The physiological strain of Freeride Mountain Biking: A health-related approach

by

Cameron I. K. Birtwell
B.Ed., University of British Columbia, 2001

A Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In the Department of Physical Education

(c) Cameron I. K. Birtwell, 2007
University of Victoria

All rights reserved. This thesis may not be reproduced in whole or in part, by photocopy
or other means, without the permission of the author.
The physiological strain of Freeride Mountain Biking: A health-related approach

by

Cameron I. K. Birtwell
B.Ed., University of British Columbia, 2001

Supervisory Committee

Dr. David Docherty (School of Physical Education)

Supervisor

Dr. Lynneth Wolski (School of Physical Education)

Departmental Member

Dr. John Anderson (School of Educational Psychology and Leadership Studies)

Outside Member
ABSTRACT

This investigation examined the acute physiological demand associated with a typical Freeride Mountain Bike (FMB) ride. Measures of cardiovascular strain (heart rate, RPE) and neuromuscular fatigue (quarter squat and handgrip MVICs) were assessed in 22 experienced mountain bikers during an observed ride on Mt. Fromme in North Vancouver, British Columbia. The ride involved an initial ascent of 350 vertical meters over horizontal distance of 5.93km, (mean duration 46.61 min). The descent covered a 350m loss in elevation through intermediate to expert level trails spanning a horizontal distance of 4.24km, (mean duration 28.55 min). Heart rate monitoring was continuous. Blood lactate was assessed pre-ride, at the top of the ascent (mid-ride), and following the descent (post-ride). RPE was assessed mid-ride and post-ride. Handgrip and quarter squat MVICs were taken pre-ride and post-ride. An a priori alpha of .05 was set for all statistical tests. Both measures of neuromuscular strain decreased pre-post ride, equal to 2.8% in quarter squat MVIC and 6.1% and 4.3% in handgrip MVIC for the right and left hands respectively. Blood lactate increased from rest to mid-ride and decreased from mid-ride to post-ride. The mean heart rates (~ 80% PHRmax) and RPEs (~14.5) associated with the ascent and descent were not significantly different. The acute physiological and ride pattern data indicate that FMB satisfies the American College of Sports Medicine’s guidelines for increasing cardiovascular health and fitness.
Table of Contents

ABSTRACT ........................................................................................................ iii

TABLE OF CONTENTS ................................................................................ iv

LIST OF TABLES ........................................................................................... v

LIST OF FIGURES ....................................................................................... v

ACKNOWLEDGEMENTS ............................................................................. vi

DEDICATION ................................................................................................. viii

INTRODUCTION ........................................................................................... 1

METHODS ....................................................................................................... 8

RESULTS ......................................................................................................... 14

DISCUSSION ................................................................................................... 23

REFERENCES ................................................................................................. 47

APPENDIX A: REVIEW OF LITERATURE .................................................... 52

APPENDIX B: INFORMED CONSENT ............................................................ 87

APPENDIX C: QUESTIONNAIRE ................................................................. 91

APPENDIX D: STATISTICAL ANALYSIS ......................................................... 96

APPENDIX E: OBSERVED RIDE ROUTE ....................................................... 106
List of Tables

Table 1. Participant Characteristics ................................................................. 8

List of Figures

Figure 1. Quarter-squat MVIC apparatus ......................................................... 10

Figure 2. Timeline of pre-ride and ascent measures ....................................... 11

Figure 3. Timeline for descent and post-tests ............................................... 12

Figure 4. Pre-post ride handgrip MVIC comparisons .................................... 16

Figure 5. Pre to post-ride quarter squat MVIC comparisons ........................... 17

Figure 6. Resting, mid-ride (ascent) and post-ride blood lactate .................... 18

Figure 7. Mean heart rate values for group ascent, descent, and 70% pHRmax .... 19

Figure 8. Mean ascent and descent heart rates with reference line corresponding to 70% of the group mean predicted HRmax ................................................ 20

Figure 9. Rating of Perceived Exertion values for the ascent and descent portions of the observed ride ................................................................. 21

Figure 10. Reported average ride frequencies .................................................. 22

Figure 11. Reported average ride durations .................................................... 22
Acknowledgements

So many to thank, so little space...

Dr. David Docherty, thank you for challenging me and pushing me to pursue excellence. Your commitment to the highest standards of research and presentation of information in both written and oral form has made me a better student and teacher. I can truly say that this is the first time I have been fully challenged in my academic career, and you have been instrumental in guiding me through it.

