women ( $M = 32.17$ ,  $SD = 2.48\%$  1RM) compared to men ( $M = 29.17$ ,  $SD = 4.92\%$  1RM), which was not a statistically significant difference,  $M = 3.00$ , 95% CI [-2.26, 8.26],  $t(7.39) = 1.33$ ,  $p = .22$ ,  $d = .77$ .

*Blood lactate concentration at LT:* The mean  $[BLa^-]$  at LT for all participants was  $6.32 \pm 1.49$  mmol•L<sup>-1</sup>. There was one outlier that was more than 1.5 box-lengths from the edge in a box plot. Inspection of the value did not reveal it to be extreme and it was kept in for the analysis. Blood lactate values at the LT were normally distributed, assessed by Shapiro-Wilk's test ( $p > .05$ ), and there was homogeneity of variances, as assessed by Levene's test for equality of variances ( $p = .54$ ). Blood lactate at LT was higher for men ( $M = 6.39$ ,  $SD = 1.66\%$  1RM) than for women ( $M = 6.25$ ,  $SD = 1.48\%$  1RM), which was not a statistically significant difference,  $M = 0.14$ , 95% CI [-2.16, 1.88],  $t(10) = 0.16$ ,  $p = .88$ ,  $d = .09$ .

*Oxygen consumption at LT:* The mean  $VO_2$  at LT for all participants was  $26.02 \pm 3.03$  ml•kg<sup>-1</sup>•min<sup>-1</sup>. There were no outliers in the data, as assessed by inspection of a boxplot. Oxygen consumption at LT was normally distributed, as assessed by Shapiro-Wilk's test ( $p > .05$ ), and there was homogeneity of variances, as assessed by Levene's test for equality of variances ( $p = .69$ ). Oxygen consumption at LT was higher for men ( $M = 26.31$ ,  $SD = 3.45$  ml•kg<sup>-1</sup>•min<sup>-1</sup>) than women ( $M = 25.72$ ,  $SD = 2.83$  ml•kg<sup>-1</sup>•min<sup>-1</sup>), which was not a

statistically significant difference,  $M = 0.59$ , 95% CI  $[-4.66, 3.46]$ ,  $t(10) = 0.33$ ,  $p = .75$ ,  $d = .19$ .

*Heart rate at LT:* The mean HR at LT for all participants was  $158.33 \pm 15.82$  beats•min<sup>-1</sup>. There were no outliers in the data, as assessed by inspection of a boxplot. Heart rate at LT was normally distributed, as assessed by Shapiro-Wilk's test ( $p > .05$ ), and there was homogeneity of variances, as assessed by Levene's test for equality of variances ( $p = .37$ ). Heart rate at LT was higher for men ( $M = 159.67$ ,  $SD = 19.71$  beats•min<sup>-1</sup>) than for women ( $M = 157.00$ ,  $SD = 12.57$  beats•min<sup>-1</sup>), which was not a statistically significant difference,  $M = 2.67$ , 95% CI  $[-23.93, 18.60]$ ,  $t(10) = 0.279$ ,  $p = .79$ ,  $d = .16$ .

## **PHYSIOLOGICAL RESPONSES DURING THE CONSTANT LOAD TRIAL PERFORMED AT THE INTENSITY EQUIVALENT TO THE LT**

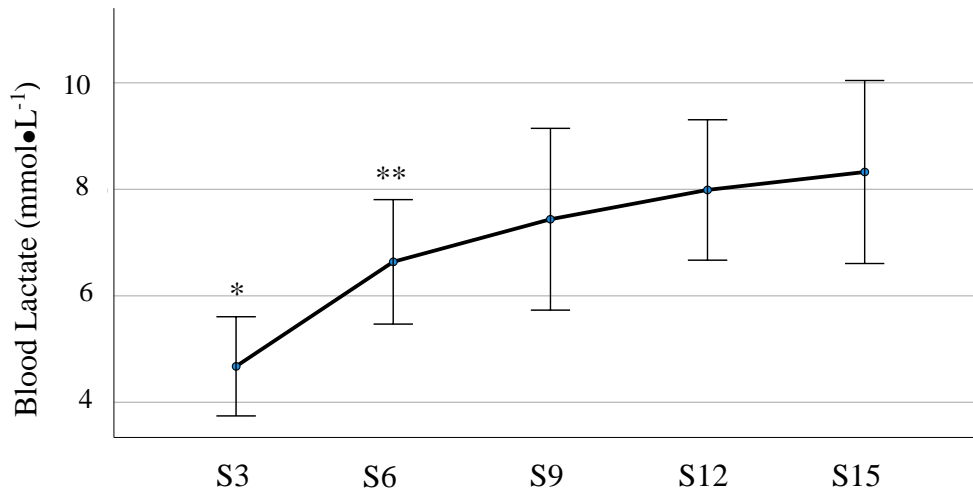
All participants completed at least 9 sets (S9), 11 participants completed at least 12 sets (S12), and 8 participants completed all 15 sets (S15) with the load equivalent to the LT intensity, as a result, statistics were run on only the eight participants, five women and three men, that completed all 15 sets. One-way repeated measures ANOVA analyses were conducted to determine whether there were statistically significant differences in the selected parameters  $[BLa^-]$ ,  $VO_2$ , and HR compared across different time points (S3, S6, S9, S12, S15) during the CL trial. There were no outliers and the data were normally distributed, as assessed by boxplot and Shapiro-Wilk's test ( $p < .05$ ), respectively (Table 3).

**Table 3:** Blood lactate and cardiorespiratory data from constant load exercise performed at the intensity equivalent to the lactate threshold.

	S3	S6	S9	S12	S15
Lactate (mmol•L <sup>-1</sup> )	4.68 ± 1.11 <sup>\$¢†‡</sup>	6.64 ± 1.39 <sup>#†‡</sup>	7.44 ± 2.04 <sup>#</sup>	7.98 ± 1.58 <sup>#</sup>	8.33 ± 2.05 <sup>#</sup>
VO2 (ml•kg <sup>-1</sup> •min <sup>-1</sup> )	25.10 ± 1.60	25.69 ± 2.58	26.07 ± 2.24	26.25 ± 2.57	27.73 ± 3.68
Heart Rate (beats•min <sup>-1</sup> )	139.38 ± 17.03 <sup>\$¢†‡</sup>	150.25 ± 15.97 <sup>#†</sup>	153.25 ± 13.58 <sup>#</sup>	156.50 ± 12.95 <sup>#</sup>	159.88 ± 12.61 <sup>#</sup>

# Differs significantly from S3 ( $p < .05$ ); \$ Differs significantly from S6 ( $p < .05$ ); ¢ Differs significantly from S9 ( $p < .05$ ); † Differs significantly from S12 ( $p < .05$ ); ‡ Differs significantly from S15 ( $p < .05$ ); n=8.

