THE PHYSIOLOGICAL RESPONSES DURING EXERCISE TO
FATIGUE AT THE RESPIRATORY COMPENSATION POINT

A Thesis

Presented to the faculty of the Department of Kinesiology
California State University, Sacramento

Submitted in partial satisfaction of
the requirements for the degree of

MASTER OF SCIENCE

in

Kinesiology
(Exercise Science)

by

Richard T. Bradley

SPRING
2012
Student: Richard T. Bradley

I certify that this student has met the requirements for format contained in the University format manual, and that this thesis is suitable for shelving in the Library and credit is to be awarded for the thesis.

__________________________, Graduate Coordinator
Michael Wright, Ph.D. 

Date

Department of Kinesiology and Health Science
Abstract

of

THE PHYSIOLOGICAL RESPONSES DURING EXERCISE TO FATIGUE AT THE RESPIRATORY COMPENSATION POINT

by

Richard T. Bradley

Introduction: The maximal steady state (SS) blood lactate concentration [La\textsuperscript{-}] and oxygen consumption (VO\textsubscript{2}) during exercise is identifiable by the second threshold from a graded exercise test (GXT). Consequently, these variables rise to peak values during exercise in excess of the maximal SS. Review articles describe the respiratory compensation point (RCP) as a second threshold determinant, but recent research has found the RCP to occur at an intensity that is greater than the maximal SS. Purpose: To determine if exercise to fatigue at RCP in a group of trained athletes represents the maximal [La\textsuperscript{-}] and VO\textsubscript{2} SS. Methods: Sixteen cyclists completed a GXT and a submaximal test on the same day to identify the power [in watts (W)] at the RCP VO\textsubscript{2} from the GXT (GXT-VO\textsubscript{2RCP}). Two single-blind constant load exercise (CLE) trials were conducted on subsequent days at the RCP W or RCP W plus 10% (RCP+). Expired air was collected continuously and recorded as 1-min averages. Lactate SS was defined as < 1 mMol/L increase from 10-min to 25-min during CLE. Analysis between GXT and CLE variables used one-way ANOVA and analysis over absolute and relative time.
intervals [% time to fatigue (TTF)] used two-way ANOVA, with an α-level of .05.

Results: The GXT-VO$_{2\text{RCP}}$ [3.86 (0.75) L/min] was 93% of GXT-VO$_{2\text{peak}}$ [4.17 (0.79) L/min]. During the RCP trial, peak VO$_2$ was not different from GXT-VO$_{2\text{RCP}}$, $p = .16$, and was highly correlated, $r = .98, p < .05$. The RCP trial peak VO$_2$ was less than GXT-VO$_{2\text{peak}}$, $p < .001$, whereas the RCP+ trial peak VO$_2$ was not different from GXT-VO$_{2\text{peak}}$, $p = .10$. Additionally, the RCP trial VO$_2$ at 60% TTF [3.83 (0.76) L/min] and 80% TTF [3.85 (0.81) L/min] were not different from 100% TTF [3.85 (0.80) L/min], $p = .98$. The 4-minute post-exercise lactate ([La$^-\text{post}$]) from the RCP trial [5.36 (2.64) mMol/L] was less than RCP+ [La$^-\text{post}$] [7.75 (2.81) mMol/L], $p < .001$, but the RCP+ [La$^-\text{post}$] was not different from GXT [La$^-\text{post}$] [8.68 (3.21) mMol/L], $p = .26, n = 15$. Only five participants exercised for more than 25 minutes at RCP, with a 10-min [La$^-\text{post}$] of 4.16 (1.8) mMol/L, and a 25-min [La$^-\text{post}$] of 5.80 (2.9) mMol/L. Conclusion: The results of this study revealed a VO$_2$ SS during RCP from 60% to 100% TTF; and exercise at RCP+ gave a VO$_2$ that was not different from GXT-VO$_{2\text{peak}}$. In support of recent research, the RCP appears to occur at an intensity that is greater than the maximal [La$^-\text{post}$]. Exercise performed to fatigue at the RCP represents the maximal VO$_2$ SS without a corresponding [La$^-\text{post}$].

_______________________, Committee Chair
Daryl Parker, Ph.D.

_______________________
Date
ACKNOWLEDGEMENTS

I would like to thank Corinne Pritchard for all of her support and advice during all stages of this thesis preparation. Additional support came from kinesiology graduate students, Mr. Martinez, Mr. Polin, and Mr. Salgado, and undergraduate intern Mr. McKinzie, who agreed to be at my disposal during the Methods and data collection portions of this thesis. Lastly, Dr. Parker and Dr. Quintana showed confidence in my abilities to attempt the difficult methodological procedures associated with this thesis, and I would like to thank them for their trust in my accuracy and thoroughness of task completion.
TABLE OF CONTENTS

Acknowledgments............................................................................................................................................. vii
List of Tables ...................................................................................................................................................... x
List of Figures ..................................................................................................................................................... xi
Chapters
1. INTRODUCTION ........................................................................................................................................... 1
   1.1 Problem .................................................................................................................................................. 4
   1.2 Purpose ............................................................................................................................................... 4
   1.3 Significance .......................................................................................................................................... 5
   1.4 Definition of Terms............................................................................................................................... 5
   1.5 Hypothesis ........................................................................................................................................... 6
2. LITERATURE REVIEW .................................................................................................................................. 7
   2.1 Introduction .......................................................................................................................................... 7
   2.2 Threshold and Domain Theory ............................................................................................................. 8
   2.3 Synthesized Research ........................................................................................................................... 11
   2.4 Rationale ............................................................................................................................................ 16
3. METHODS ...................................................................................................................................................... 19
   3.1 Participants ......................................................................................................................................... 19
   3.2 Design ................................................................................................................................................ 20
   3.3 Graded Exercise Test ............................................................................................................................ 21
   3.4 RCP-Power Detection .......................................................................................................................... 25
4. RESULTS ....................................................................................................................................................... 31
   4.1 Graded Exercise Test .............................................................................................................................. 31
   4.2 RCP-Power Detection .......................................................................................................................... 33
4.3 Cardiopulmonary Variables ................................................................. 35
  4.3.1 RCP Trial .................................................................................. 35
  4.3.2 RCP+ Trial .............................................................................. 40
  4.3.3 Percent of TTF ......................................................................... 40
4.4 Lactate .............................................................................................. 45
4.5 RPE .................................................................................................. 48
5. DISCUSSION ....................................................................................... 49
Appendix A. Informed Consent .............................................................. 60
Appendix B. Sac State Human Performance Research Laboratory Subject
           Information and Medical History .................................................. 66
References ............................................................................................ 70
### LIST OF TABLES

<table>
<thead>
<tr>
<th>Tables</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Descriptive GXT means (±SD), with relative percent of peak values ($n = 16$)</td>
<td>32</td>
</tr>
<tr>
<td>2. Data from five participants completing 25 minutes or more at RCP</td>
<td>46</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figures</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Threshold and domain graphical representation of VO(_2) kinetics.</td>
<td>10</td>
</tr>
<tr>
<td>2. Example graph from GXT of V(_\text{E}/\text{VO}<em>2) and V(</em>\text{E}/\text{VCO}_2).</td>
<td>24</td>
</tr>
<tr>
<td>3. Example RCP-power detection.</td>
<td>27</td>
</tr>
<tr>
<td>4. Relationship between the GXT-VO(_2\text{RCP}) and the RCP trial VO(_2\text{peak}).</td>
<td>34</td>
</tr>
<tr>
<td>5. Heart Rate (HR) data presented over absolute time intervals.</td>
<td>37</td>
</tr>
<tr>
<td>6. Ventilation (V(_\text{E})) data presented over absolute time intervals.</td>
<td>38</td>
</tr>
<tr>
<td>7. Oxygen uptake (VO(_2)) data presented over absolute time intervals.</td>
<td>39</td>
</tr>
<tr>
<td>8. Heart Rate (HR) data presented over relative time intervals.</td>
<td>42</td>
</tr>
<tr>
<td>9. Ventilation (V(_\text{E})) data presented over relative time intervals.</td>
<td>43</td>
</tr>
<tr>
<td>10. Oxygen uptake (VO(_2)) data presented over relative time intervals.</td>
<td>44</td>
</tr>
<tr>
<td>11. Example VO(_2) data for one male participant from both trials presented over time.</td>
<td>47</td>
</tr>
</tbody>
</table>
1. INTRODUCTION

The Respiratory Compensation Point (RCP) power from a graded exercise test (GXT) has been shown to be not different from the power used by competitive cyclists during competition (Impellizzeri, Marcra, Rampinini, Mognoni, & Sassi, 2005; Nimmerichter, Williams, Bachl, & Eston, 2010; Perrey et al., 2003). Further, the largest influence on maximum power ($W_{\text{max}}$) from a GXT has been found to be the oxygen consumption rate ($VO_2$) at RCP (Parker, Salgado, Quintana, & Faria, 2009). Also, running performance has been shown to be predictable from RCP (Iwaoka, Hatta, Atomi, & Miyashita, 1988). However, only one study has attempted to define the physiological responses during constant-load exercise (CLE) at the RCP (Simon, Young, Gutin, Blood, & Case, 1983).

The time duration for the onset of fatigue and exercise termination during high-intensity bouts of exercise closely follows the attainment of the maximal oxygen consumption rate ($VO_{2\text{max}}$). This high-intensity domain lower boundary has classically been defined as the critical power (CP) (Hill, Poole, Smith, & al., 2002; Jones, Vanhatalo, Burnley, Morton, & Poole, 2010). Exercise intensities below this particular demarcation can be maintained for long periods of time and will display a steady state (SS) in blood lactate concentration ([La$^-$]) and $VO_2$ over the duration of exercise (Gaesser & Poole, 1996). However, some investigators report that a complete SS in [La$^-$] and $VO_2$, measured from the 5th-minute to the end of exercise, was not demonstrated during CLE to exhaustion at CP (Brickley, Doust, & Williams, 2002). Moreover, exercise above
CP does not always result in the attainment of VO$_{2\text{max}}$ during exhaustive exercise (Billat, Binsse, Petit, & Koralsztein, 1988; Sawyer, Morton, Womack, & Gaesser, 2010). A classic article describing [La"] and VO$_2$ kinetics at a variety of exercise intensities, from “moderate” to “severe” exercise, report that the transition from SS to non-SS exercise is demarcated by CP (Gaesser & Poole, 1996). Unfortunately, research does not always support the physiological responses that are expected at CP.

Review articles state that the second threshold represents the demarcation between SS and non-SS exercise, and that the second threshold envelopes several different definitions, such as the CP, the maximal lactate SS (MLSS), the second lactate threshold, and the RCP (Lucia, Sanchez, Carvajal, & Chicharro, 1999; Meyer, Lucia, Earnest, & Kindermann, 2005). Exhaustive cycling at intensities greater than RCP will achieve maximal [La"] and VO$_2$ values found from the GXT (Dekerle, Baron, Dupont, Vanvelcenaher, & Pelayo, 2003; Richard et al., 2004). However, recent research has found that the RCP intensity may be too great to be the maximal SS (Dekerle, et al., 2003).