Norma Alison, thank you for your tireless work and enthusiasm with all matters relating to myself and the myriad other grateful graduate students. Your patience, caring, and efficiency are legendary and the School of Physical Education will be a lesser place without you around.

Dr. Lynneth Wolski and Dr. John Anderson, thank you both for your guidance during the development and execution of my thesis research. I do not think I could have chosen two better committee members and have valued your contributions immensely.

Tim Lindsay, thank you for inspiring me with your work ethic and personal morals. I have never met someone so dedicated to perfection in both teaching and their own studentship. Good luck down south.
Mike Nelson, I admire your drive and efficiency and you were the major reason why I decided to pursue my final thesis topic. I realized when you first came to UVic that you meant business, and that I had better pick things up if I wanted to graduate before you! Thanks for giving me that push.

Mikhail, Laura, Alison, Marc, Greg, Chris, Ben, Kai, Bahar, Miranda, Linda, Tom, Liz, Nicole, Carolyn, Yasaman, Mark, and all the rest, thanks for being around for me to meet and share good times with – from disco bowling, to firefighter testing, to bootcaming, to neurophysiology-ing, and to being my taller twin, you have all had such a positive impact upon my time at UVic.

To my varied study volunteers, I could not have done it without you and I have valued your vital contributions and assistance (in rain, heat, mosquitoes, and cold!).

To the participants in my study – thanks for riding with enthusiasm and not crashing!
Dedication

This thesis is dedicated to my family – who provided encouragement, support, relief, advice and the belief that I would always make it through.

This thesis is also dedicated to the many individuals who do not have the opportunity, money, or freedom to pursue personal and liberal education.
Introduction

Participation in mountain biking has increased greatly over the past three decades as more individuals pursue outdoor fitness and recreational activities (NSRE, 2006; Stapelfeldt, Schwirtz, Schumacher, & Hillebrecht, 2004). In 2004, upwards of 33% of all bicycles sold were mountain bikes, representing the single largest category of bike sales (National Bicycle Dealers Association, 2006).

A division between types of mountain biking can be made on the basis of the nature of the terrain encountered in a typical ride (Bader, 2006). Cross-country (XC) mountain biking typically involves moderately rough terrain combined with substantial portions of uphill riding, and is regarded as a cardiovascular fitness activity (Bader, 2006; Willis & Jones, 1999; Lee, Martin, Anson, Grundy, & Hahn, 2002; Stapelfeldt et al., 2004). The various forms of downhill mountain biking (DMB) tend to place more emphasis on speed and/or traversing substantially rougher and more challenging terrain. DMB has received little attention from performance, health, and fitness perspectives (Bader, 2006; Rhyan, 2005).

Freeride mountain biking (FMB), which involves riding natural and man-made obstacles on a primarily downhill trail, is a subset of DMB that has seen large increases in popularity in the last decade (Bader, 2006). Unlike most forms of DMB, which are geared towards maximum speed in a competitive setting (Rhyan, 2005), FMB is primarily a recreational pursuit and involves elements similar to both XC and downhill mountain biking. A typical FMB ride involves a substantial initial ascent to the trailhead that may last upwards of 45 minutes (Bader, 2006). This initial climb may be completed through pushing or cycling a heavy (16-21kg) bicycle, with the latter case involving
similar energetic requirements to XC riding. Like other forms of downhill mountain
biking, FMB descents typically involve a substantial loss in elevation, however it may
also incorporate some undulating terrain. The technical difficulty of FMB trails is also
usually higher than encountered during XC and DMB (Bader, 2006).

Studies examining XC mountain biking have shown that traversing rough terrain
on level or inclined ground is associated with significant cardiovascular strain and
neuromuscular fatigue (Stapelfeldt et al., 2004; Lee et al., 2002; Impellizzeri, Sassi,
Rodriguez-Alonso, Mognoni, & Marcera, 2002; Burke, 1996). This demand on the
neuromuscular and cardiovascular systems results from the energetic requirements for
propulsion of the bicycle combined with the use of the upper body/torso musculature for
stability and manipulation of the bicycle over and around obstacles (Burke, 1996;
Impellizzeri et al., 2002; Seifert, Luetkemeier, Spencer, Miller, & Burke, 1997; Cinque,
1987).