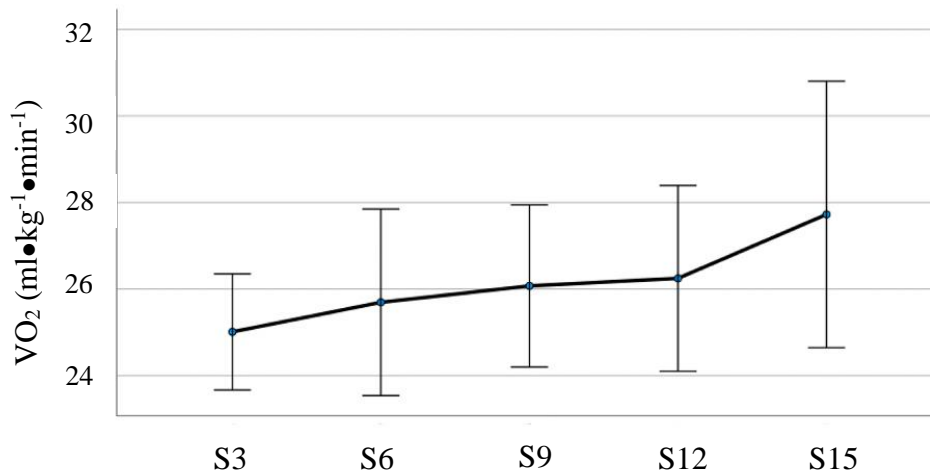
*Blood lactate concentration:* The assumption of sphericity was met, as assessed by Mauchly's test of sphericity,  $\chi^2(9) = 14.78$ ,  $p = .11$ . The series of CL sets elicited statistically significant changes in [BLa<sup>-</sup>] over time,  $F(4,28) = 25.40$ ,  $p < .001$ ,  $\eta^2 = .78$ , with La<sup>-</sup> increasing from S3 (M = 4.68, SD = 1.11 mmol • L<sup>-1</sup>) to S6 (M = 6.64, SD = 1.39 mmol•L<sup>-1</sup>) to S9 (M = 7.44, SD = 2.04 mmol•L<sup>-1</sup>) to S12 (M = 7.99 SD = 1.58 mmol•L<sup>-1</sup>) to S15 (M = 8.33, SD = 2.05 mmol•L<sup>-1</sup>). Post hoc analysis with a Bonferroni adjustment revealed that [BLa<sup>-</sup>] was statistically significantly increased from S3 to S6 (M = 1.96 mmol•L<sup>-1</sup>, 95% CI [0.32, 3.61],  $p = .02$ ), but not from S6 to S9 (M = 0.80 mmol•L<sup>-1</sup>, 95% CI [-0.50, 2.10],  $p = .43$ ), S9 to S12 (M = 0.55 mmol•L<sup>-1</sup>, 95% CI [-0.62, 1.72],  $p = .99$ ), or S12 to S15 (M = 0.34 mmol•L<sup>-1</sup>, 95% CI [-0.73, 1.42],  $p = 1.00$ ) (Figure 3).



**Figure 3:** Blood lactate concentrations during constant load resistance exercise. \*Differs significantly from all other stages ( $p < .05$ ); \*\*Differs significantly from S3, S12, and S15 ( $p < .05$ ); no statistically significant difference observed from S9 through S15. S=set #,  $n=8$ .

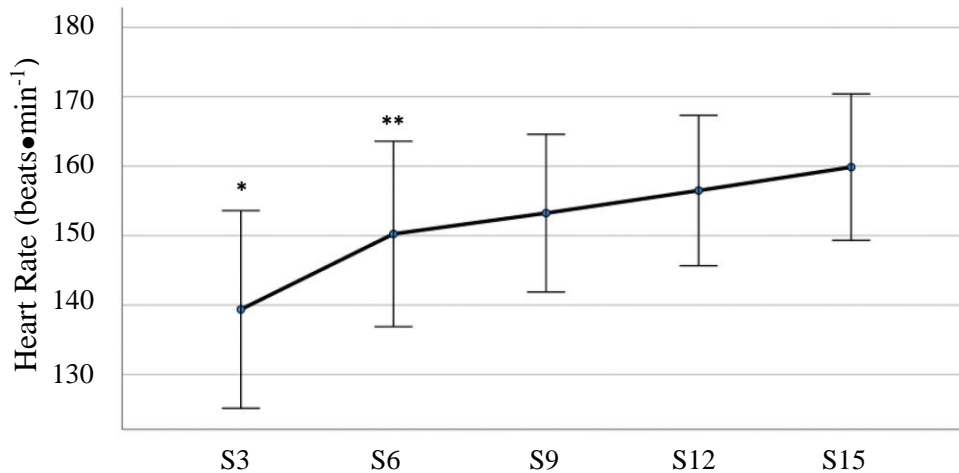
*Oxygen consumption:* The assumption of sphericity was met, as assessed by Mauchly's test of sphericity,  $\chi^2(9) = 11.16$ ,  $p = .29$ . The series of CL sets elicited statistically significant changes in  $VO_2$  over time,  $F(4,28) = 3.10$ ,  $p = .03$ , partial  $\eta^2 = .31$ , with  $VO_2$  increasing from S3 ( $M = 25.01$ ,  $SD = 1.60$   $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) to S6 ( $M = 25.69$ ,  $SD = 2.58$   $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) to S9 ( $M = 26.08$ ,  $SD = 2.24$   $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) to S12 ( $M = 26.25$ ,  $SD = 2.57$   $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ) to S15 ( $M = 27.73$ ,  $SD = 3.68$   $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ). Post hoc analysis with a Bonferroni adjustment revealed that  $VO_2$  did not statistically significantly increase from S3 to S6 ( $M = 0.68$   $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ , 95% CI [-2.97, 4.34],  $p = 1.00$ ), S6 to S9 ( $M = 0.38$   $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ , 95% CI [-1.90, 2.67],  $p = 1.00$ ), S9 to S12 ( $M = 0.18$   $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ , 95% CI [-1.83, 2.18],  $p = 1.00$ ), or S12 to S15 ( $M = 1.48$   $\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ , 95% CI [-1.88, 4.83],  $p = 1.00$ ) (Figure 4).





**Figure 4:** VO<sub>2</sub> during constant load resistance exercise. S=set #, n=8  
No statistically significant difference between consecutive stages.

*Heart rate:* The assumption of sphericity was met, as assessed by Mauchly's test of sphericity,  $\chi^2(9) = 14.03$ ,  $p = .14$ . The series of CL sets elicited statistically significant changes in HR over time,  $F(4,28) = 30.98$ ,  $p < .001$ ,  $\eta^2 = .82$ , with HR increasing from S3 (M = 139.38, SD = 17.03 beats•min<sup>-1</sup>) to S6 (M = 150.25, SD = 15.97 beats•min<sup>-1</sup>) to S9 (M = 153.25, SD = 13.58 beats•min<sup>-1</sup>) to S12 (M = 156.50, SD = 12.95 beats•min<sup>-1</sup>) to S15 (M = 159.88, SD = 12.61 beats•min<sup>-1</sup>). Post hoc analysis with a Bonferroni adjustment revealed that HR statistically significantly increased from S3 to S6 (M = 10.88 beats•min<sup>-1</sup>, 95% CI [3.24, 18.51],  $p = .007$ ), but not from S6 to S9 (M = 3.00 beats•min<sup>-1</sup>, 95% CI [-2.05, 8.05],  $p = .48$ ), S9 to S12 (M = 3.25 beats•min<sup>-1</sup>, 95% CI [-1.67, 8.17],  $p = .32$ ), or S12 to S15 (M = 3.38 beats•min<sup>-1</sup>, 95% CI [-1.13, 7.88],  $p = .19$ ) (Figure 5).



**Figure 5:** Heart rate during constant load resistance exercise.

\*Differs significantly from all other stages ( $p < .05$ ); \*\*Differs significantly from S3, and S15 ( $p < .05$ ). S=set #,  $n=8$ .

**Table 4:** Values from constant load exercise for lactate, oxygen consumption, and heart rate compared to maximal values derived from maximal treadmill test.

	S3 (n=8)		S6 (n=8)		S9 (n=8)		S12 (n=8)		S15 (n=8)	
	%Ma	%LT	%Ma	%LT	%Ma	%LT	%Ma	%LT	%Ma	%LT
	x		x		x		x		x	
[BLa <sup>-</sup> ]	67	86	96	123	112	143	119	145	116	147
VO <sub>2</sub>	56	102	59	108	59	107	59	106	62	117
HR	77	91	83	99	86	101	86	101	87	104

S(#) Set number; %Max Percentage of observed maximal value from treadmill test; %LT Percentage of observed lactate threshold value from treadmill test; [BLa<sup>-</sup>] Blood lactate concentration; VO<sub>2</sub> Oxygen consumption; HR heart rate.

## PHYSIOLOGICAL RESPONSES DURING THE CONSTANT LOAD TRIAL:

### WOMEN VERSUS MEN

To determine whether there were statistically significant differences between women ( $n = 5$ ) and men ( $n = 3$ ) in the CL trial, two-way mixed ANOVA analyses were conducted on the selected variables during the CL trial. Unless otherwise reported, there were no outliers and the data was normally distributed,

as assessed by boxplots and Shapiro-Wilk's test of normality ( $p > .05$ ), respectively. There was homogeneity of variances ( $p > .05$ ), as assessed by Levene's test of homogeneity of variances. Box's test of equality of covariances matrices was not computed because there were fewer than two non-singular cell covariance matrices.