The CP and RCP have been shown to occur at intensities that are not different (~84% VO$_{2\text{max}}$) in a group of well-trained cyclists (Dekerle, et al., 2003). Surprisingly, the exercise intensity at RCP from this study was a greater intensity than the maximal lactate steady state (MLSS; ~71% VO$_{2\text{max}}$). According to the findings of the study by Dekerle et al. (2003), the RCP would not portray a SS in [La"]. Additionally, VO$_2$ would
not be expected to demonstrate a SS response, if classical observations reporting a tight
coupling of the [La\(^-\)] and VO\(_2\) response are correct (Gaesser & Poole, 1996).

If RCP is the maximal SS however, it might explain why RCP seems to be the
chosen intensity when athletes are competing during relatively short durations (~30 min)
(Nimmerichter, et al., 2010; Perrey, et al., 2003), and even long durations (~2 hours)
(Impellizzeri, et al., 2005). Additionally, a study performed in our lab has found that
eight well-trained cyclists performed a self-paced 20-kilometer time trial (TT) at a VO\(_2\)
that was not different from the VO\(_2\) at RCP from the GXT (VO\(_2\)RCP, ~85% VO\(_{2\text{max}}\)).
Interestingly, during the 20K TT (~35 min), HR, power, respiratory exchange ratio
(RER), ventilation (V\(_E\)), and VO\(_2\) were not different over the successive time intervals
(every 5K) of the TT (p > .05), indicating a complete physiological SS during the course
of the TT. Recently, other investigators have found a SS in all physiological variables at
the second lactate threshold (Pires et al., 2011). However, the intensity from the study by
Pires et al. (2011) is much lower than the intensity commonly found to accompany RCP
(~78% vs. ~85% VO\(_{2\text{max}}\)) (Dekerle, et al., 2003; Impellizzeri, et al., 2005; Nimmerichter,
et al., 2010; Perrey, et al., 2003), and is similar to the MLSS intensity (Baron et al., 2008;
Billat, Sirvent, Py, Koralsztein, & Mercier, 2003; Dekerle, et al., 2003). This finding
suggests that the RCP occurs at an intensity that is too great to portray a physiological SS
in [La\(^-\)], even though a SS in VO\(_2\) may exist.
1.1 Problem

Review articles have described the second threshold, whether it be CP, MLSS, the second lactate threshold, or RCP, as the maximal SS exercise (Gaesser & Poole, 1996; Lucia, et al., 1999; Meyer, et al., 2005). Unfortunately a consensus has not been achieved between research studies that have looked at the responses during exercise relative to these second thresholds (Baron et al., 2003; Billat, et al., 1988; Brickley, et al., 2002; Poole, Ward, Gardner, & Whipp, 1988; Richard, et al., 2004; Sawyer, et al., 2010). Moreover, to the best of our knowledge no single study has looked at the physiological responses during CLE to fatigue at RCP, and an intensity greater than RCP, in a group of trained endurance athletes. The RCP represents an enhanced ventilatory response as a consequence of an accompanied metabolic acidosis, and exercise at intensities greater than RCP are met with the eventual attainment of VO$_{2\text{max}}$, but still too few studies support this theory.

1.2 Purpose

The purpose of this study is to investigate the physiological responses during fatiguing CLE at the GXT-VO$_{2\text{RCP}}$, and to determine if the RCP represents the maximal SS. Secondly we aim to verify if CLE above the GXT-VO$_{2\text{RCP}}$ will lead to maximal [La$^-$] and VO$_2$ values determined from the GXT.
1.3 Significance

The exercise response relative to RCP has been described with respect to healthy, fit individuals (Azevedo et al., 2011; Meyer, et al., 2005), but the responses at RCP are potentially similar for clinical and sedentary populations. A demarcation between SS and non-SS exercise would aid all exercising individuals and exercise prescribers. High-level endurance athletes commonly choose to perform at the power associated with the GXT-\(\text{VO}_2\text{RCP}\), which would aid in target-training for performance gains, and more research may find that this model applies to less fit individuals. Furthermore, an easily identifiable variable from the GXT would help identify a crucial threshold intensity with which to study the ability of the exercising human body to continue exercise in [La\(^-\)] and \(\text{VO}_2\) homeostatic SS conditions.

1.4 Definition of Terms

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demarcation</td>
<td>the threshold-point describing a transition in physiological responses</td>
</tr>
<tr>
<td>[La(^-)]</td>
<td>blood lactate concentration, a muscle metabolite freely circulating in the blood, expressed in millimols per liter</td>
</tr>
<tr>
<td>HR</td>
<td>heart rate, expressed as beats per minute</td>
</tr>
<tr>
<td>HR(_{\text{peak}})</td>
<td>peak heart rate during GXT and trials</td>
</tr>
<tr>
<td>HR(_{\text{RCP}})</td>
<td>heart rate at RCP from GXT</td>
</tr>
<tr>
<td>Metabolic cart</td>
<td>a device used to collect and analyze expired air</td>
</tr>
<tr>
<td>RER</td>
<td>ratio of carbon dioxide production to oxygen consumption</td>
</tr>
<tr>
<td>RPE</td>
<td>ratings of perceived exertion, a relative rating based on the perceived total body discomfort</td>
</tr>
</tbody>
</table>
### Table

<table>
<thead>
<tr>
<th><strong>Symbol</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>RPE$_{\text{peak}}$</td>
<td>Peak RPE from GXT</td>
</tr>
<tr>
<td>TTF</td>
<td>Time to fatigue, exercise end time</td>
</tr>
<tr>
<td>$V_E$</td>
<td>Ventilation, expressed in liters per minute</td>
</tr>
<tr>
<td>$V_{E\text{peak}}$</td>
<td>Peak ventilation during GXT and trials</td>
</tr>
<tr>
<td>$V_{E\text{RCP}}$</td>
<td>Ventilation at RCP from GXT</td>
</tr>
<tr>
<td>$VO_{2\text{peak/max}}$</td>
<td>Peak oxygen consumption, expressed in liters per minute, used interchangeably with $VO_{2\text{max}}$</td>
</tr>
<tr>
<td>$VO_{2\text{RCP}}$</td>
<td>$VO_2$ at RCP from GXT</td>
</tr>
<tr>
<td>$VO_{2\text{VT}}$</td>
<td>$VO_2$ at VT from GXT</td>
</tr>
<tr>
<td>$W_{\text{peak/max}}$</td>
<td>Peak power from GXT, used interchangeably with $W_{\text{max}}$</td>
</tr>
</tbody>
</table>

#### 1.5 Hypothesis

The RCP from the GXT represents the maximal $[\text{La}^-]$ and $VO_2$ SS during CLE in trained cyclists, whereas exercise above RCP will display peak $[\text{La}^-]$ and $VO_2$ values determined from a GXT.
2. LITERATURE REVIEW

2.1 Introduction

Endurance exercise is commonly prescribed based off of the metabolic response, perceived effort, and intensity, relative to thresholds from the GXT. Metabolic responses have been described in relation to CLE in an attempt to predict extra-laboratory exercise response. The second threshold in ventilation ($V_E$), evident during GXT, known as the RCP represents an increased ventilatory response associated with the metabolic acidosis resulting from high intensity exercise. The RCP occurs at a relatively high percentage of $VO_{2\text{max}}$ (~80-95%) and is highly correlated with performance measures of high-level endurance athletes (Impellizzeri, et al., 2005). In addition, exercise at such a high intensity contributes to higher levels of cardiovascular fitness ($VO_{2\text{max}}$) (Gormley et al., 2008). However, the exact physiological responses during CLE at RCP have rarely been looked at, and are not clearly defined.

This review will briefly define the classical definitions of the two thresholds that occur during the GXT, and the responses to CLE during the three commonly described, and prescribed, exercise domains. Secondly, an attempt will be made to synthesize the existing literature in relation to these thresholds and domains. Finally, RCP will be discussed in terms of its exercise-response significance.
2.2 Threshold and Domain Theory (Figure 1, ascending from low to high intensity)

Moderate domain: Exercise in the moderate domain is described by a linear relationship between VO\textsubscript{2} and work-rate (power), and no significant increase in blood [La\textsuperscript{-}] compared to resting values is observed (Binder et al., 2008; Gaesser & Poole, 1996; Meyer, et al., 2005). This domain represents exercise of \(~70\%\) VO\textsubscript{2max} and less.

The first threshold from GXT: The lactate threshold (LT) represents the first increase in blood [La\textsuperscript{-}] appearance above resting values (Binder, et al., 2008; Meyer, et al., 2005). A non-invasive measure of the LT is the ventilation threshold (VT), defined as an increase in V\textsubscript{E} disproportionate to the increase in VO\textsubscript{2}. The LT and VT been found to occur within one 3-minute stage of each other during GXT testing (Caiozzo et al., 1982).

Heavy domain: During heavy exercise, blood [La\textsuperscript{-}] increases as the intensity increases, but is eventually stabilized to maintain equilibrium. The greatest concentration in blood [La\textsuperscript{-}] that still displays an equilibrium (< 1 mMol/L increase from 10-min to 25-min during CLE) is defined as the MLSS (Billat, et al., 2003). Oxygen consumption for a given intensity is no longer predicted by the VO\textsubscript{2}-power relationship from “moderate exercise.” In the heavy domain, a “slow component” of VO\textsubscript{2} appears within approximately three minutes, which delays the SS of VO\textsubscript{2} until between \(~10\) and \(~20\) minutes of CLE (Gaesser & Poole, 1996).
The second threshold from GXT: Many definitions of the second threshold have been described, such as the second non-linear increase in lactate (LT2) (Binder, et al., 2008; Meyer, et al., 2005). The RCP, measured non-invasively by expired air collection, is a hyper-ventilatory response of the body partially due to the metabolic acidosis associated with this blood [La−] increase, causing a disproportionate increase in $V_E$ compared to the production of $VCO_2$ (Beaver, Wasserman, & Whipp, 1986). The upper boundary of heavy exercise, demarcated by the second threshold, is identifiable by the MLSS and maximal VO₂ SS. The CP has most commonly been described in the literature as the demarcation point between SS and non-SS exercise (Gaesser & Poole, 1996; Jones, et al., 2010).

Severe domain: Severe exercise is demarcated on the lower boundary by the power-time relationship of the CP model, which represents the MLSS and maximal VO₂ SS (Gaesser & Poole, 1996; Jones, et al., 2010). The CP model is described by an exponentially reduced time to fatigue for increased intensity during CLE. All CLE in the severe domain leads to maximal [La−] and VO₂ values at the end of exercise (Gaesser & Poole, 1996; Hill, et al., 2002).
Figure 1. Threshold and domain graphical representation of VO\textsubscript{2} kinetics.