The heart rate responses of mountain bikers tend not to decrease with losses in
elevation, indicating that downhill riding involves a significant cardiovascular strain
(Stapelfeldt et al., 2004). This demand is likely driven by muscle actions not related to
pedaling, as mountain bike descents are associated with low pedal power outputs
(Stapelfeldt et al., 2004; Impellizzeri et al., 2002). Researchers suggest that upper and
lower body muscular involvement is substantial during descents over rough terrain, with
extensive eccentric and isometric muscle actions required to absorb impacts, manipulate
the bicycle, and stabilize the rider’s body (Burke, 1996). The lower body muscles act
differently during a FMB descent compared to the ascent, as riders are often standing on
the pedals (out of the saddle) 80-90% of the time (Bader, 2006) and pedaling for only brief periods.

Although the existing research has exclusively dealt with XC mountain biking, it appears that riding downhill over rough terrain is physically demanding. Some of the results of studies examining XC riding may be conservatively applied to FMB due to several similarities between the two types of mountain biking. However, the trail features involved in FMB (including roughness of terrain and steepness of descents) and characteristics of typical Freeride mountain bikes indicate that there may be differences in terms of the neuromuscular and cardiovascular demands on the body between the two types of mountain biking.

Assessing the level of acute cardiovascular strain and neuromuscular fatigue associated with FMB will help to physiologically define this specific form of mountain biking and indicate necessary fitness requirements for participation and performance. In addition, acute data can be used to predict any possible health and fitness benefits from chronic participation. The purpose of this study was to provide a preliminary examination of the physiological strain associated with a typical FMB ascent and descent using selected cardiovascular and neuromuscular measures, with the goal of evaluating FMB as a potential health and fitness-related activity.
Research questions

1. What is the nature of the acute cardiovascular strain associated with Freeride Mountain Biking?
   
a.) Is the acute cardiovascular strain of the ascent portion of the observed ride above the ACSM’s minimum threshold for cardiovascular fitness gains (60% PHRmax)?
   
b.) Is the acute cardiovascular strain of the descent portion of the observed ride above the ACSM’s minimum threshold for cardiovascular fitness gains (60% PHRmax)?
   
c.) What is the level of perceived effort associated with a typical FMB ascent and descent?
   
d.) Does perceived effort differ between the ascent and descent portions of a typical FMB ride?
   
e.) What is the relationship between blood lactate concentration, heart rate, and Rating of Perceived Exertion (RPE) during FMB ascents and descents?

2. What is the nature of the acute neuromuscular fatigue associated with Freeride Mountain Biking?
   
a.) Is there a significant decrement in handgrip MVIC force pre to post ride?
   
b.) Is there a significant decrement in quarter-squat MVIC force pre- to post-ride?
Assumptions

1. The trail route chosen for the ride portion of the study represents a typical FMB experience.
2. Participants will travel up to the observed ride starting point at their normal pace.
3. Participants will perform the ride down the trail route at their normal pace.
4. The cardiovascular strain of the FMB ascent and descent (as measured by heart rate) will exceed the influence of any psychophysiological factors.
5. Heart rate and RPE are valid descriptors of cardiovascular strain and are directly related to energy expenditure.
6. Pre-post ride handgrip and squat MVICs are valid descriptors of neuromuscular fatigue.
7. Blood lactate is an indicator of intensity of effort.

Delimitations

1. Participants had a minimum self-reported intermediate to expert FMB riding competency and were able to ride the blue square (intermediate) and black diamond (expert) trails of the observed ride route in their entirety.
2. Participants were restricted to the age range of 25 to 50.
3. Participants had a minimum of 3 years experience with freeride mountain biking.

Limitations

1. Blood lactate measured at the periphery is an indicator of muscle lactate concentration.
2. Due to the nature of the trail network, participants were not observed continuously during the travel up to the ride start point, or during the ride down.

3. A non-standardized questionnaire was used as part of the data gathering process.

4. Results from this study are applicable mainly to regular participants in Freeride Mountain Biking with an intermediate skill level or higher.

*Operational Definitions*

Freeride Mountain Biking: Involves an initial ascent of a fire road lasting from 45-60 minutes followed by a 25 to 35 minute descent through blue square (intermediate) to black diamond (expert) level trails. The descent route involves negotiating natural and man-made obstacles and a substantial loss in elevation while including some undulating terrain. The ascent and descent portions of the ride are performed at each rider’s self-selected riding pace.

Intermediate Mountain Biking Competency: Describes the participants’ ability to ride the features and terrain of the chosen route (*7th Secret*, *Leopard*, *Kirkford*, *Crinkum Crankum*, *Cedar Trail*, and *Road Side Attraction* on Mt. Fromme, North Vancouver) continuously and in their entirety.