*Blood lactate concentration ([BLa<sup>-</sup>]):* There was no statistically significant interaction between sex and time on [BLa<sup>-</sup>],  $F(4,24) = 1.02$ ,  $p = .42$ , partial  $\eta^2 = .15$ . The main effect of sex showed that there was no statistically significant differences in [BLa<sup>-</sup>] between women and men,  $F(1,6) = 4.66$ ,  $p = .07$ , partial  $\eta^2 = .44$ . The main effect of time showed a statistically significant difference in [BLa<sup>-</sup>] at the different time points,  $F(4,24) = 22.29$ ,  $p < .001$ , partial  $\eta^2 = .79$  (Table 5).

**Table 5:** Blood lactate response comparison between women and men during constant load exercise.

	Women (n = 5) (Blood lactate mmol•L <sup>-1</sup> )	Men (n = 3) (Blood lactate mmol•L <sup>-1</sup> )
Constant Load Set 3	5.09 ± 1.21*	3.98 ± 0.50*
Constant Load Set 6	7.41 ± 1.07**	5.35 ± 0.77**
Constant Load Set 9	8.41 ± 1.88	5.82 ± 1.08
Constant Load Set 12	8.57 ± 1.47	7.02 ± 1.45
Constant Load Set 15	9.20 ± 1.84	6.87 ± 1.70

\*Differs from all other sets ( $p < .05$ ); differs significantly from Set 3, 12, and 15 ( $p < .05$ ). No statistically significant interaction between sex and time; no main effect of sex; statistically significant main effect of time on blood lactate.

*Oxygen consumption (VO<sub>2</sub>):* There was no statistically significant interaction between sex and time on VO<sub>2</sub>,  $F(4,24) = 0.76$ ,  $p = .56$ , partial  $\eta^2 = .11$ . The main effect of sex showed no statistically significant difference in mean VO<sub>2</sub> between women and men,  $F(1,6) = 0.78$ ,  $p = .42$ , partial  $\eta^2 = .12$ . The main effect of time showed no statistically significant difference in VO<sub>2</sub> at the different time points,  $F(4,24) = 2.73$ ,  $p = .052$ , partial  $\eta^2 = .31$  (Table 6).

**Table 6:** Oxygen consumption response comparison between women and men during constant load exercise.

	Women (n = 5) (VO <sub>2</sub> ml•kg <sup>-1</sup> •min <sup>-1</sup> )	Men (n = 3) (VO <sub>2</sub> ml•kg <sup>-1</sup> •min <sup>-1</sup> )
Constant Load Set 3	24.06 ± 1.20	26.60 ± 0.26
Constant Load Set 6	25.73 ± 2.17	25.63 ± 3.72
Constant Load Set 9	25.62 ± 1.85	26.83 ± 3.05
Constant Load Set 12	24.40 ± 2.28	27.67 ± 2.80
Constant Load Set 15	24.24 ± 4.09	28.53 ± 3.51

No statistically significant interaction between sex and time; no main effect of sex; no main effect of time ( $p < .05$ ).

*Heart rate (HR):* There was no statistically significant interaction between sex and time on HR,  $F(4,24) = 2.40$ ,  $p = .08$ , partial  $\eta^2 = .29$ . The main effect of sex showed there was a statistically significant difference in mean HR between women and men,  $F(1,6) = 21.56$ ,  $p = .004$ , partial  $\eta^2 = .78$ . The main effect of time showed a statistically significant difference in mean HR at the different time points,  $F(4,24) = 39.07$ ,  $p < .001$ , partial  $\eta^2 = .87$  (Table 7).

**Table 7:** Heart rate response comparison between women and men during constant load exercise.

	Women (n = 5) (Heart Rate beats•min <sup>-1</sup> )	Men (n = 3) (Heart Rate beats•min <sup>-1</sup> )
Constant Load Set 3	150.20 ± 6.06*	121.33 ± 12.66*‡
Constant Load Set 6	160.80 ± 5.17**	132.67 ± 9.87**‡
Constant Load Set 9	161.60 ± 6.88	139.33 ± 9.29‡
Constant Load Set 12	164.40 ± 5.89	143.33 ± 10.07‡
Constant Load Set 15	167.40 ± 3.65	147.33 ± 12.34‡

\*Differs significantly from all other sets ( $p < .05$ ); \*\*Differs significantly from S3, and S15 ( $p < .05$ ); ‡differs from women ( $p < .05$ ). No statistically significant interaction between sex and time; statistically significant main effect of sex; statistically significant main effect of time.

## CHAPTER V: DISCUSSION

The discussion of the study is presented in the following sections: a) lactate and ventilatory threshold identification, b) physiological responses during constant load exercise at the intensity equivalent to the lactate threshold, c) comparison between sexes and steady-state resistance exercise, d) limitations, e) conclusion.

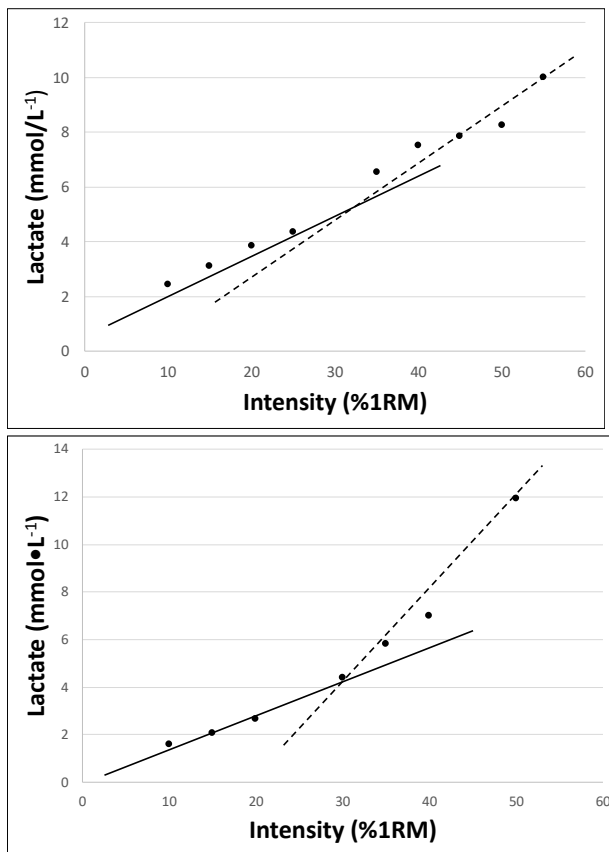
This is the first study to examine a combined upper- and lower-body resistance exercise using DIT and CL protocols and also the first to compare acute responses between women and men. Previous literature has focused on either upper-body resistance exercise, specifically biceps curl (Spendier, Müller, Korinek, & Hofmann, 2020) and bench press (Moreira et al., 2008; Oliveira et al., 2006) or lower-body exercise, specifically leg press (Campos et al., 2017; de Sousa et al., 2011; Oliveira et al., 2006; Rodrigo P Simões et al., 2016, 2010; Sperling et al., 2016) and half-squat (Garnacho-Castaño, Domínguez, Ruiz-Solano, & Maté-Muñoz, 2015; Maté-Muñoz et al., 2015). Acknowledging prior research demonstrated the identification of LT and VT during DIT, as well as, stabilization of physiological parameters during CL (de Sousa et al., 2012; Garnacho-Castaño, Domínguez, & Maté-Muñoz, 2015; Maté-Muñoz et al., 2015), this study extended findings to an exercise with different biomechanical and muscle recruitment profiles then currently exist in the literature. Inclusion of women as participants provided both descriptive and comparative analyses to inform a fundamental understanding of resistance exercise in this intensity and

volume domain and for additional evidence-based exercise program design and recommendations for both sexes.