Expected VO\textsubscript{2} kinetics calculated from moderate domain exercise (dotted line), and with the VO\textsubscript{2} slow-component addition (dashed line).
2.3 Synthesized Research

The first threshold from a GXT demarcates the moderate and heavy exercise domains. Exercise below the first threshold is sustainable for long periods (> 1 hour), and the physiological responses are well defined. Exercise in the heavy domain is accompanied by an increased VO\(_2\) above predicted values from the moderate domain (VO\(_2\) slow-component). The upper boundary demarcation point of heavy exercise has traditionally been defined as the highest SS exercise intensity, above which [La\(^-\)] and VO\(_2\) will rise to maximum GXT values at the end of exercise. However, there exists conflicting research in support of this theory.

During 30 minutes of exercise at MLSS, after the initial ~10 minutes, [La\(^-\)] and VO\(_2\) stabilize at SS values corresponding to ~75% VO\(_{2\max}\) (Baron, et al., 2003; Baron, et al., 2008). Recently others have also found a similar SS in [La\(^-\)] and VO\(_2\) at the LT2, ~75% of VO\(_{2\max}\) (Pires, et al., 2011). Moreover, a classic study on [La\(^-\)] and VO\(_2\) kinetics during high intensity exercise reported that [La\(^-\)] and VO\(_2\) reached SS during 24 minutes of CLE at CP, and that these two variables were positively correlated (\(r = .73, p < .05\)) (Poole, et al., 1988). These three examples demonstrate that a SS in [La\(^-\)] and VO\(_2\) exist at the upper limit of heavy exercise as demarcated by the second thresholds CP, LT2 and MLSS. Conversely, some investigators report that [La\(^-\)] rises over time during 30 minutes of exercise “slightly below” RCP, indicating a loss of SS (Simon, et al., 1983). Surprisingly, this study did have subjects exercising at nearly the same relative intensity
as Pires et al. (2011), ~74% of VO$_{2\text{max}}$, where a [La$^{-}$] SS was observed. Unfortunately, Simon et al. (1983) did not report VO$_2$ data in the study.

The CP and RCP have been found to occur at an intensity that is not different in well-trained males, ~84% of VO$_{2\text{max}}$ (Dekerle, et al., 2003). These investigators also found CP and RCP to occur at an intensity that was greater than the MLSS intensity of ~71% of VO$_{2\text{max}}$ (Dekerle, et al., 2003). The findings of Dekerle et al. (2003) suggest that there might be a separation between the MLSS and maximal VO$_2$ SS, assuming CP and RCP exhibit a SS in VO$_2$. This hypothesis is contrary to classical views but in-line with the non-SS [La$^{-}$] findings at RCP by Simon et al. (1983). Furthermore, Hagberg et al. (1978) exercised participants with a ride range in fitness (39.7 to 60.7 ml/kg/min/VO$_{2\text{max}}$), at 80% VO$_{2\text{max}}$ and found a rise in [La$^{-}$] and VO$_2$ from 5-minutes to 20-minutes during CLE (Hagberg, Mullin, & Nagle, 1978). This suggests that a SS in [La$^{-}$] and VO$_2$ does not exist at or above 80% VO$_{2\text{max}}$, which would mean a SS would not exist at a CP or RCP intensity of ~84% VO$_{2\text{max}}$, as reported in the study by Dekerle et al. (2003). However, a more accurate analysis of [La$^{-}$] and VO$_2$ SS would require measurements starting after five minutes of exercise, to account for the accumulated VO$_2$ slow-component of (Gaesser & Poole, 1996).

In summary, if LT2 and MLSS are the highest SS exercise intensities for [La$^{-}$], and possibly VO$_2$, then CP and RCP will likely not portray a SS in [La$^{-}$] or VO$_2$ because
these two thresholds are commonly greater than the intensity at LT2 and MLSS as a percentage of \( \text{VO}_2\text{max} \) (~71 vs. ~84% for MLSS & RCP respectively).

The physiological responses to exercise in the severe domain are defined as being non-SS, in which \([\text{La}^-]\) and \(\text{VO}_2\) reach maximum values at exhaustion, as determined from GXT. Compared to the variable exercise responses during exercise relative to the second threshold, the severe domain exercise-response should be much more clear. Exercise above the second threshold would not exhibit SS values over time, but would lead to maximum \([\text{La}^-]\) and \(\text{VO}_2\) values from GXT. Dekerle et al. (2003) report that exhaustive CLE bouts to fatigue at and above 90% \(\text{VO}_2\text{max}\) (~4-min to 12-min) nearly reach or exceed \(\text{VO}_2\text{max}\) from GXT. Another study exercising subjects at 90% \(\text{VO}_2\text{max}\) to fatigue found that both \([\text{La}^-]\) and \(\text{VO}_2\) were not different than maximum GXT \([\text{La}^-]\) and \(\text{VO}_2\) values \((p > .05)\), and that both variables seem to have a mirrored response (i.e., increasing \([\text{La}^-]\) and \(\text{VO}_2\) relationship after the 4\(^{th}\)-minute of exercise) (Richard, et al., 2004). Conversely, high-level runners are able to maintain a SS in \(\text{VO}_2\) during exercise at 90% of the velocity eliciting \(\text{VO}_2\text{max}\), whereas \([\text{La}^-]\) rises over time (Billat, et al., 1988). This study had runners exercising at an intensity above critical velocity (critical velocity \(= \text{CP}\), except that velocity is used in place of power for treadmill running). In a similar study analyzing the responses of \([\text{La}^-]\) and \(\text{VO}_2\) during exercise to exhaustion at 90% \(\text{VO}_2\text{max}\), during both running and cycling, it appears that runners have a significantly lower \(\text{VO}_2\) slow-component magnitude than cyclists (20.9 vs. 268.8 mL/min), and that not all participant exercise bouts reached \(\text{VO}_2\text{max}\) (Billat, Richard, Binsse, Koralsztein, &
Haouzi, 1998). As expected however, [La\(^-\)] values during both running and cycling (7.2 & 7.3 mMol/L) were not different from maximal GXT values (\(p = .79\) & \(p = .85\)).

Unfortunately, the study by Billat et al. (1988) did not report the exercise intensity being analyzed in relation to any second threshold parameters such as RCP, so it is possible that the mixed responses by the runners and cyclists reflected different metabolic responses relative to CP, LT2 or RCP.

In the severe exercise domain, specifically above CP, the VO\(_2\) is said to not display a SS, but rather increase to maximum GXT values (Gaesser & Poole, 1996). However, investigators recently have found that CLE to exhaustion above the CP does not necessarily result in VO\(_{2\text{max}}\) (Sawyer, et al., 2010). Additionally, other investigators report that [La\(^-\)] and VO\(_2\) increase over time during CLE at CP (\(p < .001\)), which suggests that CP may not be the maximal SS (Brickley, et al., 2002). These, along with the previous example by Billat et al. (1988) of runners maintaining a VO\(_2\) SS during CLE above critical velocity, demonstrate that CP may not be an accurate demarcation of heavy to severe exercise as has been traditionally described. Critical power has been classically defined as the demarcation of SS from non-SS exercise, and the controversy found in the literature could be a consequence of the inconsistent methods, and mathematical models, used in determining CP (Bull, Housh, Johnson, & Perry, 2000). Therefore, a physiological response during GXT, such as RCP, may serve as a clearer demarcation for the VO\(_2\) kinetics from the heavy to the severe domain. But even this suggestion is not without its complications, as determination of the exact power eliciting a particular
threshold from the GXT requires subsequent sub-maximal exercise testing (Faude, Meyer, & Kindermann, 2006), and consideration of the magnitude of the VO$_2$ slow component (Lucia, Hoyos, & Chicharro, 2000).

Current theory supports a coincident maximal [La$^-$] and VO$_2$ SS (Billat, et al., 2003; Binder, et al., 2008; Gaesser & Poole, 1996; Meyer, et al., 2005). Whereas some researchers report that CP and RCP, representing the maximal VO$_2$ SS, occur at intensities greater than MLSS (Dekerle, et al., 2003). Furthermore, some investigators report a SS in [La$^-$] and VO$_2$ at CP (Poole, et al., 1988), and some do not (Brickley, et al., 2002). There is also controversy as to whether exercise above CP is accompanied by increasing [La$^-$] and VO$_2$ to maximal GXT values (Billat, et al., 1988; Sawyer, et al., 2010), even though some investigators have found agreement (Dekerle, et al., 2003; Poole, et al., 1988).

Exercise at RCP appears to occur at an intensity that would not display a [La$^-$] SS (Dekerle, et al., 2003; Simon, et al., 1983). Although, when cyclists are allowed to adjust the power during a self-paced TT, the power chosen by the cyclists elicited a VO$_2$ that was not different from the GXT-VO$_2$RCP, and no change in [La$^-$] and VO$_2$ over the duration of the TT was observed, suggesting a [La$^-$] and VO$_2$ SS at RCP (Perrey, et al., 2003). Controversy exists with RCP exercise, but a consensus exists with the studies looking at exercise intensities that are greater than the RCP. The responses at intensities greater than RCP are accompanied by increasing [La$^-$] and VO$_2$ values that either achieve
or nearly achieve maximal GXT values (Dekerle, et al., 2003; Richard, et al., 2004; Simon, et al., 1983). Recent research conducted on non-traditional endurance exercise (Table Tennis) supports these findings, and has shown that exhaustive exercise at an intensity greater than RCP will display maximal [La'] and VO$_2$ values (Zagatto, Miranda, & Gobatto, 2011). This example also suggests the versatility of RCP as an exercise parameter, as well as the importance of exercise threshold and domain mapping for a wide range of exercise-mode prescription.

2.4 Rationale

To the best of our knowledge, only one research study has compared the physiological responses during CLE bouts relative to the RCP (Simon, et al., 1983), unfortunately the VO$_2$ kinetics were not reported. There exists a need to examine the responses at RCP, as exercise in this realm is favorable to health and performance. In healthy and clinical populations, increased exercise intensity promotes VO$_{2\text{max}}$ (Gormley, et al., 2008; Moholdt et al., 2009), and increased VO$_{2\text{max}}$ is inversely associated with all-cause mortality (Kodama et al., 2009). Further, the VO$_2$ at RCP predicts VO$_{2\text{max}}$ in athletes (Oshima et al., 1997).

Cycling performance has commonly been found to be related to RCP. Grand-Tour-contending cyclists, such as those in the Tour de France, spend more time at an intensity greater than RCP during the TT than non-contenders, ($p < .05$) (Earnest et al., 2009). Other investigators have found that elite cyclists performed a self-paced 20-
minute TT at the power equal to RCP from GXT (Nimmerichter, et al., 2010). Therefore, it appears that when cyclists are allowed to adjust their maximal sustainable intensity using power, they tend to exercise at a power relative to the RCP power. Additionally, evidence exists in support of a relationship between RCP and performance in off-road high-level cyclists (Impellizzeri, et al., 2005). This study compared race time (< 2 hours) with physiological variables from a laboratory GXT and found that only the power output and VO₂ at RCP, when normalized to body mass, correlated to performance \( (r = .63 \text{ and } r = .66, \text{ respectively; } p < .05) \). Running-performance measures also display a relationship to RCP. Extra-laboratory run performance, for men and women respectively, correlated well with the velocity at RCP from the GXT \( (r = .76, p < .05; r = .95, p < .001) \) (Iwaoka, et al., 1988). Finally, recent research has demonstrated a relationship between \( \text{VO}_2\text{RCP} \) and \( W_{\text{max}} \) performance from the GXT in cyclists (Parker, et al., 2009). These researchers found that the \( \text{VO}_2\text{RCP} \) contributes to \( W_{\text{max}} \) more than economy, \( \text{VO}_{2\text{max}} \) or the \( \text{VO}_2\text{VT} \).