Cardiovascular Strain: The acute demand placed on the cardiovascular and respiratory systems of the body, (measured by minute-by-minute heart rate and pre-mid-post-ride RPE) as a result of participating in the observed ride described in the methodology.
Heart rate values are or were expressed as a percent of predicted maximum heart rate (%PHRmax).

Neuromuscular fatigue: The acute force decrement in finger flexor and knee extensor muscle groups (assessed by pre-post handgrip and quarter squat MVICs) as a result of participating in the observed ride described in the methodology.
Methods

Participants

Twenty-one males and one female volunteered to participate in this study. All participants were experienced mountain bikers and had been involved in FMB for at least 3 years prior to the study. The participants were familiar with the blue square (Intermediate) and black diamond (Expert) trails involved in the observed ride portion of the study and reported their ability to ride the trail route continuously and in its entirety. Recruitment of participants and all experimental procedures were approved by the University of Victoria Human Research Ethics Board. Descriptive characteristics of the participants are presented in Table 1.

Table 1. Participant Characteristics

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age</td>
<td>37.09</td>
<td>9.40</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.80</td>
<td>0.07</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>81.01</td>
<td>11.49</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>24.67</td>
<td>2.08</td>
</tr>
<tr>
<td>Age-Predicted HRmax (bpm)</td>
<td>186.50</td>
<td>16.17</td>
</tr>
<tr>
<td>Mountain Bike Riding Experience(years)</td>
<td>12.97</td>
<td>6.44</td>
</tr>
</tbody>
</table>

Experimental Design

Given the exploratory nature of this research, a descriptive design was utilized. The physiological demand of an entire FMB ride (ascent and descent) was assessed through observation of participants during a single session. The session involved riding a route representative of a typical Freeride Mountain Biking ride on Mt. Fromme in North Vancouver, British Columbia. Basic measures of neuromuscular fatigue, cardiovascular
strain, and perceived effort were used to evaluate the level of perceived and actual physiological demand associated with the observed ride.

Instrumentation

The bodyweight of the participants (clothed) was recorded from a portable scale (Biomedics Healthline). Participant heights were self-reported.

Handgrip maximum voluntary isometric contractions (MVICs) were used to assess upper body neuromuscular fatigue pre- to post-ride. Takkei Instruments T.K.K. 5001 handgrip dynamometer was used and demonstrated test-retest reliability (ICC) of .96. The hand spacing of the grip dynamometer was standardized for each participant.

To evaluate neuromuscular fatigue in the lower body, a special isometric squat device was used (see Figure 1). A cable tensiometer (Opti Manufacturing Corp., Model # T5-2002-104-00, Luquillo, PR) was placed on one side of the apparatus to assess peak isometric force. The chain and cable length were adjusted to establish a knee angle of 135° for each of the participants. This knee angle was selected to closely replicate the range of flexion of the knee joint common to the descent posture during FMB. The cable tensiometer and squat apparatus showed a high test-retest reliability (ICC), r = .98.
Small samples of capillarized blood were obtained from the fingertips of the participants and analyzed for blood lactate concentration pre-, mid-, and post-ride via a Lactate Pro handheld device (Arkay/KDK, Japan). Previous authors have reported that the Lactate Pro device is a reliable and accurate tool for assessing blood lactate concentration (Pyne, Boston, Martin & Logan, 2000).

Cardiovascular strain was assessed both continuously (heart rate monitoring) and at mid-ride and post-ride measurement points (RPE). Polar s610i heart rate monitors (Polar Electro, Kempele, Finland) collected heart rate data at 5 second intervals for the duration of the ascent and descent portions of the observed ride. Perceived effort was measured with the use of Borg’s 6-20 Rating of Perceived Exertion (RPE) scale. The RPE scale has been validated within steady-state and intermittent exercise contexts for its strong relationship with measures of physical work.

In addition, a non-standardized questionnaire evaluating riding patterns and demographics was administered to the participants.
Procedure

Upon arrival at the base of the trail network on Mt. Fromme, participants performed three right and left handgrip maximum voluntary isometric contractions (MVICs) to establish their peak pre-ride handgrip force. Following the handgrip testing, each participant performed three MVIC back squats. The peak value from the three trials was set as the pre-ride (resting) maximum for each participant. Bodyweight and height of the participants were recorded. A ten minute rest period was followed by blood lactate analysis and fitting of the heart rate monitors. Once fitted with a heart rate monitor, participants were instructed to ascend a gravel access road to the Seventh Secret trailhead at their normal pace. The ascent involved approximately 350m of vertical climbing and a horizontal distance of 5.93km. The average ascent time was $46.61 \pm 7.68$min. Figure 2 illustrates the timeline of pre-ride and ascent measures.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>20</th>
<th>25</th>
<th>~70</th>
<th>72</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participant Arrival 2nd Gate, Mt. Fromme</td>
<td>Pre-Handgrip MVIC</td>
<td>Pre Quarter-Squat MVIC</td>
<td>Height Weight Seated Rest</td>
<td>Pre Blood Lactate</td>
<td>Ascent Begins (Fire access road)</td>
<td>Ascent Ends</td>
<td>Mid Blood Lactate</td>
</tr>
</tbody>
</table>