### **Lactate and Ventilatory Threshold Identification**

A LT was successfully identified in all participants using the VI method and therefore hypothesis 1 was accepted. The observed value of  $31.67 \pm 6.15\%$  1RM was consistent with the literature which ranges from about 25% to 37% 1RM (de Sousa et al., 2013; de Sousa et al., 2012; Maté-Muñoz, Domínguez, Lougedo, & Garnacho-Castaño, 2017; Moreira et al., 2008; Oliveira et al., 2006; Simões et al., 2013; Simões et al., 2010). The first VT was not successfully identified using the VI method in all participants and therefore we failed to accept hypothesis 2. For the seven participants demonstrating a VT (women = 4, men = 3), the observed VT value of  $29.71 \pm 3.49\%$  1RM was consistent with the literature (de Sousa et al., 2012; Maté-Muñoz et al., 2017). In the participants demonstrating both thresholds, the observed difference of 4.58% between LT ( $32.29 \pm 5.35\%$  1RM) and VT ( $29.71 \pm 3.49\%$  1RM) which was not statistically significant. Therefore, hypothesis 3 was accepted, but it is noted that there was a reduced sample size ( $n = 7$ ) for this finding. For those demonstrating LT and VT, both occurred at the same relative intensity. However, the correlation between LT and VT was weak and not statistically significant ( $r = -.34$ ,  $p = .45$ ). There were no statistically significant differences observed during the DIT between women and men (Table 2) therefore hypothesis 7 was accepted.

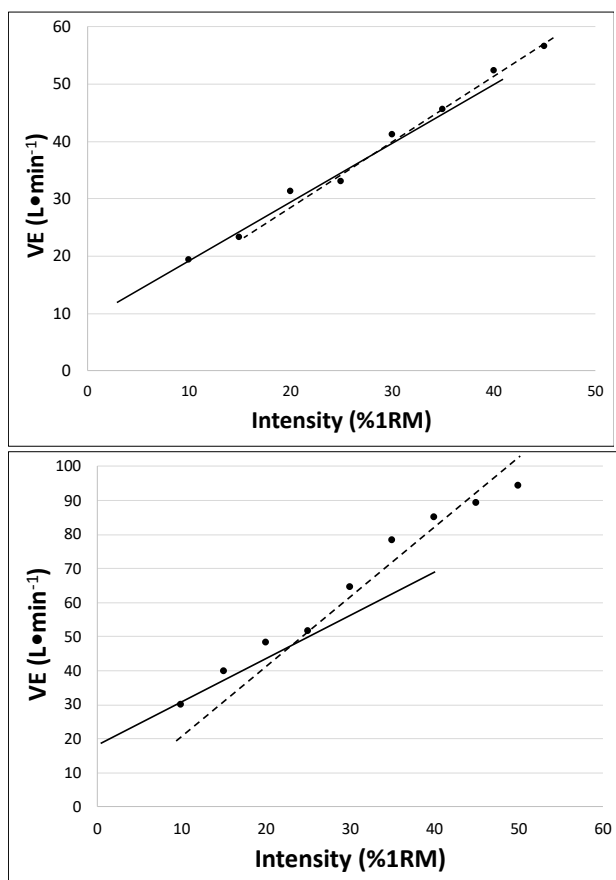
Our DIT lactate data revealed that while we were able to identify an LT in all participants, blood lactate kinetics demonstrated variation between individuals. Some participants demonstrated a clear threshold while others demonstrated less pronounced breakpoints (Figure 6). Similar to lactate kinetics, VT identified as a nonlinear increase in ventilation with increasing intensity (VT1), revealed differences in individual profiles with clearly defined and less dramatic breakpoints and an inability to identify a VT at all in some participants (Figure 7).



**Figure 6:** Lactate threshold visual identification for participant # 2 (left) and participant #5 (right).

Lactate values of stages from discontinuous incremental hexagonal bar deadlift protocol; Intensity as percentage of 1-repetition maximum.





**Figure 7:** Ventilatory threshold visual identification for participant #8 (left) and participant #2 (right).

VE Ventilation values of stages from discontinuous incremental hexagonal bar deadlift protocol; Intensity as percentage of 1-repetition maximum.

The between subject variations in lactate and ventilation profiles may in part explain a weak correlation between our observed relative intensity at LT versus VT ( $r = -.34$ ,  $p = .45$ ). This finding was inconsistent with previous studies where a statistically significant correlation was observed between LT and VT (de Sousa et al., 2012; Simões et al., 2013). However, these other studies did not report or provide figures describing between-subject variation in profile or goodness of fit for threshold identification. The choice of protocol and method to identify

thresholds can impact LT identification (Jamnick, Pettitt, Granata, Pyne, & Bishop, 2020), however, the DIT protocol used for this study replicates those predominant in the literature (Campos et al., 2017; de Sousa et al., 2011; Garnacho-Castaño et al., 2015; Maté-Muñoz et al., 2015; Moreira et al., 2008; Oliveira et al., 2006; Simões et al., 2016, 2010; Sperling et al., 2016) and the VI method has been shown to provide similar LT results compared to other methods for resistance exercise protocols (de Sousa et al., 2011). We therefore suggest our data demonstrates that the HBDL provides a different metabolic demand during this protocol compared to exercises used in previous studies, and there is potentially a large variation between individual lactate and ventilation responses.

In our study the mean relative intensity of  $31.67 \pm 6.15\%$  1RM for LT and  $29.71 \pm 3.49\%$  1RM for VT were not significantly different and are in general accordance with the literature. Previous studies, in which a RE protocol was used to identify LT, relative intensities were reported as  $27.1 \pm 3.7\%$  1RM (de Sousa et al., 2012);  $27.9 \pm 5\%$  1RM (de Sousa et al., 2013);  $28 \pm 6.3\%$  to  $32.2 \pm 4.4\%$  1RM (Barros, Agostini, Garcia, & Baldissera, 2004);  $29.2 \pm 6\%$  1RM young adults and  $28 \pm 4\%$  1RM elderly (Simões et al., 2013);  $30 \pm 6\%$  1RM (Simões et al., 2010);  $31 \pm 1.4\%$  to  $36.7 \pm 5.6\%$  1RM (Moreira et al., 2008); and  $36.6 \pm 1.4\%$  (Oliveira et al., 2006). Fewer studies have reported VT results, de Sousa et al. (2012) reported  $30 \pm 7.9\%$  1RM using a leg press and Maté-Muñoz et al. (2017) reported  $23.5\%$  1RM using the half-squat exercise. Maté-Muñoz also reported a lower relative intensity at LT,  $24.8\%$  1RM, compared to our findings. These discrepancies may be explained in part by the DIT protocol where the work-to-

rest ratio was the same 1:2, however, Maté-Muñoz used a lifting tempo of two-seconds per repetition for a total of 30 repetitions per stage on the half-squat exercise, representing a fifty-percent greater volume per set/stage compared to the present study. The substantial difference in stage volume most likely contributed to earlier onset of increased anaerobic metabolism and the consequent increase in [BLa] (Jamnick et al., 2020). When examining the results from studies using the LP, our relative intensity for LT is within the ranges reported, 27% to 36% 1RM. This is an interesting finding considering the HBDL is a different movement from both biomechanical and muscle mass recruitment perspectives. In the leg press the participant is sitting with the torso and hips supported by the equipment, with hip motion ranging from about a 90- to 45-degree angle, compared to the HBDL where the participant moves from a triple flexion (hips, knees, ankles) to triple extension standing position, requiring additional synergist and stabilizing muscle actions. The average 1RM load for the leg press reported by de Sousa et al. (2012) was  $290 \pm 35.9\text{kg}$  compared to the HBDL in our study of  $142.93 \pm 38.85\text{kg}$  (all participants) and  $177.32 \pm 16.23\text{kg}$  (men only).

The similarity between findings of previous research and our current study may be explained partially by physiological and hemodynamic factors previously described for RE at the LT intensity. Higher intensities, above ~30% 1RM, elicit increased skeletal muscle tension and concomitant intramuscular pressure which surpasses vascular pressure, resulting in blood flow occlusion. This occlusion increases reliance on anaerobic glycolysis activity contributing to increased

lactate production via the LDH reaction, signifying a metabolic transition of energy metabolic pathways (de Sousa et al., 2012). In addition, Simões et al. (2010) reported a significant intensification in sympathetic activity, using HRV, at 30% 1RM. While not measured or assessed in our study, it can be speculated that an increase in sympathetic activity above this threshold may increase catecholamine release, which in turn would stimulate adrenergic muscle receptors contributing to elevated glycolysis. Furthermore, the workload systematically increased during the DIT larger, fast-twitch motor units are recruited which are more glycolytic in nature.