Clearly, RCP is highly related to endurance performance, and is a training intensity that has been found to contribute to cardiorespiratory fitness. Additionally, high-level endurance athletes rely on the RCP threshold for pacing. Unfortunately, the exact physiological responses during CLE at RCP have not been fully defined, and have scarcely been investigated. The physiological responses at RCP might contribute to the understanding of athletic performance in cyclists, runners, and perhaps other athletics such as table tennis. More importantly, the RCP may have importance with exercise.
prescription when the outcome goal is to increase cardio-respiratory fitness (VO$_{2\text{max}}$) as a means of decreasing all-cause mortality.
3. METHODS

3.1 Participants

Twenty trained cyclists (female \( n = 3 \)) volunteered for this study; they were recruited by advertising at greater Sacramento, California area bicycle shops and cycling and triathlon clubs. Two participants voluntarily declined further testing after the first day, one due to scheduling conflicts and one due to unforeseen illness. Two additional participants were removed from future data analysis; they were determined outliers because their CLE TTF results lied outside of two standard deviations from the RCP and RCP+ trials’ TTF means. The 16 remaining participants [(female \( n = 2 \), 32.88 (8.69) years, 177.75 (8.17) cm, 77.70 (8.06) kg & 9.84 (7.48) years cycling experience] have all had prior experience with high-intensity cycling, and 13 have had prior GXT experience.

Cyclists had been training for cycling endurance competition for at least two years (> 5 hours/week on average), and have been participating in high-intensity cycling (> 8 on a scale of 1–10) on average of once per week for the last year. All participants were determined low risk for cardiovascular events (Appendix B) (ACSM, 2010). The participant pool choice was based on their familiarity with high-intensity sustained exercise, such as a 10-mile TT, as was required by the inclusion criteria. Participants were instructed to not engage in strenuous exercise or racing for 48 hours prior to testing (e.g., high-intensity intervals, race rides, racing, high-intensity resistance exercise, etc.). A 24-hour activity log was kept throughout the duration of the study. Testing was
postponed when the participant had engaged in excessive strenuous exercise within 48 hours prior to testing. Participants were instructed to not consume alcohol or caffeine, or excessive food and water, within the 4-hours prior to testing. The University Institutional Review Board for the Protection of Human Subjects approved the procedures and the consent and health screening forms for this study (appendices A & B). All participants were made aware of the procedures, commitments, benefits, and freedoms prior to any testing. The pre-participation screening and the informed consent forms were delivered to each participant, signed, and collected prior to any testing. Additionally, participants were assigned a coded identification, not revealed in the results section, to ensure anonymity. All personal information and results were kept in a secure facility until data analysis. Following data analysis, any information linking the participant to the results were destroyed.

3.2 Design

Participants reported to the lab on three separate occasions, which equated to a total laboratory commitment time of approximately five hours. All visits were separated by at least 48 hours in between visits; the time course of the study for each participant was approximately 14 days. The first visit included general participant measures such as height and body mass. Also during the first visit, a GXT and a sub-maximal exercise test were conducted. Visit two and three were single-blinded CLE trials, which were performed until participant fatigue. Constant load exercise trials were evenly distributed using a Latin square design. All participant visits were scheduled at approximately the
same time of day (within ~2 hours). All tests and trials took place in a thermostatically controlled building on the college campus. Laboratory environmental conditions, barometric pressure, humidity and temperature, were recorded immediately prior to every testing or trial session.

3.3 Graded Exercise Test

Initial power was set at 70 watts (W) and was increased by 35 W per minute for males, and was set at 50 W and increased by 25 W per minute for females. Cycling cadence was freely chosen by the participant, as previously recommended to elicit individual efficiency (Dekerle, et al., 2003). All exercise testing and trials were conducted on a Lode cycle ergometer (Gronigen, The Netherlands). The Lode saddle and handlebar positions were adjusted to replicate the positioning of the participants’ own bicycle. Heart Rate was monitored continuously using telemetry (Polar, Lake Success, New York), and recorded every 20 seconds. Ratings of perceived exertion (RPE) were recorded during the last 15 seconds of every stage using a 6 to 20 rating scale (Borg, 1982). Expired air was continuously analyzed by a computerized metabolic cart for gas concentrations and recorded every 20 seconds (ParvoMedics Trueone 2400 metabolic measurement system, Sandy, Utah). A two-way valve and mouthpiece, with headgear to hold the mouthpiece, and a nose clip were placed on the participant and connected to a pneumotach via a large-bore flexible plastic breathing hose. Expired volume was measured through a heated pneumotach, which was calibrated prior to each participant visit across a variety of flow rates (50–80, 100–200, 200–300, 300–400, & > 400 L/min).
using a 3-liter calibrated syringe. The neumotach calibration procedure was consistent with manufacturer specifications. The metabolic cart gas analyzers were also calibrated prior to testing using a medically certified gas of known concentration (16% O\textsubscript{2}; 4% CO\textsubscript{2}). Peak oxygen consumption (VO\textsubscript{2peak}) was determined by the greatest VO\textsubscript{2} attained for a 1-minute average. Verbal encouragement was withheld during testing. Termination of the GXT was determined by a drop in cadence below 70 revolutions per minute (rpm), as was verbalized to the participant prior to testing. Peak aerobic power (W\textsubscript{peak}) was determined from the following equation:

\[
W_{\text{peak}} = (W_{\text{prior}} + \%W_{\text{end}})
\]

Where \(W_{\text{prior}}\) equals the W of the prior completed 1-minute stage and \(\%W_{\text{end}}\) equals the fraction of time completed during the terminal stage multiplied by the difference in W from \(W_{\text{prior}}\) to \(W_{\text{end}}\). Participants completed an active recovery after test termination for at least five minutes at their respective first-stage GXT power.

Blood lactate was determined by a blood collection (~0.7 micro-liters) from an earlobe capillary sample using a small lancet at 4-minutes post exercise ([La\textsuperscript{-}])\textsubscript{posd}) and was analyzed using enzymatic methods (Lactate Plus, Nova Biomedical, Waltham, MA, USA).

After completion of the GXT, the VT and RCP thresholds were determined from 20-second gas collection averages using the ventilatory equivalents of VO\textsubscript{2} and carbon
dioxide production (VCO₂ L/min) as described previously (Beaver, et al., 1986; Caiozzo, et al., 1982). The VO₂ corresponding to the first non-linear increase in Vₑ/VO₂ defined VT, and the VO₂ corresponding to the non-linear increase in Vₑ/VCO₂ with a concomitant increase in Vₑ/VO₂ defined the RCP (GXT-VO₂VT & GXT-VO₂RCP respectively; Figure 2).
Figure 2. Example graph from GXT of $V_E/VO_2$ and $V_E/VCO_2$.
Arrows indicate the VO$_2$ at the first (VT) and second (RCP) ventilation thresholds.
Two independent experienced investigators made threshold determinations; a third investigator was used in the case that the first two investigators did not reach a consensus. The “two-out-of-three” protocol has been used previously (Dekerle, et al., 2003; Faude, et al., 2006).

3.4 RCP-Power Detection

An RCP-power detection sub-maximal test (SXT) was necessary because the VO\textsubscript{2} during the GXT has a variable time delay starting at the onset of power administration, which may cause an overestimation of the power associated with the GXT VO\textsubscript{2RCP} (Faude, et al., 2006). Furthermore, VO\textsubscript{2} and power are not co-linear at intensities above the LT during a GXT (Bearden & Moffatt, 2001). However, the VO\textsubscript{2} at RCP during GXT has been found to be consistent across a variety of GXT protocols (McLellan, 1985).

After a 15-minute passive recovery following the GXT and active recovery period (~20 min total), participants were instructed to warm-up at a resistance equivalent to their respective stage-one intensity from the GXT. The first-stage power of the SXT was calculated as 70% of the power at the GXT-VO\textsubscript{2RCP}; the GXT-VO\textsubscript{2RCP} power was determined using a similar equation as that used to determine W\textsubscript{peak}. Pilot data in our lab has been successful with this equation to give a reduction in power that elicits a VO\textsubscript{2} that is well below the GXT-VO\textsubscript{2RCP} during the first stage of the SXT.
Each subsequent stage power was increased in an asymptotic method, per 4-minute stage, using the following equation:

$$ W \text{ increase} = \frac{((\text{target VO}_2 - \text{stage VO}_2)/2) / (\text{stage VO}_2 / \text{stage W})}{\text{target VO}_2} $$

Where target VO$_2$ is the GXT-VO$_2^{RCP}$; stage VO$_2$ is the 1-minute VO$_2$ from the end of the 4-minute stage during the SXT; and stage W is the coincident power during the stage. Minimum power increases were 10 W for men, and 7 W for women. The testing was terminated when a 1-min VO$_2$ exceeded GXT-VO$_2^{RCP}$ at any point during the 4-minute stage of the SXT. The W from the stage immediately prior to the excessive VO$_2$ was considered the RCP power. The power for RCP+ was calculated as RCP power plus 10%. This protocol was designed to increase power that would take the VO$_2$ to approximately half-way between the target and current-stage VO$_2$ on subsequent stages, and to elicit the GXT-VO$_2^{RCP}$ at approximately 16 minutes (4 stages).

This power associated with the GXT-VO$_2^{RCP}$ was determined by the highest power that does not give a VO$_2$ greater than the target GXT-VO$_2^{RCP}$ during a 4-minute stage of the SXT (Figure 3). The differences in power were recorded from both the determined RCP power from the SXT, and the power from the stage that exceeded the target GXT-VO$_2^{RCP}$ in order to report the RCP power accuracy range.
Figure 3. Example RCP-power detection.