**Figure 2.** Timeline of pre-ride and ascent measures.

Rating of perceived exertion was assessed upon each participant’s arrival at the top of the ascent. The mid-ride blood lactate measurement was taken within 2 minutes of participant arrival. A period of light activity ensued while participants prepared themselves for the descent (including changing tire pressure and donning protective body...
armor). Turn-around time between participants reaching the top of the ascent and beginning the descent was on average 9.25 ± 1.7min.

The descent portion of the observed ride involved traversing Seventh Secret, Leppard, Kirkford, Crinkum Crankum, Cedar, and Roadside Attraction trails in a continuous fashion at each participant's normal riding speed. While descending through the trail network, the participants negotiated natural and man-made obstacles (such as rocks, roots, and bridges) while traveling over rough and often steep terrain. The descent route incorporated an elevation loss of 350m over a horizontal distance of approximately 4.24km, and was covered by the participants in an average time of 28.55 ± 4.75min. Heart rate monitoring was continuous during this descent.

After arriving at the bottom of the descent portion of the ride, participants underwent the post-ride battery of tests. Blood lactate was assessed first and the measurement was taken within two minutes of participant arrival. Handgrip MVIC followed the blood lactate testing and the peak value out of two trials was recorded for each participant. Post-ride MVIC squats were performed (2 trials) and RPE for the descent portion of the ride was obtained. In most cases, all of the post-ride measures were completed within eight minutes of participant arrival.

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>82</th>
<th>112</th>
<th>114</th>
<th>116</th>
<th>120</th>
<th>124</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Descent Begins (Trail Network)</td>
<td>Descent Ends</td>
<td>Post Blood Lactate</td>
<td>Post Handgrip MVIC</td>
<td>Post Quarter-Squat MVIC</td>
<td>RPE</td>
</tr>
</tbody>
</table>

Figure 3. Timeline for Descent and Post-tests.
**Statistical Analyses**

SPSS version 13.0 was used to perform all statistical analyses with an a priori alpha of .05. The raw data was sifted for erroneous values (heart rate) and box plots were run to identify extreme scores. Two blood lactate scores were identified as extreme by the SPSS software and removed from the data. Bivariate correlation analyses were performed to investigate the nature of the relationships between selected variables.

Repeated measures Analysis of Variance (ANOVA) was used to determine differences between ascent and descent heart rate, and to compare heart rate in both ride portions to a reference line corresponding to 70% of the participant group's mean predicted maximum heart rate (PHRmax). Post-hoc LSD comparisons were run when indicated to further examine differences between ascent, descent, and reference heart rates. A one-way ANOVA was used to compare pre- mid- and post-ride blood lactate concentrations.

Paired-samples t-tests were used to assess pre-to-post handgrip MVIC for both the left and right hands, pre-to-post quarter squat MVIC and to examine RPE over the course of the ascent and descent portions of the ride. Intraclass Correlation Coefficients were performed to evaluate the reliability of the Handgrip Dynamometer and quarter squat apparatus.
Results

Handgrip MVIC

Post-ride handgrip measurements showed a significant decrease in MVIC force for both the left and right hands of the participants from the pre-test measure (see Figure 4). Mean right hand MVIC force decreased from pre-ride (52.33 ± 8.51 kg) to post-ride (49.16 ± 9.09 kg), equal to a 6.1% decrement, p < .05. Left hand MVIC force decreased from pre-ride (48.18 ± 9.20 kg) to post-ride (46.14 ± 8.37 kg), representing a 4.3% decrease in force, p < .05.

Quarter squat MVIC

A significant decrease was seen in quarter squat peak force (measured in arbitrary force units) from pre-ride (58.91 ±12.03 units) to post-ride (56.79 ±11.58 units), p < .05 (see Figure 5). This difference is equal to an average decrease of 2.8%.