### **Physiological Responses During Constant Load Exercise at the Intensity Equivalent to the Lactate Threshold**

Observations from the constant load exercise protocol at the intensity equivalent to LT revealed three men and one woman were unable to successfully complete all 15 sets resulting in a 25% reduction in total sample size and an unequal samples comparison between women ( $n = 5$ ) and men ( $n = 3$ ) for CL analyses. Statistical analyses on CL were performed on the remaining participants ( $n = 8$ ) and therefore conclusions are provided with the express recognition the reduction in sample size makes external validity problematic.

During the CL session at LT intensity ( $n = 8$ ) blood lactate stabilized from S9 through S15 and therefore hypothesis 4 was accepted. Oxygen consumption stabilized from S3 through S15 and therefore hypothesis 5 was accepted. Heart rate stabilized from S9 through S15 and therefore hypothesis 6 was accepted. A

significant main effect of sex on heart rate during the CL was observed, therefore hypotheses 8 was rejected.

During the constant load resistance exercise trials, we observed stabilization of  $[BLa^-]$  between S9 and S15. In the low to moderate intensity domain, exercise can be maintained over time without a continual increase in blood lactate, a dynamic equilibrium between the rate of lactate appearance and removal from the blood stream (Beneke, Hütler, & Leithäuser, 2000; Billat, Sirvent, Py, Koralsztein, & Mercier, 2003), reflecting a predominance of aerobic metabolism. After an initial increase in  $[BLa^-]$  other studies have reported stabilization during CL RE occurring between the tenth and the fifteenth minute of exercise with lactate values of  $4.58 \pm 1.96 \text{ mmol} \cdot \text{L}^{-1}$  (de Sousa et al., 2012),  $\sim 3.5 \text{ mmol} \cdot \text{L}^{-1}$  (Garnacho-Castaño et al., 2015), and  $3.45 \pm 0.7 \text{ mmol} \cdot \text{L}^{-1}$  (Maté-Muñoz et al., 2015). Blood lactate kinetics in our study stabilized starting at S9, 25-minutes into the trial, and showed a nonsignificant increasing trend with an average lactate value of  $8.33 \pm 2.05 \text{ mmol} \cdot \text{L}^{-1}$  in S15 (Figure 3). The differences observed in our data in time to stabilization ( $\sim 25$  minutes versus 10- to 15-minutes) and absolute  $[BLa^-]$  ( $8.33$  vs  $4.58$  and  $3.45 \text{ mmol} \cdot \text{L}^{-1}$ ) may be a result of methodological differences between protocols and exercise selection.

Because the HBDL requires gripping of the bar and constant isometric contraction of the upper extremities plus additional torso work to stabilize the free weight it is reasonable to infer not only greater overall muscle mass involvement, but also high levels of muscular tension leading to blood flow occlusion in the upper extremities which would contribute to higher blood lactate values. When

comparing  $[BLa^-]$  identified at LT in the DIT to values observed in CL expressed as a percentage values ranged from 86% at S3 to 147% at S15 (Table 4). This suggests that identification of LT during DIT we used may be specific to this exercise and an incremental protocol and may not represent the intensity that can be maintained for greater volumes or longer durations. This could partially explain why three of the 12 participants were unable to complete all 15 sets (300 repetitions) of the CL session due to fatigue. Clearly exercise modality will affect lactate kinetics not only between resistance exercises but also demonstrated by the average submaximal HBDL absolute  $[BLa^-]$  ranged from 67% to 116% of the peak values measured during maximal TM running (Table 4).

Oxygen consumption in the present study increased from rest to S3 then stabilized from S3 ( $25.10 \pm 1.60 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ;  $1.76 \pm 0.39 \text{ L} \cdot \text{min}^{-1}$ ) to end of exercise, S15 ( $27.73 \pm 3.68 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$ ;  $1.98 \pm 0.46 \text{ L} \cdot \text{min}^{-1}$ ), which is consistent with previous studies where  $\text{VO}_2$  increased initially from rest to S3 and then stabilized for the remainder of the exercise bout. Oxygen consumption values reported by de Sousa et al. (2012) during the CL were lower than we observed (S3 =  $0.77 \pm 0.33 \text{ L} \cdot \text{min}^{-1}$ ; S15 =  $0.83 \pm 0.16 \text{ L} \cdot \text{min}^{-1}$ ) and the nonsignificant increase from S3 to S21 of  $0.168 \pm 0.02 \text{ L} \cdot \text{min}^{-1}$  reported by Maté-Muñoz et al. (2015) was slightly lower than the increase of  $0.22 \pm 0.07 \text{ L} \cdot \text{min}^{-1}$  we observed from S3 to S15. It is interesting to note that while there was not a statistically significant difference between stages in  $\text{VO}_2$  during the CL protocol, there was a trend for  $\text{VO}_2$  to increase over time to a similar magnitude in our study compared to these previous studies, despite differences in exercise

selection and protocols. The stability of  $\text{VO}_2$  for over 30-minutes of intermittent exercise is consistent with our observed  $[\text{BLa}^-]$  during the CL protocol and further supports the characterization of aerobic predominance for this intensity, duration, and work-to-rest design. In our study  $\text{VO}_2$  as a percentage of  $\text{VO}_{2\text{max}}$  on average ranged from 55% at S3 to 63% at S15 (Table 4), meeting the moderate intensity recommendation from the American College of Sports Medicine for developing and maintaining fitness in apparently healthy adults (Garber et al., 2011). Constant load  $\text{VO}_2$  was close to that identified at LT during the DIT, ranging from 102% at S3 to 117% at S15 (Table 4).

Heart rate demonstrated similar responses as  $[\text{BLa}^-]$  during CL, showing an initial increase from rest to S9 ( $153.25 \pm 13.58 \text{ beats} \cdot \text{min}^{-1}$ ), followed by a nonsignificant increase until the end of exercise at S15 ( $159.88 \pm 12.61 \text{ beats} \cdot \text{min}^{-1}$ ) (Figure 5). The initial increase in HR could be modulated by increase in workload, peripheral vascular resistance/blood flow occlusion, but also partially by the autonomic nervous system via a withdrawal in parasympathetic activity and in increase in sympathetic drive at the heart to meet cardiac output requirements as suggested by Simoes, 2012. Heart rate mean values from S9 to S15 were 86% to 87% of peak HR recorded during TM  $\text{VO}_{2\text{max}}$  test and 101% to 104% of HR at LT from DIT (Table 4).

### **Women Compared to Men During Steady-State Resistance Exercise**

For both the DIT and CL protocols there were no statistically significant differences observed in  $[\text{BLa}^-]$  or  $\text{VO}_2$  responses between women and men.

Heart rate was not statistically different between women and men in the DIT, but women demonstrated a significantly higher HR from S3 through S15. This is the first study comparing men and women on acute responses to RE under LT conditions, and our results provide useful information for clinical, fitness, and performance professionals to make more informed decisions when prescribing safe and effective exercise programs to meet individual needs. All of the participants were trained and experienced in both resistance and high intensity exercise and had moderate to high levels of muscular strength on the HBDL. While the results of this study may not be extrapolated to women and men with lower levels of fitness, our findings suggest sex did not have a statistically significant impact on physiological responses to DIT or CL exercise using the HBDL, with the exception of heart rate in the CL session.

While “aerobic” exercise is often relegated to continuous, rhythmic activities such as running, cycling, rowing, or similar activities, our findings corroborate previous studies demonstrating resistance exercise performed at the LT intensity in a discontinuous manner for 30-minutes creates a steady-state metabolic stimulus which meets recommendations for improving fitness. A steady-state metabolic exercise bout may be desirable, for some individuals with health conditions, specifically types of CAD (Moreira et al., 2008; Simões et al., 2016) and DM2 (Moreira et al., 2008) which can require strategies to ensure effectiveness and safety in exercise prescription. In addition, a steady-state exercise stimulus like the CL used in our study may be effective to improve fitness and performance in the general population, recreational, and competitive



athletes who are seeking cross-training and concurrent training strategies which can address cardiorespiratory and strength-endurance components of fitness.