Protocol for target VO$_2^{RCP}$ determined from GXT; RCP power determined as the power of the previous stage to that which exceeded the target GXT-VO$_2^{RCP}$ of 4.10 L/min.
3.5 Constant Load Exercise Trials

A standardized 15-minute warm-up protocol was used for all participants (5 min at 20% $W_{\text{peak}}$; 5 min at 35% $W_{\text{peak}}$; 5 min at 50% $W_{\text{peak}}$). The RCP or RCP+ power was administered on the Lode immediately upon start of participant pedaling. The participants were required to keep the gas collection mouthpiece in for continuous sampling. Drinking-water and a fan were offered ad-lib; energy replenishment was not offered. When water was desired, the participant was relieved of the mouthpiece and data collection was suspended for approximately one minute. Missing data was replaced with the average VO$_2$ of the 1-minute VO$_2$ from both before and after the missing data point for HR, $V_E$ and VO$_2$. Heart rate, $V_E$ and VO$_2$ were monitored and recorded the same as described for GXT. Verbal encouragement was withheld during the entire duration of testing. Ratings of perceived exertion were recorded during the last 15 seconds of every 5-minute period. Blood lactate was recorded during the last 30 seconds of the 10-minute and 25-minute period of the trial (Billat, et al., 2003), and again at 4-minutes post exercise ([La]$^{\text{post}}$). Only cadence (cycle ergometer tachometer) was revealed during the CLE trials; elapsed time and all other measured variables were withheld from the participant during the trials. Pilot data in our lab found that the exercise duration at these expected intensities (~80 to 95% VO$_{2\text{max}}$) would last between ~10 and 45 minutes, in trained cyclists. Participants were instructed to cycle for “as long as possible”, and were stopped using the same criteria as mentioned prior for GXT test termination (< 70 rpm). Participants only had self-constraints as they were free to end
testing at any time during each CLE trial. Post-exercise HR and signs and symptoms, were continuously monitored during five minutes of active recovery (ACSM, 2010).

3.6 Statistical Analysis

All data analyzed and presented as means (±SD). Heart rate data presented as end 20-second measurement; \( V_e \) and \( VO_2 \) presented as 60-second average. Statistical comparisons of HR, \( V_e \) and \( VO_2 \), from RCP+ trials were made using one-way analysis of variance (ANOVA) with repeated measures. Post exercise \([La^-]\) from the GXT, and the RCP and the RCP+, and the RPE at GXT-\( VO_2^{peak} \) and GXT-\( VO_2^{2RCP} \), as well as at time intervals during RCP and RCP+ trials for both variables, were used for analysis. Lactate and RPE measurements were analyzed using one-way ANOVA with repeated measures.

Cardiopulmonary variables at absolute time intervals (3-min, 5-min & end) from both CLE trials were analyzed using two-way ANOVA with repeated measures for 20-second HR, and 60-second \( V_e \) and \( VO_2 \). Additional analysis of time data was conducted in relative terms, and presented as a percentage of TTF (40, 60, 80, & 100%).

When ANOVA analysis failed Mauchly’s Sphericity Test, the Greenhouse-Geiser \( p \)-value adjustments were used. Tukey’s post hoc was used when statistical significance was observed. The last fully recorded 1-minute average measurement for \( V_e \) and \( VO_2 \) before termination for all trials was considered end-data (end); end-HR was the last 20-second measurement before termination. Pearson’s product-moment correlation
coefficient ($r$) was used to analyze relationships between variables. Statistical analysis was performed using Statistica software (StatSoft Inc, Tulsa, OK). An $\alpha$-level of .05 was used for significance.
4. RESULTS

4.1 Graded Exercise Test

All peak VT and RCP variables from the GXT are presented in Table 1.
Table 1. Descriptive GXT means (±SD), with relative percent of peak values ($n = 16$).

<table>
<thead>
<tr>
<th>GXT Variable</th>
<th>Values</th>
<th>% of Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{VO}_{2\text{peak}}$ (ml/kg/min)</td>
<td>53.20 (8.07)</td>
<td></td>
</tr>
<tr>
<td>$\text{VO}_{2\text{peak}}$ (L/min)</td>
<td>4.17 (0.79)</td>
<td></td>
</tr>
<tr>
<td>$\text{HR}_{\text{peak}}$ (bpm)</td>
<td>179.22 (12.27)</td>
<td></td>
</tr>
<tr>
<td>$\text{VE}_{\text{peak}}$ (L/min)</td>
<td>136.06 (35.38)</td>
<td></td>
</tr>
<tr>
<td>$W_{\text{peak}}$ (watts)</td>
<td>383.15 (78.27)</td>
<td></td>
</tr>
<tr>
<td>$\text{RPE}_{\text{peak}}$ (6–20)</td>
<td>18.16 (1.80)</td>
<td></td>
</tr>
<tr>
<td>$\text{VO}_{2\text{RCP}}$</td>
<td>3.86 (0.75)</td>
<td>93%</td>
</tr>
<tr>
<td>$\text{HR}_{\text{RCP}}$ (bpm)</td>
<td>168.81 (14.49)</td>
<td>94%</td>
</tr>
<tr>
<td>$\text{VE}_{\text{RCP}}$ (L/min)</td>
<td>103.96 (24.23)</td>
<td>76%</td>
</tr>
<tr>
<td>$W_{\text{RCP}}$</td>
<td>324.16 (73.86)</td>
<td>85%</td>
</tr>
<tr>
<td>$\text{RPE}_{\text{RCP}}$</td>
<td>16.56 (1.41)</td>
<td>91%</td>
</tr>
<tr>
<td>$\text{VO}_{2\text{VT}}$ (L/min)</td>
<td>3.16 (0.69)</td>
<td>76%</td>
</tr>
</tbody>
</table>
4.2 RCP-Power Detection

During the SXT, the VO₂<sub>RCP</sub> was exceeded at 14.31 (1.85) minutes and was within 9.81 (1.33) W of the subsequent stage. The RCP and RCP+ power were identified as 272.94 (58.9) W and 300.25 (64.75) W, 71 & 78% W<sub>peak</sub> respectively. The GXT-VO₂<sub>RCP</sub> [3.86 (0.75) L/min] was not different from peak VO₂ during the RCP trial [3.96 (0.78) L/min], \( p = .16 \), and was highly correlated, \( r = .98, p < .05 \) (Figure 4).
Figure 4. Relationship between the GXT-VO₂<sub>RCP</sub> and the RCP trial VO₂<sub>peak</sub>.

\[ R^2 = 0.9695 \]
4.3 Cardiopulmonary Variables

Of the 8 hours and ~42 minutes of combined CLE trial duration for both RCP and RCP+ trials, 9 minutes and 40 seconds (~1.85%) were spent with the gas collection gear absent. These missing data points were replaced using the averaging of the prior and subsequent 1-minute average data.

4.3.1 RCP Trial

Mean TTF was 22.02 (9.20) minutes, with a range of 10.67 to 40.98 minutes. Peak HR [176.75 (9.86) bpm] was significantly greater than GXT-HR_{RCP} [168.81 (14.49) L/min], \( p < .001 \), but not different from GXT-HR_{peak} [179.22 (12.27) L/min], \( p = .50 \).

Peak \( V_e \) [123.87 (32.07) L/min] was significantly greater than GXT-\( V_{E_{RCP}} \) [103.96 (24.23) L/min], \( p < .001 \), and significantly less than GXT-\( V_{E_{peak}} \) [136.06 (35.38) L/min], \( p < .05 \). Peak \( VO_2 \) [3.96 (0.78) L/min] was not different from GXT-\( VO_{2RCP} \) [3.86 (0.75) L/min], \( p = .16 \), and was significantly less than GXT-\( VO_{2peak} \) [4.17 (0.79) L/min], \( p < .001 \).

Absolute time interval data showed a significant interaction for both time and intensity for HR (\( p < 0.001 \)), \( V_E \) (\( p < 0.005 \)) and \( VO_2 \) (\( p < 0.05 \)). End-trial HR [174.85 (9.27) bpm], \( V_E \) [120.65 (32.84) L/min] and \( VO_2 \) [3.85 (0.80) L/min] were greater than the 5-minute HR [163.07 (9.56) bpm], \( V_E \) [97.77 (22.67) L/min] and \( VO_2 \) [3.67 (0.70) L/min], \( p < .005 \), and greater than the 3-minute HR [160.00 (10.16) bpm], \( V_E \) [91.95 (21.90) L/min] and \( VO_2 \) [3.55 (0.68) L/min], \( p < .001 \). Five-minute HR, \( V_E \) and \( VO_2 \)
were greater than 3-minute HR, $V_E$ and $VO_2$, $p < .005$. The HR at 3-minutes, 5-minutes, and end were less than the RCP+ HR at 3-minutes, 5-minutes, and end, $p < .005$. The $V_E$ at 3-minutes, 5-minutes, and end were less than the RCP+ $V_E$ at 3-minutes, 5-minutes, and end, $p < .001$. And the $VO_2$ at 3-minutes, 5-minutes, and end were less than the RCP+ $VO_2$ at 3-minutes, 5-minutes, and end, $p < .001$. The $VO_2$ at 5-minutes was not different from the RCP+ $VO_2$ at 3-minutes, $p = .66$, and the end $VO_2$ was not different from the RCP+ $VO_2$ at 5-minutes, $p = .32$ (Figures 5, 6 & 7).
Figure 5. Heart Rate (HR) data presented over absolute time intervals. 

(*) HR data points display a significant variation over time, $p < .05$. (#) significant variation between trials at same time, $p < .05$. Mean $HR_{peak}$ (dashed line) as determined from GXT.
Figure 6. Ventilation (VE) data presented over absolute time intervals.

(*) VE data points display a significant variation over time, $p < .05$. (#) significant variation between trials at same time, $p < .05$. Mean $VE_{peak}$ (dashed line) as determined from GXT.
Figure 7. Oxygen uptake (VO\(_2\)) data presented over absolute time intervals.

(*) VO\(_2\) data points display a significant variation over time, \( p < .05 \). (#) Significant variation between trials at same time, \( p < .05 \). Mean VO\(_{2\text{peak}}\) (dashed line) as determined from GXT. Mean RCP trial VO\(_2\) at 5-minutes not different from RCP+ VO\(_2\) at 3 minutes, \( p = .66 \), and RCP VO\(_2\) at end not different from RCP+ at 5-minutes, \( p = .32 \).
4.3.2 RCP+ Trial

Mean TTF was 10.62 (3.13) minutes, with a range of 6.00 to 16.23 minutes. Peak HR [178.28 (11.12) bpm] was significantly greater than GXT-HR_{RCP}, p < .001, but not different from GXT-HR_{peak}, p = .95. Peak V_E [132.47 (30.17) L/min] was significantly greater than GXT-V_{ERCP}, p < .001, but not significantly different from GXT-V_{Epeak}, p = .81. Peak VO_2 [4.06 (0.85) L/min] was significantly greater than GXT-VO_{2RCP} [3.86 (0.75) L/min], p < .001, but was not significantly different from GXT-VO_{2peak} [4.17 (0.79) L/min], p = .10.

Absolute time interval data showed a significant interaction for both time and intensity for HR (p < .001), V_E (p < .005) and VO_2 (p < .05). End-trial HR [178.13 (11.13) bpm], V_E [130.42 (31.07) L/min] and VO_2 [3.99 (0.83) L/min] were greater than the 5-minute HR [171.25 (10.26) bpm], V_E [113.97 (26.25) L/min] and VO_2 [3.89 (0.78) L/min], p < .001, and greater than the 3-minute HR [167.36 (9.38) bpm], V_E [102.28 (22.83) L/min] & VO_2 [3.70 (0.72) L/min], p < .001. The RCP+ 5-minute HR, V_E and VO_2 were greater than 3-minute HR, V_E and VO_2, p < .001.