Blood Lactate

A significant increase was seen in blood lactate concentration from resting (2.15 ±0.41 mmol/L) to mid-ride (6.49 ±3.71 mmol/L), p <.05. Blood lactate concentration decreased from mid-ride (6.49 ±3.71 mmol/L) to post-ride (3.26 ±1.15 mmol/L), p <.05. Pre-ride and post-ride blood lactate values were not significantly different, p =.169 (see Figure 6).
Heart Rate

A 22 level repeated measures ANOVA was used to examine any possible differences between ascent and descent heart rates. A significant main effect of time (Wilks' Λ = .042, F = 32.78) and time-by-group (mean ascent heart rates, mean descent heart rates, and mean 70%PHRmax) interaction (Wilks' Λ = .015, F = 10.15) were observed, p < .05. Eta-Squared values for the effects of time and time-by-group interaction were .958 and .877 respectively. Post-Hoc LSD comparisons revealed no difference between ascent heart rate (156.34 ± 8.99bpm) and descent heart rate (149.77 ± 6.89bpm), p < .05. Both the mean ascent heart rate and mean descent heart rate were significantly above the average of the groups 70% PHRmax (132.56 ± 11.21bpm), p < .05. Figure 8 illustrates the participant group's mean heart rate response during the ascent and descent portions of the observed ride in comparison to a reference line corresponding to 70% PHRmax.

Rating of Perceived Exertion

RPE values were not significantly different between the ascent (14.55 ± 1.54) and descent (14.2 ± 1.87) portions of the ride, p = .186 (See Figure 9).

Participation Patterns

The participants reported a mean frequency of 3.21 ± 1.58 days per week for an average duration of 2.50 ± 0.43 hours (see Figures 10 and 11). 73.7% of participants rated the physical requirements associated with FMB as “High”. When describing reasons for participating in FMB, 94.7% of participants chose “Fitness” and 89.5% chose “Stress Release” as primary reasons for participating in FMB.
Figure 4. Pre to post-ride right (R) and left (L) handgrip MVIC comparisons. Asterisk denotes significant difference from pre- to post-ride, p < .05.
Figure 5. Pre to post-ride quarter squat MVIC comparison. Asterisk (*) denotes significant difference pre- to post-ride, p < .05.
Figure 6. Resting, Mid-ride (Ascent) and Post-ride blood lactate. Asterisk (*) denotes significant difference from Resting and Post-ride values, p < .05.
Figure 7. Mean heart rate values for group Ascent, Descent, and 70% PHRmax. Asterisk (*) denotes significant difference from 70% PHRmax.
Figure 8. Mean ascent and descent heart rates with reference line corresponding to 70% of the group mean predicted HRmax.
Figure 9. Rating of Perceived Exertion values for the ascent and descent portions of the observed ride.
Figure 10. Reported average ride frequencies, (n=21).

Figure 11. Reported average ride durations (n=21).
Discussion

The main observation of this study was that a typical FMB ride is associated with significant levels of acute cardiovascular and neuromuscular fatigue as evidenced by the responses of heart rate, blood lactate, RPE, handgrip MVIC, and quarter squat MVIC. It is also evident that regular participation in FMB could increase levels of health and fitness.

Neuromuscular fatigue

The decrease in handgrip and quarter squat MVIC from pre- to post-ride is an indicator of the acute neuromuscular fatigue associated with the observed ride. Several authors (Millet & Lepers, 2004; Lepers, Hausswirth, Maffiuletti, Brisswalter, & Hoecke, 2000; Bentley; Smith, Davie, & Zhou 2000) have demonstrated that endurance exercise is associated with acute decrements in force output in the lower body, especially when force is measured isometrically or eccentrically (Millet & Lepers, 2004). Very little research has investigated the effects of lower body endurance exercise on fatigue of the upper body.

Handgrip force requirements during rock climbing (Watts, 1996; Watts, 2004) may be similar to the type of upper body neuromuscular fatigue that occurs during FMB descents. In both rock climbing and FMB, there is a reliance on sustained submaximal gripping. In mountain bike descents over rough terrain, this occurs primarily as a result of grasping the handlebars with the bodyweight biased towards the rear of the bike (De Lorenzo & Hull, 1999). In addition, riders apply force intermittently to the front and rear brake levers and execute strong upward pulls on the handlebars to clear obstacles (Rhyan,
2005). In the current study, it is unlikely that substantial muscular effort was required of the forearm flexors during the ascent portion of the ride, as the road surface was fairly smooth, braking requirements were minimal to non-existent, and the riders stayed seated in the saddle for the entire duration.