This is the first study to use the HBDL exercise to identify the LT intensity and validate a steady-state metabolic profile during CL exercise. The HBDL is considered a full body exercise because of the primary muscle actions of the lower-body plus the stabilizing and synergistic actions of the torso and arms. The HBDL exercise also includes the additional load of lifting a percentage of body mass. For this reason, the HBDL is considered a more functional movement, transferable to other sport and duty-related tasks and has been demonstrated to be favorable with respect to force and power generation compared to traditional straight bar deadlift movements (Lockie, Balfany, Denamur, & Moreno, 2019; Malyszczek et al., 2017; Swinton, Stewart, Agouris, Keogh, & Lloyd, 2011). Given the cardiorespiratory and metabolic responses associated with the intensity and volumes described in our study and the biomechanical specificity of the HBDL these protocols and exercise modality may provide testing and training benefits for certain occupational groups such as military, firefighter, law enforcement and other first responders.

### **Limitations**

There were some limitations in this study which should be considered. Our data are best applied to young, healthy, aerobically fit individuals with at least a novice level of strength. Not all participants were able to complete all 15 stages of the CL protocol, all 12 completed S9, 11 completed S12, and 8 completed

S15. Those that did not complete all stages voluntarily stopped due to fatigue. As a result, data from CL may be biased to characteristics of participants who were able to complete all stages. All results in this study may be protocol dependent, specifically regarding the duration of stages and rest periods.

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## CHAPTER 6: SUMMARY, CONCLUSIONS, FINDINGS, RECOMMENDATIONS

### Summary

The objectives of this study were to identify the lactate threshold (LT) and the first ventilatory threshold (VT) during resistance exercise in a discontinuous incremental test, determine if both thresholds were observed at the same relative workload, and to analyze the acute cardiorespiratory and metabolic responses during a separate constant load resistance exercise protocol. Twelve healthy, trained women ( $n = 6$ ) and men ( $n = 6$ ) performed a maximal running test on a treadmill followed by three protocols using the hexagonal bar deadlift (HBDL) exercise. The treadmill test was performed to determine maximal oxygen consumption, peak heart rate, and lactate maximum. The HBDL protocols performed included a 1RM to determine maximal strength, an incremental test to identify both thresholds, and a constant load session at the LT intensity to determine if selected physiological parameters demonstrated steady-state responses. The relative intensity of the LT and VT was  $31.67 \pm 6.15\%$  and  $29.71 \pm 3.49\%$  1RM respectively ( $p = .45$ ). During constant load exercise, no significant difference was observed in blood lactate from set 9 (S9) through S15 (end of exercise) ( $7.44 \pm 2.04$  and  $8.33 \pm 2.05$  mmol•L<sup>-1</sup>, respectively,  $p = .99$ ), in oxygen consumption from S3 through S15 ( $25.10 \pm 1.60$  and  $27.73 \pm 3.68$  ml•kg<sup>-1</sup>•min<sup>-1</sup>, respectively,  $p = 1.00$ ) or in heart rate from S9 through S15 ( $153.25 \pm 13.58$  and  $159.88 \pm 12.61$  beats•min<sup>-1</sup>, respectively,  $p = .19$ ). There were no statistically significant differences in physiological responses during either the incremental or constant load protocols between women and men, with the exception men had a

lower HR during CL. This study demonstrated that using the HBDL exercise, both a lactate and ventilatory threshold can be identified at the same relative workload in trained women and men. Additionally, intensity equivalent to the lactate threshold can be maintained in an intermittent constant load exercise session to elicit steady state responses in blood lactate, oxygen consumption, and heart rate. Implications of these results indicate the HBDL exercise performed at the LT intensity may be effective for improving cardiorespiratory and muscular fitness for men and women.

## **Conclusions**

The HBDL exercise was a suitable exercise to identify the lactate threshold during a discontinuous resistance exercise test and additionally for a discontinuous constant load exercise session to elicit steady-state responses in blood lactate accumulation, oxygen consumption, and heart rate in those recruited for the current study. Specifically, the DIT protocol used of 20 repetitions at a three-second tempo interspersed with two-minutes of passive rest between stages, with 5% 1RM load increments, provided sufficient work and rest intervals to identify nonlinear increases in  $[BLa^-]$  in all participants and VE in some participants. The relative intensity identified at LT, approximately 30% 1 RM from the DIT subsequently used for CL exercise elicited a stabilization of  $[BLa^-]$ ,  $VO_2$ , and HR, representing a predominant reliance on aerobic metabolism. These findings were not significantly different between women and men in the



study, with the exception of HR. Based on the analysis of the results, and within the limitations of this study, the following conclusions were drawn:

- Using the HBDL exercise, a lactate threshold was successfully identified in all participants from blood lactate responses from the discontinuous incremental test and occurred at an average relative intensity of  $31.67 \pm 6.15\%$  1RM for all participants.
- The first ventilatory threshold was identified from the HBDL discontinuous incremental test at an average relative intensity of  $29.71 \pm 3.49\%$  1RM for seven of the participants.
- The relative intensity at which the lactate threshold and the ventilatory threshold was observed was not statistically significantly different from each other,  $p = .45$ .
- During the CL exercise at the LT intensity blood lactate demonstrated steady-state levels from S9 through S15.
- During the CL exercise at the LT intensity oxygen consumption demonstrated steady-state levels from S3 through S15.
- During the CL exercise at the LT intensity heart rate demonstrated steady-state levels from S9 through S15.
- There were no statistically significant differences in the analyzed physiological responses during the DIT between women and men in the study.

- There were no statistically differences in  $[BLa^-]$  or  $VO_2$  responses during the CL exercise between women and men in this study, however, men consistently had lower HR.

## Findings

In addition to the conclusions drawn in the study, the following findings were made:

- There were noticeable individual differences between participants in blood lactate and ventilation responses during the DIT, suggesting the precision in identification of the LT and VT is related to other characteristics or qualities not accounted for in this study.
- Although the physiological parameters analyzed demonstrated steady-state responses during the CL exercise, each one ( $[BLa^-]$ ,  $VO_2$ , HR) showed a nonsignificant trend to systematically increase over time (Figures 3, 4, and 5).
- Four of the 12 participants were unable to complete the entire CL exercise due to volitional fatigue. There were no distinguishing characteristics or qualities identified in these participants.

## Recommendations

Future research should address the following points:

1. Manipulation of resistance exercise DIT protocol variables such as exercise selection, stage duration, rest interval, intensity increments, work

rates and the effects on identification, reliability, and precision of different anaerobic threshold measures and their relationships to each other.

2. Examination of inter-individual differences in acute responses during discontinuous incremental resistance exercise tests to better explain why some may display clear break points and others have less defined threshold kinetics.
3. Examination of constant load, intermittent exercise protocols which result in highest steady-state levels of specific physiological parameters such as blood lactate, oxygen consumption, carbon dioxide production, and heart rate in order to potentially optimize the cardiorespiratory, metabolic, and muscular endurance stimuli.
4. Longitudinal training studies to describe and quantify the chronic training adaptations on VO<sub>2</sub>, anaerobic threshold, muscular strength, hypertrophy, and endurance using low intensity (at the LT work rate) high volume resistance exercise performed not to volitional fatigue.
5. How using this type of RE programming, integrated into a holistic periodized training program, impacts performance of different populations such as athletes, tactical personnel, and those certain known disease.