4.3.3 Percent of TTF

Time data was normalized and presented as a percentage of TTF, so comparison between the same relative times of each trial were possible (40, 60, 80, & 100% TTF). Relative HR data revealed a significant time effect, p < .001. The HR at 40, 60, 80, and
100% for both RCP and RCP+ trials were all ascending and different for each subsequent percent time interval, \( p < 0.01 \) (Figure 8).

Relative \( V_E \) data revealed a significant interaction for both time and intensity, \( p < 0.005 \). The \( V_E \) at 40, 60, 80, and 100% for both RCP and RCP+ trials were all ascending and different over time, \( p < .05 \). The RCP \( V_E \) at 60, 80, and 100% were all significantly less than the RCP+ \( V_E \) at 60, 80, and 100% respectively, \( p < .001 \), whereas the RCP \( V_E \) at 40% was not different from the RCP+ \( V_E \) at 40%, \( p = .22 \). The RCP \( V_E \) at 60% was not different from the RCP+ \( V_E \) at 40%, \( p = .09 \), and the RCP \( V_E \) at 80% was not different from the RCP+ \( V_E \) at 60%, \( p = .99 \) (Figure 9).

Relative \( VO_2 \) data revealed a significant interaction for both time and intensity, \( p < .001 \). The RCP \( VO_2 \) at 60% was significantly greater than the RCP \( VO_2 \) at 40%, \( p < .001 \), but the RCP \( VO_2 \) at 100% was not different from the RCP \( VO_2 \) at 80%, \( p = .99 \), or 60%, \( p = .98 \), and the RCP \( VO_2 \) at 80% was not different from 60%, \( p = .95 \) (Figure 2). The RCP \( VO_2 \) at 60, 80, and 100% were all significantly less than RCP+ 60, 80, and 100%, \( p < .001 \), whereas the RCP \( VO_2 \) at 40% was not different from RCP+ 40%, \( p = .42 \). The RCP+ \( VO_2 \) at 60% was significantly greater than the RCP+ 40%, \( p < .001 \), and RCP+ \( VO_2 \) at 80% was greater than RCP+ 60%, \( p < .001 \), but the RCP+ \( VO_2 \) at 100% was not different from RCP+ 80%, \( p = .99 \) (Figure 10).
Figure 8. Heart Rate (HR) data presented over relative time intervals (%TTF).

(*) significant variation from prior time interval for trial, $p < .05$. Mean HR_{peak} (dashed line) as determined from GXT.
Figure 9. Ventilation ($V_E$) data presented over relative time intervals (%TTF).

(*) significant variation from prior time interval for trial, $p < .05$. (#) significant variation between trials at same time, $p < .05$. Mean $V_{Epeak}$ (dashed line) as determined from GXT.
Figure 10. Oxygen uptake (VO$_2$) data presented over relative time intervals (%TTF).

(*) significant variation from prior time interval for trial, $p < .05$. (#) significant variation between trials at same time, $p < .05$. Mean VO$_{2peak}$ (dashed line) as determined from GXT.
4.4 Lactate

The RCP trial [La⁻]_{post} [5.36 (2.64) mMol/L] was less than the RCP+ [La⁻]_{post} [7.75 (2.81) mMol/L], \( p < .001 \) and the GXT [La⁻]_{post} [8.68 (3.21) mMol/L], \( p < .001 \). The RCP+ [La⁻]_{post} was not different from the GXT [La⁻]_{post}, \( p = .26 \). The [La⁻] responses for participants completing 25 minutes of exercise, or more, at RCP are presented in Table 2, and shown graphically from one participant’s data, in relation to VO₂ kinetics, in Figure 11.
Table 2. Data from five participants completing 25 minutes or more at RCP.

<table>
<thead>
<tr>
<th>Participant/ TTF</th>
<th>Variable</th>
<th>10-min</th>
<th>25-min</th>
<th>End</th>
<th>Change (10 to 25)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/ 40:59</td>
<td>[La−]</td>
<td>5.1</td>
<td>6.7</td>
<td>5.1</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>VO₂</td>
<td>3.69</td>
<td>3.97</td>
<td>3.92</td>
<td>0.28</td>
</tr>
<tr>
<td>2/ 30:17</td>
<td>[La−]</td>
<td>5.9</td>
<td>8.6</td>
<td>NA</td>
<td>2.7</td>
</tr>
<tr>
<td></td>
<td>VO₂</td>
<td>3.42</td>
<td>3.52</td>
<td>3.55</td>
<td>0.1</td>
</tr>
<tr>
<td>3/ 34:20</td>
<td>[La−]</td>
<td>2</td>
<td>2.7</td>
<td>2</td>
<td>0.7</td>
</tr>
<tr>
<td></td>
<td>VO₂</td>
<td>2.91</td>
<td>3.06</td>
<td>2.99</td>
<td>0.15</td>
</tr>
<tr>
<td>4/ 34:12</td>
<td>[La−]</td>
<td>2.4</td>
<td>2.7</td>
<td>2.6</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>VO₂</td>
<td>4.22</td>
<td>4.15</td>
<td>4.21</td>
<td>-0.07</td>
</tr>
<tr>
<td>5/ 31:00</td>
<td>[La−]</td>
<td>5.4</td>
<td>8.3</td>
<td>8.9</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>VO₂</td>
<td>4.39</td>
<td>4.53</td>
<td>4.73</td>
<td>0.14</td>
</tr>
<tr>
<td>Means</td>
<td>[La−]</td>
<td>4.2</td>
<td>5.8</td>
<td>NA</td>
<td>1.6</td>
</tr>
<tr>
<td></td>
<td>VO₂</td>
<td>3.73</td>
<td>3.85</td>
<td>3.88</td>
<td>0.12</td>
</tr>
</tbody>
</table>
Figure 11. Example VO₂ data for one male participant from both trials presented over time.

Data points represent 1-minute VO₂ during the RCP (solid squares) and RCP+ trials (solid triangles), and [La⁻] during the RCP (open triangles) and RCP+ trials (open squares). Dashed lines represent mean values from GXT. Rise in [La⁻] and VO₂ from 10-min to 25-min was 2.9 mMol/L and 14 mL/min respectively.
4.5 RPE

The RPE at 5-minutes [13.27 (1.03)] and 10-minutes [15.00 (1.31)] during the RCP trial, and the RPE at 5-minutes [15.13 (1.46)] during the RCP+ trial were all less than the GXT-RPE\textsubscript{RCP} [16.67 (1.40)] and GXT-RPE\textsubscript{peak} [18.23 (1.84)], \( p < .005, n = 15 \). The RPE during the RCP trial at 10-minutes was greater than 5-minutes, \( p < .001 \), and the RPE at 5-minutes during RCP+ was greater than 5-minutes at RCP, \( p < .001 \), but the RPE at 5-minutes during the RCP+ trial was not different from the RPE at 10-minutes for the RCP trial, \( p = .99 \).
5. DISCUSSION

The findings from this study support the oxygen kinetics described in previous review articles associated with CLE cycle ergometer work at the RCP intensity from the GXT (Binder, et al., 2008; Gaesser & Poole, 1996; Meyer, et al., 2005). Mean VO$_2$ reached SS during the RCP trial from the time point at 60% TTF until the end of exercise. Additionally, the VO$_2$ during the RCP+ trial was not different from 80% TTF until the end of exercise, and, the peak VO$_2$ during the RCP+ trial was not significantly different from GXT-VO$_2$peak.

The first threshold from a GXT represents the onset of the VO$_2$ slow component (Gaesser & Poole, 1996). Exercise above the first threshold is met with increasing [La$^-$] and VO$_2$, but a SS is still achievable. The [La$^-$] and VO$_2$ kinetics have been described as “tightly coupled” (Gaesser & Poole, 1996). A second threshold occurs above the first, in which the acidosis associated with [La$^-$] exceeds the buffering capacity of the body, and the VO$_2$ slow component eventually rises to VO$_2$max. Several definitions of the second threshold exist including the CP, LT2, MLSS and RCP. However, very little research exists supporting the second threshold concept relative to RCP (Richard, et al., 2004; Simon, et al., 1983).

The demarcation between SS VO$_2$ and non-SS VO$_2$ has classically been described as CP (Gaesser & Poole, 1996). Critical power has also been described as relating to an intensity that can be maintained for ~1 hour. (Brickley, et al., 2002). However, Brickley
et al. (2002) found that CLE at CP was sustainable for much less than one hour (~30 min). Our research looked at CLE at RCP. The CP and RCP have been shown to be not different in their intensity (Dekerle, et al., 2003; Zagatto, et al., 2011), and according to our findings represent similar theoretical VO₂ kinetics (SS in VO₂). The TTF at RCP for our participants was ~22 minutes, while achieving a VO₂ SS for the last 40% of exercise time (after ~13 minutes). Of note is the difference in age and fitness of the participants from the study by Brickley et al. (2002) and our study, 23 years and 61 ml/kg/min versus 33 years and 53 ml/kg/min respectively. A greater VO₂max, or greater threshold as a percentage of VO₂max, are described as predicting endurance capacity (Meyer, et al., 2005). Our participants displayed a relatively high second threshold as a percent of max (93%), but had a lower VO₂max than those of Brickley et al. (2002) which may explain the lower TTF in our study. Additionally, our participants had a relatively high BMI for elite athletes, slightly less than 25, which may affect TTF. However, we found a weak and insignificant correlation between BMI and RCP-trial TTF, r = .14, p = .60.

According to our findings, CLE at RCP accurately represents the demarcation between SS and non-SS VO₂, whereas classic theory defines the maximal SS demarcation to be CP. However, a recent review article has described the second threshold to envelope both CP and RCP, along with LT2 and MLSS (Binder, et al., 2008). Brickley et al. (2002) found VO₂ to significantly rise from 5-minutes to 20-minutes. We found VO₂ to significantly rise from 5-minutes to ~22-minutes, so it may be possible that there existed a SS in VO₂ in the latter half of exercise in the study by
Brickley et al. (2002), similar to our findings. Conversely, CP and RCP may represent two completely different phenomena since CP is a measure of performance and RCP is a measure of physiology.

The CP concept is described by the physiological responses of both [La\(^-\)] and VO\(_2\), but CP is determined by a performance protocol of several TTF trials of short duration (~1 to 10 min). Researchers have also shown that the protocols used to determine CP vary in their intensity outcomes (Bull, et al., 2000). Because the transition from SS to non-SS [La\(^-\)] and VO\(_2\) kinetics is a physiological event, it might be more appropriate to define the transition with a physiological threshold such as LT2, MLSS or RCP. Additionally, during CLE at intensities above the CP and/or critical velocity, VO\(_{2\max}\) is not always achieved (Billat, et al., 1988; Sawyer, et al., 2010).