Following maximally fatiguing rock climbing protocols, handgrip force was seen to decrease 22% (Watts, 1996) and 13% (Theodosiou, 2000). The current study design resulted in a mean decrease in handgrip MVIC of 6.1% for the right hand and 4.3% for the left hand, which are significantly lower than that seen with the climbing research. This may be due to the fact that participants in the current study were instructed to ride at their normal pace, which most likely did not result in acute maximal fatigue. Riding downhill to the extent of maximal fatigue would have been dangerous as this would have resulted in the loss of steering and braking control.

The decreases in handgrip MVIC following the observed ride were also less than was seen in pilot work by the author. A mean decrease of 9.6% across both hands was observed in 11 participants over the shorter ascent and descent route of the pilot study (essentially the bottom two thirds of the trails involved in the current study). The different environmental conditions between the two studies may have played a significant role in this discrepancy. The pilot research was conducted on a day with steady rainfall, necessitating greater braking to control speed and representing a more challenging steering and bike control stimulus on the descent. The current study was run on a series of dry days in the middle of summer when riding conditions were arguably easier. These latter conditions may have decreased the muscular demand on the forearm flexors associated with the descent. It is doubtful that the environmental conditions played a
significant role as far as neuromuscular fatigue on the ascent as bike control and braking actions are minimally required.

The decrease seen in quarter squat MVIC was equivalent to a mean change of 2.8% from pre to post-ride. Several authors have examined decrements in isometric force following cycling protocols of varying length and intensity, all whom reported more substantial decreases than was seen in the current study. Sahlin and Seger (1995) reported a decrease of 34% in isometric force in the knee extensors following 85 minutes of cycling. Booth, McKenna and Ruell (reported in Millet & Lepers, 2004) observed a decrement of 28% with 72 minutes of cycling. Both of these protocols involved participants riding at a constant workload representing 75% VO2max until exhaustion.

Neuromuscular fatigue is also evident in less fatiguing protocols. Lepers et al. (2000) observed a smaller decrease in knee extensor force (13%) following 120 minutes of cycling at 70% VO2max. Lepers Maffiuletti, Rochette, Brugniaux, & Millet (2002) saw a 9% reduction in knee extension MVC within the first hour of cycling exercise at approximately 55% of VO2max.

The participants in the current study were active for a similar duration (75 minutes), with 62% (47 minutes) consisting of steady uphill cycling. The intensity of work during the FMB ride was also similar to the previous investigations. A mean intensity of 85.3% of predicted maximum heart rate during the ascent and 83.1% during the descent were recorded. These values approximate 70-75% of VO2max in normally-fit participants (Powers & Howley, 2004). Several methodological factors could have contributed to the difference in force decrements observed between the current project and the studies reported above.
The absence of instruction or motivation to ride until exhaustion is likely a cause of the difference between these prior studies and the FMB study. The participants in the current study were instructed to ride at their normal pace, which for most individuals does not result in an exhaustive level of effort. The physiological processes inherent to maximal and exhaustive exercise create a metabolic and energetic environment that can have substantial impact on neuromuscular fatigue (Lattier, Millet, Martin, & Martin, 2004; Green, 1997, Billaut, Basset, Giacomoni, Lemaitre, Tricot, & Falgairette, 2004).

The studies of Lepers et al. (2000) and Lepers et al. (2002) both involved lower intensities of exercise not continued to fatigue. These protocols also resulted in less decreases in knee extensor force. In the study of Sahlin & Seger (1995), the exhaustive exercise was followed immediately by occlusion of blood flow to the lower body until immediately before the muscular tests, preventing any short-term substrate and metabolic recovery. This is in direct contrast to the seated rest and light activity involved in the current study at both the mid-ride and post-ride sites.

The participants involved in the FMB project were habituated to the intensity and duration of exercise they were exposed to during the observed ride. The mean reported ride frequency was 3.21 days per week for an average duration of 2.5 hours. In fact, several participants, upon completing their study duties, departed for “second laps” of the trail network, many planning on completing the same ascent route. In this respect, these participants could be classified as highly trained in this endurance activity and that the intensity and duration of the observed ride was well within their physiological limits. The participants involved in the Lepers et al. (2000) and Lepers et al. (2002) studies were trained cyclists and triathletes, and experienced less decrease in isometric muscle force
following prolonged cycling than the participants of Sahlin & Seger (1995) who were defined as normally active individuals.

The influence of specific training on the delaying fatigue can be substantial, indicating that the high frequency and duration patterns seen in the participants in the current study could be expected to result in lower levels of fatigue than if normally-active individuals were involved. Volunteer bias likely influenced the type of participant who was interested in the study—most likely, this participant group was representative of experienced Freeride mountain bikers.