**APPENDICES**

- A. Informed Consent
- B. Data Collection Sheets

## APPENDIX A.

### Cardiorespiratory and Metabolic Responses to Hexagonal Barbell Deadlift Task Performed at an Intensity Corresponding to the Anaerobic Threshold **Consent to Participate in Research**

**Purpose of the study:** You are being asked to participate in a research study conducted by Dr. Len Kravitz, the Principal Investigator and his associates from the Department of Health, Exercise and Sports Sciences at the University of New Mexico. The purpose of this study is to describe and quantify the metabolic (oxygen consumption, lactate accumulation), cardiovascular (heart rate), mechanical (velocity, power output) and perceptual (ratings of perceived exertion) responses to 3 different resistance exercise/weight lifting protocols using the hexagonal bar (trap bar) deadlift exercise in men and women 18 to 40 years of age. You are being asked to take part in this study because you are between 18 and 40 years old, and a healthy individual who engages in > 30 minutes of physical activity on most days of the week, specifically at least 2 days/week of high intensity resistance training and at least 2 days/week aerobic training (for at least the previous 6 months). Twelve people will take part in this study at the University of New Mexico. All data collection will take place in the exercise physiology lab at the University of New Mexico. This study will not be funded by any organization.

This form will explain what to expect when joining the research, as well as the possible risks and benefits of participation. If you have any questions, please ask one of the study researchers.

**What you will do in the study:** If you agree to participate you will be asked to sign this consent form, and the following things will happen:

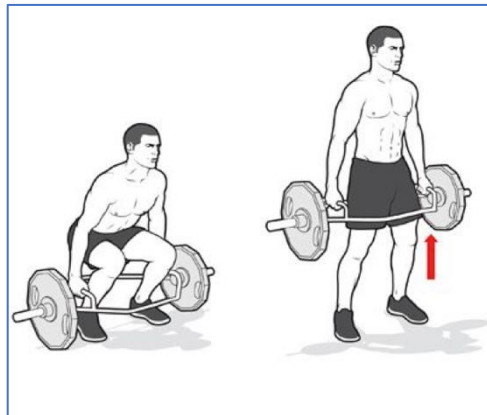
- You will be asked to visit the exercise physiology lab in Travelstead (Room B17) at the University of New Mexico, Albuquerque, NM on three separate occasions.
- All visits will be separated by a minimum of 48 hours with each participant completing all trials (approximately 4 hours in total) within 8-12 days.
- Prior to each visit, you will be asked not to perform any exercise 24 hours before the session, not ingest caffeine 4 hours prior or alcohol 24 hours prior to the session, and to consume at least a pint of water as well as a small meal 2-3 hours before the session.
- Each visit will take approximately 75-90 minutes.
- During your first visit, you will do each of the following: Fill out paperwork including a consent form and physical activity/health history questionnaire.

You will be asked to fill out this questionnaire about your health and that of your close relatives in order to screen for any issues that could cause additional risk to you by being a part of the study.

- If you are a woman, you will be required to perform a urine pregnancy test to ensure you are not pregnant. This test will be provided at no cost to you. Women who test positive for pregnancy will be referred to their own health care provider or one at SHAC to follow up with a confirming test and other follow-up health care as needed.
- Your resting heart rate, height and weight will be measured, and body fat will be estimated via skinfold (SKF) measurements. The SKF measurements are done using a skinfold caliper to measure a double layer of skin and underlying (subcutaneous) fat. The SKF sites include the chest, abdomen and thigh for the male participants and the triceps, top of hip joint (suprailiac) and thigh for the female participants. The sum of the SKF measurements is used to estimate body density (Db). The determined Db is used to estimate percent body fat.
- You will then be asked to perform a maximal oxygen uptake test ( $\text{VO}_2$  max) on a motorized treadmill that lasts approximately 8-12-minutes. This test will require you to run on the treadmill with an increasing intensity (speed) until you cannot continue. During exercise, you will be wearing a heart rate monitor (strapped around the chest), a mouthpiece and nose clip. This equipment is connected to a gas analyzer to measure your ventilation, exhaled oxygen, and carbon dioxide. All equipment is fitted individually for maximum comfort and will only be worn for the duration of exercise that gas analysis is occurring, in this case between 8 and 12 minutes. The mouthpiece and nose clip will not be worn during the warm-up and cool-down period.
- Your rating of perceived exertion (how hard you feel you are working) on a scale of 6-20 will be recorded at the end of each exercising stage. A 3-minute cool-down will be performed after the  $\text{VO}_2$  max test and you will be asked to rest for approximately 15-20 mins.
- After your rest period, the researchers will demonstrate the correct exercise form and technique you will be performing in the subsequent exercise sessions. You will then perform the deadlift exercise on the hexagonal bar under the guidance of the researchers in order to become competent with safe and effective exercise performance. This familiarization process will last 10-15 min.
- You will then perform a one-repetition maximum test. You will perform 2 warm-up sets using light weights for 5 to 10 repetitions. The load will then be adjusted based on your perception of what the maximum weight you feel you can lift, using proper form, for only one repetition. You will have up to a 5-min rest between attempts, and you will perform no more than 4 to 5 attempts.
- You will be asked to schedule your next session at the end of the first session.
- This visit will take approximately 7590 minutes.

During your second and third visits, the following will occur:

- The researchers will measure your weight, manually take your blood pressure and fit you for a heart rate monitor. The heart rate monitor is on a strap that is placed around your upper body.
- The exercise protocol that you will be asked to perform during your session will follow a specific sequence.
- Before the start of the warm-up protocol, you will be re-familiarized with the correct exercise technique shown to you in your first session.
- Following a self-selected 10-min warm-up protocol on the treadmill and stretching exercises, you will perform one of the three resistance exercise protocols using the hexagonal bar deadlift exercise:



protocols using the hexagonal bar deadlift exercise:

- The second resistance exercise session (visit 2) will start with the same 10-min warm-up and will then consist of a test where you perform 20 repetitions per stage with 2-min rest between stages. The protocol will start with a light weight (15% of your maximum) and will increase by small amounts (5-10% of your maximum) until you are unable to continue or are not able to perform the exercise with good form. This visit will last approximately 75 minutes.
- The third and final session (visit 3) will require you to perform 15 sets of 20 repetitions at the weight identified as your anaerobic threshold intensity (about 30% of your maximum) (anaerobic threshold is the exertion level between aerobic and anaerobic training). During this protocol you will have 1-min rest between sets and the total exercise time will be 30-min, excluding the same 10-min warm-up and stretching. This visit will last approximately 75 minutes.
- During all exercise protocols, except the 1RM test, you will be wearing the same heart rate monitor and mouthpiece/nose clip configuration from the  $\text{VO}_2$  max test.
- After each exercise protocol has been completed, you will perform a 3-min cool down on the treadmill at a very light intensity.
- Rating of perceived exertion (RPE) will be recorded immediately after each stage during the resistance exercise protocols, and immediately after the end of the  $\text{VO}_2$  max test.
- A small blood sample will be taken after each stage of the resistance exercise protocols to measure blood lactate levels. This will require us to take 6-9 samples during visit 2 and visit 3. The blood sample is taken from your earlobe using a small pin prick. Approximately one drop of blood will be collected in each sample. All equipment used are sterile, the trained researcher taking the blood sample will be wearing non-latex gloves and

will be following all appropriate safety measures. The small size of the lancet (pin) and the sample location of the earlobe makes this a virtually painless procedure. However, if you have a fear of blood or pin pricks you should consider carefully your participation. All blood samples will be destroyed after blood sampling is complete.

- Finally, you will be asked to schedule your next session, which will take place at least 48 hours after the completion of each session and the only change for the following sessions will be in the exercise protocol that you will be asked to perform.
- Participation in this study will take a total of approximately 4 hours over a period of three separate sessions. Each session will last approximately 75-90 min. All visits are intended to be completed over 8-12 days.

**Risks:** There are risks associated with maximal/submaximal exercise testing including the following: brief feelings of nausea, lightheadedness, muscle cramps, or dizziness. The mouthpiece/headgear/nose clip gear can be uncomfortable, especially during exercise. We will adjust the gear to be as comfortable as possible.

The risks associated with aerobic exercise (treadmill  $\text{VO}_2$  max test) and resistance exercise (hexagonal bar deadlift) include tiredness, soreness or strains of skeletal muscles. The risks associated with a pin prick for blood lactate may also include discomfort and infection.