The results from our study found VO\(_2\) during RCP+ to rise to a value that was not different from GXT-VO\(_{2\text{peak}}\). This response has been characterized previously in review articles for exercise above the second threshold (Binder, et al., 2008; Gaesser & Poole, 1996; Meyer, et al., 2005). Previous research done during CLE specifically above the RCP was characterized by a rise in VO\(_2\) to max GXT values (Richard, et al., 2004), and a rise in [La\(^-\)] to max GXT values (Simon, et al., 1983). Accordingly, [La\(^-\)]\(_{\text{post}}\) values from the RCP+ trial were not different from [La\(^-\)]\(_{\text{post}}\) values from the GXT trial in our study.
The second lactate threshold also represents the demarcation between a SS [La−] and non-SS [La−], commonly referred to as the MLSS. Recent research supports this theory. Pires et al. (2011) described the [La−] kinetics during CLE at LT2 as SS, whereas exercise above LT2 did not achieve a SS in [La−] (Pires, et al., 2011). Interestingly, the intensity that was used above LT2 displayed a SS in VO₂. Therefore, according to the study by Pires et al. (2011) there would appear to be a separation between the [La−] and VO₂ maximal SS. However, the definition of a SS in [La−] is described as being a change in [La−] from 10-minutes to 25-minutes of less than 1.00 mMol/L (Billat, et al., 2003), which is different than the statistical analysis used by Pires et al. (2011). Therefore, there remains the potential, in the study by Pires et al. (2011), for a maximal SS in [La−] and VO₂ at the same intensity if using the parameters described by Billet et al. (2003).

Our participants cycling at RCP reached a SS in VO₂ from ~13 minutes to the end of exercise, ~22 min. However, [La−] kinetics were highly varied between participants, and only five participants exercised for longer than the 25 minutes needed for a second blood [La−] measurement. Of the five participants, only two had a gain in [La−] of less than 1.00 mMol/L from 10-minutes to 25-minutes. We chose to run a sub-set of data analysis on the participants exercising longer than 25 minutes (t-test; n = 5). The mean increase in [La−] from 10-minutes to 25 minutes was 1.64 mMol/L (4.16 to 5.80), and was significant, p < .05. The mean increase in VO₂ from 10-minutes to 25-minutes was 0.12 L/min [3.73 (0.60) L/min to 3.85 (0.57) L/min], was not statistically different, p = .10, and was highly correlated, r = .98 p < .05. For these five participants there appears to be
a separation between the maximal [La\(^{-}\)] and VO\(_2\) SS. However, two other participants did in fact achieve a [La\(^{-}\)] SS during the RCP trial (Table 2, participants 3 & 4).

Similar to our study, previous researchers have shown that exercise at “slightly below” RCP was sustainable for 30 minutes in only a portion of the study participants (Simon, et al., 1983). In that study, [La\(^{-}\)] increased to values similar to that of our participants that lasted longer than 25-minutes (6.1 vs. 5.8 mMol/L). Additionally, exercise at “slightly above” RCP in the study by Simon et al. (1983), lasted for 13 minutes; CLE at the RCP+ lasted for ~11 for our participants (n = 16). Simon et al (1983) also reported a wide range of TTF for the trial “above” RCP (6 to 23 min), similar to our findings (6 to 16 min). These examples predict RCP exercise to be sustainable for ~25 minutes, and RCP+ exercise for about half as long.

We exercised our participants to fatigue during CLE at both RCP and RCP+. The TTF for RCP was ~22 min, with a range of 11 to 41 minutes. In a review article by Meyer, et al. (2005), cardiopulmonary variables from the GXT such as VO\(_{2\text{max}}\) and the first and second ventilation thresholds reflect endurance capacity (Meyer, et al., 2005), which would suggest that endurance capacity should be fairly linear across the exercise continuum. However, the results from our study of TTF at RCP and RCP+ do not share similar endurance capabilities. There was a weak and insignificant correlation between the TTF at RCP and RCP+, \(r = .26\) \(p = .34\). The sustainability of exercise in relation to
RCP appears to be highly individualized, and that a prediction of TTF at intensities above RCP cannot necessarily be determined by the exercise capacity at, or below, RCP.

The HR responses during RCP and RCP+ in our study were more similar than the VO₂ response for the two intensities. The peak HR for both trials were not different from the GXT-HR_{peak}, p > .50, even though the HR at 3-minutes during RCP+ was ~7 bpm higher than 3-minutes at RCP. The longer TTF at RCP appears to accommodate a drift in HR to the GXT-HR_{peak}. Given that exercise tolerance was almost half the duration during RCP+ versus RCP, exercise prescription using HR should account for the magnitude in drift and the intensity prescribed in relation to RCP.

The HR response during exercise is commonly used for exercise prescription. However, the HR drift at high intensities (>RCP) may be steep, and eventually lead to HR_{peak}. Previous research found the HR at RCP to be 93% of GXT-HR_{peak} in a group of men with high cardiorespiratory fitness (Azevedo, et al., 2011), which is similar to the findings of our study (~94%). Azavedo et al. (2011) also found that the GXT-HR_{RCP}, as a percent of HR_{peak}, did not change with age. Our study did include two females, but the similarities in the percentage of GXT-HR_{peak} for the GXT-HR_{RCP} are likely useful for exercise prescription. The responses to exercise, and tolerable duration, at intensities in relation to RCP are better predicted based upon the findings from this study. However, the identification of the RCP demarcation based on HR alone may be problematic. The HR at 3-minutes and 5-minutes during the RCP trial were 160 and 163 bpm, respectively,
whereas the HR_{RCP} from GXT was 169 bpm. Therefore, if an intensity is chosen for exercise based on the target HR_{RCP} from GXT, there would appear to be the likelihood of exercising at too great an intensity to mimic the responses we found at RCP, along with mimicking an exercise duration of ~22 minutes.

The RPE is also a common variable used for exercise prescription (Borg, 1982). The results of this study found that the GXT-RPE_{RCP} did not equate to the RPE during CLE at RCP or RCP+. During exercise at the RCP trial, RPE measures at 5-minutes (~13) and 10-minutes (15) were both lower than the GXT-RPE_{RCP} (~16.5), p < .001. Additionally, the RPE during the RCP+ trial at 5-minutes (~15) was also lower than the GXT-RPE_{RCP}, p < .005. The GXT-RPE_{RCP} likely overestimates exercise at the maximal VO_{2} SS, and potentially overestimates exercise at a slightly higher intensity (RCP +10%). Because the power from the GXT at RCP also overestimates the actual power at RCP, it is possible that the RPE coincides with the strain on the legs, particularly from cycle ergometry. However, the power at RCP during GXT was only 85% W_{peak}, whereas the GXT-RPE_{RCP} was 91% GXT-RPE_{peak}. The participants were instructed to give RPE scores related to “overall” perception, so the exact influence of the strain from the legs on RPE is not known. Further research is needed to identify the influence of factors contributing to the RPE at RCP score such as HR, peripheral strain, V_{E} and possibly VO_{2}.

The peak V_{E} response during RCP+ (132 L/min) was not different from GXT-V_{Epeak} from (136 L/min), but during the RCP trial, the peak V_{E} (124 L/min) was
significantly lower than GXT-VE_{peak}, p < .05. Contrary to the HR response, the VE response did not show the same time dependent increase to peak values from the GXT during the RCP trial, but did increase to peak during the RCP+ trial. Because RCP represents the threshold of increased ventilatory response associated with metabolic acidosis, the rise in VE to GXT-VE_{peak} during RCP+ is to be expected.

“Steady state” exercise has been defined primarily in the context of [La-] and VO2 kinetics. We did not observe a SS in [La-], HR or VE, even though we can confirm that RCP does describe the highest SS in VO2 without the achievement of VO2peak. Exercise at the MLSS (~71% VO2max) has been shown to not reflect a complete physiological SS in HR and VE, even though some have confirmed a SS in these variables at LT2 (~78% VO2max) (Baron, et al., 2008; Pires, et al., 2011). Additionally, others have shown a significant increase in HR at CP (~80% of VO2peak), which would suggest that there would not be a complete physiological SS at CP as well (Brickley, et al., 2002). Exercise termination was highly variable during exercise at these maximal-SS threshold points, and is perhaps influenced by other variables such as HR or VE. According to these studies, exercise at MLSS lasts for 55 minutes (Baron, et al., 2008); exercise at LT2 lasts for ~45 minutes (Pires, et al., 2011); and exercise at CP lasts for ~20 minutes (Brickley, et al., 2002). We found exercise at RCP to last for ~22 minutes, but a true physiological SS has been described as allowing exercise to continue indefinitely (Gaesser & Poole, 1996). Therefore other factors responsible for the termination of exercise should be considered when describing SS exercise. For example, in our study the HR at the end of
RCP exercise was not different from HR_{peak}. Brickley et al. (2002) suggest that CP, as a SS representative, would better be defined as “the highest non-steady-state…that can be maintained for a period in excess of 20 min, but generally no longer than 40 min.” In agreement, we found that exercise at RCP lasts for ~22 minutes, and only with a SS in VO_{2}. Our findings give support that the RCP represents the separation between SS and non-SS exercise, but the RCP does not represent a true physiological SS in all cardiopulmonary variables.

The findings from our study are based upon the assumption that the protocol we used to determine the actual power intensity at the RCP VO_{2} is correct. First, the detection process using the ventilator equivalents method has been widely used (Beaver, et al., 1986; Caiozzo, et al., 1982; Meyer, et al., 2005), and we followed the same verification method often employed (2-out-of-3). Second, the RCP-power detection trial developed successfully determined the power that elicits the GXT-VO_{2RCP}. We determined the power at RCP to be ~273 W (71% W_{peak}), which was ~50 W less than the power associated with GXT-VO_{2RCP} (324 W). Other investigators have recommended a second sub-maximal test to accurately determine the power that elicits the VO_{2} for the given ventilation threshold from GXT (Faude, et al., 2006). We chose to follow a similar protocol. However, the power increase used by Faude et al. (2006) overestimated the target VO_{2} during subsequent stage increases. The difficulty of predicting the VO_{2} response at intensities near RCP would prove to be even more problematic because of the unpredictability of the VO_{2} slow-component. We chose to use a protocol that made
intentional W increases of less than what might be calculated (10 mL/W/min) as the power at VO$_2$RCP to ensure an underestimation of stage W increases. However, the relatively high intensity at RCP might limit the tolerable exercise duration of the participant. Therefore, the protocol design had to consider exercise durations of less than 20 minutes, as has been demonstrated with pilot work in our lab. The power-detection protocol we used successfully found the power at GXT-VO$_2$RCP in ~14 minutes, and with a subsequent stage error of less than 10 W. Therefore, we believe our protocol to have accurately identified the power at GXT-VO$_2$RCP within 10 watts. Additionally, the GXT-VO$_2$RCP and the peak VO$_2$ during the RCP trial were not different, and were highly correlated, $r = .98$, $p < .05$.

In conclusion, the findings from our study support the two-threshold model of VO$_2$ kinetics. Exercise at RCP displayed a SS in VO$_2$ from 60% TTF (~13 minutes) to the end of exercise (~22 minutes). Only five of the 16 participants were able to tolerate exercise for more than 25 minutes, and three displayed an increase in [La$^-$] from 10-minutes to 25-minutes of > 1 mMol/L. Additionally, [La$^-$]$_{post}$ from the RCP trail was significantly less than [La$^-$]$_{post}$ from GXT, $p < .001$.

Exercise at RCP+ displayed a marked decrease in TTF compared to RCP (11 vs. 22 minutes). During RCP+ all cardiopulmonary and [La$^-$] variables achieved maximal values from GXT. The literature clearly supports the response to exercise above the second threshold as that attaining maximal values from a GXT. Our study supports RCP
as the demarcation for SS and non-SS VO$_2$. However, future research is still needed to support these findings, as well as to investigate the potential separation between the [La$^+$] and VO$_2$ kinetics at RCP.
Appendix A

Informed Consent

Sustained High-Intensity Exercise, Relations to Laboratory Testing

Purpose of Study

Endurance exercise and performance is measured both in the field and in the laboratory. The link between these measures is often debated in its applicability and physiology. We will look at long-duration sustained exercise (10-60 min) as it relates to laboratory testing. This investigation is being conducted by Rick Bradley in the Kinesiology department at California State University Sacramento. Mr. Bradley will be assisted in the laboratory by Professor Daryl Parker, PhD, and graduate students completing their education at CSUS. Any questions regarding the study can be directed to Mr. Bradley at xxxxxxxxxxxxxxxxxxxxxxxx

Testing Procedures

Maximal stress testing (VO2 max) will be completed on an electronically braked bicycle. The testing procedure will begin at 70 Watts (50 Watts for females). Every minute thereafter the load will increase 35 Watts (25 Watts for females). Testing will be terminated when >70 rpm can no longer be maintained. During the testing procedure you will have to breathe through a two-way valve to collect expired air while wearing valve-supporting headgear and a nose clip. During the test, heart rate will be monitored with a heart rate monitor strapped around your torso. You will also be asked to give a rating of
perceived exertion, which indicates the relative difficulty of the exercise. In a sterile environment, a small drop of blood will be collected from a lancet pin prick to the ear lobe shortly following test termination.

Submaximal intensity identification trial will be conducted on the same day as the maximal test, following a 15 minute break for water and recovery. The trial will last <30 minutes, and will be used to locate the power that will be used for the constant-load trials. If you should fatigue and terminate exercise prior to the completion of testing, you will be asked to return on a following day, allowing recovery. Expired air, heart rate and perceived exertion scores will be collected as in the maximal testing.

Constant-intensity cycle trials will be performed on separate days and with at least one day off in between for rest. You will be asked to pedal for as long as possible. Testing will be terminated should your pedal cadence consistently fall below your self-selected value. Exercise time for each test will range between 10 and 60 minutes. Expired air, heart rate and perceived exertion scores will be collected as in the maximal testing. A blood drop will be collected using the same procedures as in the maximal stress test, but with an additional two collections mid-way through both constant-load trials, for a total of up to seven very small drops throughout the study.
Total study time commitment is approximately 5 hours, spread over the 3 days of testing. A fourth day will be required if premature termination of submaximal testing should occur, as described above.

Risks and Discomforts

Vigorous exercise, such as maximal testing, involves a certain amount of risk. The associated death rate with vigorous exercise is very low in low risk individuals. During the testing procedures you will experience increased blood pressure, rapid breathing, increased heart rate, increased exertion, sweating, muscular discomfort, and fatigue. The American College of Sports Medicine suggests that the risk for sudden cardiac death in low-risk (low prevalence of cardiovascular disease) younger males (ages <30-40 years) is 0.00075% and is more than 5 times lower in females. Blood drop collections using a lancet may result in slight discomfort and residual soreness at the collection site. Risk of infection will be minimized by using a sterile collection technique (e.g., alcohol swipe, latex-free gloves, and adhesive bandage). If any adverse reactions occur due to the blood collection procedure, you will be referred to your personal physician or the CSUS Student Health Center if you are a CSUS student. Also during this procedure it is possible that you will experience an alteration in heart rhythm, and in rare cases, a heart-attack or stroke. Risks of these events taking place, however, will be minimized by pre-health screening and monitoring during the tests. In the event of an emergency, we will activate the emergency medical response process for the university. Any medical treatment or response that incurs a charge will be the responsibility of the
research participant and not the university. The investigators of this study are trained in CPR and basic first aid.

Responsibilities of the Participant

Knowledge of your current health status and any abnormalities associated with it could profoundly affect the outcomes of your test, as well as your safety during the testing procedure. It is your responsibility to disseminate accurate and complete information regarding your health and condition prior to undergoing the test procedures. During the procedure it is your responsibility to provide the technicians with accurate information regarding how you feel. It is also your responsibility to report any chest pain, chest tightness, or other abnormal discomfort during the testing procedures.

Benefits of the Testing Procedure

The exercise test may provide you with information regarding your current state of health and physical fitness. These tests can be used as a baseline beginning assessment to determine changes in physical state over time as well as various states of conditioning. Further, this information may be beneficial in developing an exercise program for the enhancement of your current physical fitness.

Use of Medical Records

The data collected during this study will be treated as confidential. No one may view your results without your express written consent. This data will be coded with a
random identification number and used for statistical analysis with your right to privacy maintained. All data results will be reported as a whole; no identifiable information related to you will be reported or made public in any way. Additionally, information and data related to you will remain under the security of the department even after the completion of the study.

Consent to Participate

This testing procedure is voluntary and you are free to withdraw from the procedure at any time. Please feel free to ask questions regarding the procedure at any time. This may include clarification of the consent form, instructions on the procedure, or any part of the testing process that you are not comfortable with. You may also feel free to contact Rick Bradley, the primary investigator at any time regarding questions that you have at xxxxxxxxxxxxxxxxxxxxxxxxxxxx. Additionally, Dr. Parker can be reached at xxxxxxxxxxxxxxxxxxxxxx.

I have read this consent form, and understand the procedure, risks involved and my responsibilities during the testing process. Knowing the risks involved and having had my questions answered to my satisfaction I hereby consent to participate in this study.

________________________________________
Date                                      Print Name
Signature

_________________________
Date

_________________________
Print Name of Witness

_________________________
Signature of Witness
Appendix B

SAC STATE HUMAN PERFORMANCE RESEARCH LABORATORY
SUBJECT INFORMATION AND MEDICAL HISTORY

NAME:______________________________________________________________
DATE______________________________________________________________
ADDRESS:__________________________________________________________
PHONE:____________________________________________________________
EMAIL:______________________________________________________________
OCCUPATION:________________________________________________________

GENDER: M__ F___ AGE_______ yrs DATE OF BIRTH__________________________
TOTAL CHOLESTEROL___________ mg/dL HDL_______ mg/dL
LDL_______ mg/dL TG___________ mg/dL

FASTING BLOOD GLUCOSE________________________ mg/dL Other blood
results:______________________________________________________________

We will take the following 4 measurements (do not answer):

WEIGHT__________ kg HEIGHT_________ cm BP____ / ____ mmHg

HR_________ beats/min

MEDICAL HISTORY: (Please Circle your Answer/s)
Are you currently taking any medications: Yes or No:

If yes, please
list:______________________________________________________________

Please list all medical conditions (e.g. ulcers, arthritis, mono, hepatitis, HIV,
musculoskeletal injury)?_________________________________________

______________________________________________________________

Please list any hospitalizations and/or
surgeries?______________________________________________________

Have you ever been diagnosed with a breathing problem such as asthma? Yes or No:
If yes, please explain: ________________________________________________

Have you ever been diagnosed with a heart problem or condition? Yes or No:
If yes, please explain: ________________________________________________

Do you have any of the following symptoms at rest or with low to moderate physical activity? Yes or No:

- Lightheadedness
- Shortness of Breath
- Chest Pain
- Numbness
- Fatigue
- Coughing
- Wheezing
- Other __________

If yes, please explain: ________________________________________________

Do you have any of following cardiovascular disease risk factors? Yes or No

- Family History of Heart Attacks
- Hypertension
- High Cholesterol
- Sedentary Lifestyle (refer to next page)
- Diabetes
- Current cigarette smoker
- Obesity (Calculate BMI= ______ kg/m²)

If yes, please explain: ________________________________________________

Do you have an immediate family member with any of the following diseases? Yes or No

- Diabetes
- Hypertension
- High Cholesterol
- Obesity

If yes, please explain: ________________________________________________

Are there any other conditions that might affect your health/exercise ability? Yes or No:
If yes, please explain: ______________________________________________________

Training History

What type of athlete are you? Please circle the best answer:

A) Professional-National class  B) Competitive at Regional-Local level  C) Age or Class Competitor

D) Well Trained  E) Other: _____________________________________________________________

How many years have you been training competitively?______________________________

Over the last year, what has been your weekly mileage? (cycling; running)____________________________

Over the last year, what percentage of your overall training is at a pace faster than “somewhat hard” or \( \geq 70\% \) of VO\(_{2}\)\(_{max}\)?

_____________________________________________________________________

What are your 3 best performances and include date and event/course?

1: __________________________________________ _____________________________

2: ____________________________________________________________

3: ____________________________________________________________

Please give your best performance over the last 18 months include date, time and course?__________________________________________________________

The questions below concern your training over the 20 weeks:

What is the average number of exercise sessions per week?______________________________

What is the average duration of your exercise sessions?______________________________

What is the average intensity of your exercise sessions?______________________________
Give us the respective volume of easy, moderate (=”somewhat hard” or 70% VO2max) and hard workouts (>=“Hard” or 85% VO2max) per week (miles per week)?

<table>
<thead>
<tr>
<th>Easy</th>
<th>Moderate</th>
<th>Hard</th>
</tr>
</thead>
</table>

What is the total volume of your workouts per week (miles per week)?

____________________________________________

Any recent significant injuries which have limited your training?

____________________________________________

Additional Information:

Have you ever performed a fitness or maximal exercise test? Yes or No (circle)

If yes, what were the results of your tests?

Protocol_________________ VO2 max_______________

Speed/Power_______________ Lactate Threshold________

Overall Interpretation:___________________________________________

Additional questions for females:

Please indicate how many menstrual cycles you have had within the past 12 months:__________________________________

Are you taking oral contraceptives or estrogen replacement therapy? Yes or No: If yes, indicate type & brand:______________

Lab technician fills out below:

COMMENTS & OBSERVATIONS:___________________________________________

OVERALL RISK STRATIFICATION:__________________________________________

EXERCISE & EXERCISE TEST RECOMMENDATIONS:___________________________________________
References


Sawyer, B. J., Morton, H. R., Womack, C. J., & Gaesser, G. A., FACSM. (2010). VO$_{2\text{max}}$ may not be reached during exercise to exhaustion above the critical power. *Unpublished abstract presented at Southwest ACSM, annual meeting, San Diego, CA.*