Every reasonable effort will be made to protect the information you give us. However, there is a risk of loss of privacy and/or confidentiality that may result in hardship or inconvenience. There are risks of stress, emotional distress, injury, inconvenience and possible loss of privacy and confidentiality associated with participating in this study.

For more information about risks and side effects, ask the investigators.

**Benefits:** There is no direct benefit to you for participating in this study. However, you will receive the following information specific to your fitness:  $\text{VO}_2$  max results, maximal heart rate results, body composition results, and lower body maximal strength results. This information is useful in determining your current level of physical fitness, in planning and evaluating exercise programs. In addition, it is anticipated information gained from this study will provide new information for exercise professionals to improve physical activity prescriptions to achieve specific training adaptations in healthy, physically active women and men.

**Confidentiality of your information:** Your name and other identifying information will be maintained in locked files, available only to authorized member of the research team for the duration of the study. For any information entered into a computer, the only identifier will be a unique study identification



(ID) number. If a participant decides to withdraw from the study, all data which has been previously collected will be destroyed immediately. Any personal identifying information and any record linking that information to study ID numbers will be destroyed when the study is completed. Information resulting from this study will be used for research purposes and may be published; however, you will not be identified by name in any publications.

We will take measures to protect the security of all your personal information, but we cannot guarantee confidentiality of all study data. The University of New Mexico Institutional Review Board (IRB) that oversees human subject research may be permitted to access your records. Your name will not be used in any published reports about this study.

Research related injury:

If you are injured or become sick as a result of this study, any emergency treatment will be at your cost. UNM makes no commitment to provide free medical care or money for injuries to participants in this study.

It is important for you to tell the one of the Principal Investigators immediately if you have been injured or become sick because of taking part in this study. If you have any questions about these issues or believe that you have been treated carelessly in the study, please contact the Office of the IRB at (505) 277-2644 for more information.

**Use of your information for future research:** Your information collected for this project will NOT be used or shared for future research, even if we remove the identifiable information like your name or date of birth.

**Payment:** Participants successfully completing all testing protocols will receive \$50.00 in compensation. This sum will be split into \$20 after session 1, and \$15 after both sessions 2 and 3.

**Right to withdraw from the study:** Your participation in this study is completely voluntary. You have the right to choose not to participate or to withdraw your participation at any point in this study without penalty. Any such data which may have been previously collected will be destroyed if you do decide to withdraw from the study, however you will be given your own test results up to that point.

If you have any questions, concerns, or complaints about the research study, please contact:

Len Kravitz, Ph.D.  
University of New Mexico Department Health, Exercise and Sport Sciences  
Johnson Center, MSC04 2610  
1 University of New Mexico

Albuquerque New Mexico 87131  
 (505) 277-4136  
[lkraivit@unm.edu](mailto:lkraivit@unm.edu)

If you would like to speak with someone other than the research team to obtain information or offer input or if you have questions regarding your rights as a research participant, please contact the IRB. The IRB is a group of people from UNM and the community who provide independent oversight of safety and ethical issues related to research involving people:

UNM Office of the IRB, (505) 277-2644, [irbmaincampus@unm.edu](mailto:irbmaincampus@unm.edu). Website: <http://irb.unm.edu/>

## CONSENT

You are making a decision whether to participate in this study. Your signature below indicates that you have read this form (or the form was read to you) and that all questions have been answered to your satisfaction. By signing this consent form, you are not waiving any of your legal rights as a research participant. A copy of this consent form will be provided to you.

I agree to participate in this study.

\_\_\_\_\_  
 Name of Adult Participant

\_\_\_\_\_  
 Signature of Adult Participant

Date \_\_\_\_\_

### **Researcher Signature** (to be completed at time of informed consent)

I have explained the research to the participant and answered all of his/her questions. I believe that he/she understands the information described in this consent form and freely consents to participate.

\_\_\_\_\_  
 Name of Research Team Member

\_\_\_\_\_  
 Signature of Research Team Member

Date \_\_\_\_\_

**APPENDIX B.**

AT During HBDL Exercise  
Data Collection Sheet – Visit 1

Subject # \_\_\_\_\_ Date: \_\_\_\_\_ Research Team  
Member Initials: \_\_\_\_\_

Height (cm): \_\_\_\_\_ Weight (kg): \_\_\_\_\_ Age (yr): \_\_\_\_\_  
Gender M F

**SKF (3 site)**

Triceps/Chest	SI/Abdominal	Thigh	Total	BD	BF%

**VO<sub>2</sub>max: TM Protocol**

Est HR max: \_\_\_\_\_

Stage/Speed	Time	HR	RPE	VO <sub>2</sub>
	0 - 1			
	1 - 2			
	2 - 3			
	3 - 4			
	4 - 5			
	5 - 6			
	6 - 7			
	7 - 8			
	8 - 9			
	9 - 10			
	10 - 11			
	11 - 12			
	12 - 13			
	13 - 14			
	14 - 15			
	15 - 16			

VO<sub>2</sub>max

15-sec average: \_\_\_\_\_ BxB: \_\_\_\_\_

AT During HBDL Exercise  
Data Collection Sheet – Visit 1

**1RM**

Body Weight (lbs): \_\_\_\_\_

Stage	Load	Reps	Velocity	RPE
Baseline				
Warm-up	~50% BW	7 - 10		
Rest (1-min)				
Warm-up	~80% BW	3 - 5		
Rest (1-min)				
Max Trial 1		1		
Rest (5-min)				
Max Trial 2		1		
Rest (5-min)				
Max Trial 3		1		
Rest (5-min)				
Max Trial 4		1		
Rest (5-min)				
Max Trial 5		1		
Rest (5-min)				
Max Trial 6		1		
			1RM =	

**1RM/BW** \_\_\_\_\_

Meets strength criteria (M 1.6 x BW / F 1.4 x BW): Y N

# AT During HBDL Exercise Data Collection Sheet – Visit 2

Subject # \_\_\_\_\_  
Member Initials: \_\_\_\_\_

Date: \_\_\_\_\_

Research Team

## DIT

Body Weight (lbs): \_\_\_\_\_

1RM Results: \_\_\_\_\_

Warm-up & stretching 10 minutes "light"

Protocol: 1-min work stage/2-min recovery period

Stage	Load (%/lbs)	HR	VO <sub>2</sub>	RPE	[BLa <sup>-</sup> ]	Velocity
Baseline						
1	15%/					
2	20%/					
3	25%/					
4	30%/					
5	35%/					
6	40%/					
7	50%/					
8	60%/					
9	70%/					

\*Attach bar loading scheme

([https://docs.google.com/spreadsheets/d/1YXR7IE\\_c7tn355z7MrRu73z70Wmyzfsue\\_eytsYo3Vw/edit?usp=sharing](https://docs.google.com/spreadsheets/d/1YXR7IE_c7tn355z7MrRu73z70Wmyzfsue_eytsYo3Vw/edit?usp=sharing))

Example:

			H Bar 1							L Bar 2							
		Tare	50	Plate Load Per Side						25	Plate Load Per Side						
1 RM	Target Load			2.5	5	10	25	45	Actual Load		2.5	7.5	10	25	50	Actual Load	Target Load
	15%	0	-50						50	-25						25	0
	20%	0	-50						50	-25						25	0
	25%	0	-50						50	-25						25	0
	30%	0	-50						50	-25						25	0
	35%	0	-50						50	-25						25	0
	40%	0	-50						50	-25						25	0
	45%	0	-50						50	-25						25	0
	50%	0	-50						50	-25						25	0
	55%	0	-50						50	-25						25	0
	60%	0	-50						50	-25						25	0
	65%	0	-50						50	-25						25	0
	100%	0							50	0						25	

AT During HBDL Exercise  
Data Collection Sheet – Visit 3

Subject # \_\_\_\_\_

Date: \_\_\_\_\_

Research Team

Member Initials: \_\_\_\_\_

Body Weight (lbs): \_\_\_\_\_

CL/AT Load: \_\_\_\_\_

Warm-up &amp; stretching 10 minutes "light"

Protocol: 1-min work stage/1-min recovery period

Stage	Load	HR	VO <sub>2</sub>	RPE	[BLa <sup>-</sup> ]	Velocity
Baseline						
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						