Another explanation for the minimal decrease in quarter squat MVIC relative to other studies is that the mid-ride pause and descent portion of the ride provided some level of recovery for the musculature of the lower body. Following the ascent, the participants were involved in seated rest and light activity for an average of 9.25 minutes. This interval is significant in that several processes of metabolic recovery can occur over a relatively short duration. In particular, for moderate concentrations of blood lactate, half-clearance can occur within 15 minutes or less depending on the training status of the individual and the intensity of the prior activity (Bassett, Merrill, Nagle, Agre, & Sampedro, 1991). Substantial recovery of MVIC can also take place rapidly. Sahlin & Seger (1995) observed a half-recovery of knee extensor MVIC within 2 minutes following their fatiguing cycling protocol.

Light activity increases the clearance rate of lactate and is enhanced in individuals with an endurance training background (Taoutaou, Granier, Mercier, Mercier, Ahmaidi, & Prefaut, 1996). The clearance of blood lactate is an indicator of the body’s transition back to metabolic homeostasis. The transition period between the ascent and descent
may have offered a significant break from fatiguing activity, blunting the effect of accumulated fatigue from the ascent and providing partial recovery before the beginning of the descent. In contrast, Bentley et al. (2000) saw impairment of muscular activation in cyclists 6 hours after participation in a combined steady-state and interval session, indicating that significant prior metabolic strain can influence performance even after a substantial period of rest.

During mountain bike descents over rough terrain, the upper and lower extremities act as shock absorbers and are subjected to substantial isometric, concentric, and especially eccentric muscle actions (Burke, 1996). FMB riders typically spend 90% of the descent supported by four points of contact (handlebars and pedals) (Bader, 2006; Warner, Shaw, & Dalsky, 2002). This essentially requires the musculature of the upper and lower body to maintain a sustained semi-isometric state for the duration of the descent (28 minutes in this case). The result is a considerable amount of muscular work dispersed over a large number of muscle groups. The knee extensors, while producing muscle actions for duration of the descent, may be acting at such a low percentage of maximum for the majority of the ride that only minimal fatigue results.

One of the largest sources of error may have been the methodology and apparatus used for measuring the quarter squat MVIC. Although the system showed high test-retest reliability, the sensitivity of the apparatus was not ideal. In the range of tensions produced by the participants (50-65 units of force), calibration revealed that an increase of approximately 3kg was necessary in order to see a change in the dial reading of the tensiometer. This lack of sensitivity may have obscured more substantial changes in knee extensor force and contributed to an overall lack of accuracy with this measure. The pre-
ride quarter squat measurements were taken immediately upon arrival at the pre-ride station, following an extended (1km) uphill walk. This prior exercise may have affected the pre-ride quarter squats, creating a false pre-ride value.

Other investigations (Lepers et al., 2000; Lepers et al., 2002; Sahlin & Seger, 1995; Bentley et al., 2000) have attempted to determine the location and cause of decrements in muscle force due to exposure to prolonged cycling exercise. The structure of the current study prohibited any such conclusions due to the absence of mid-ride measures of neuromuscular fatigue and by the selection of highly practical and portable dependent measures. Although blood lactate provided an indication of the metabolic milieu, direct relationships between blood lactate concentration and neuromuscular performance were not possible after the ascent (due to a lack of mid-ride measures) or the descent (due to the absence of a valid pre-descent blood lactate value).

It is also not clear if the observed neuromuscular fatigue was the result of the ascent, descent, or a cumulative result of the two phases of the ride. As stated in the purpose of this study, the effects of the total ride experience were targeted for examination. Future research designs may choose to investigate the mechanisms and nature of the neuromuscular fatigue of FMB with more physiological scrutiny.

_Cardiovascular Strain_

_Ascent_

The heart rate response seen during the ascent shows a fairly consistent level of intensity interspersed with some short periods of less demanding work. These small undulations in heart rate may be in response to subtle changes in the ascent route grade.
On smooth surfaces, the cardiovascular strain of biking oscillates in concert with changing elevations and grades (Stapelfeldt et al., 2004). The ascent route involved traveling on a fairly smooth gravel surface with no obstacles, indicating that the mean heart rate of 80.31% PHRmax can be attributed directly to the energetic cost of pedaling. Participants were instructed to perform the ascent at their normal pace, which for these participants resulted in a heart rate consistent with other self-pacing literature.

Mastroianni, Zupan, Chuba, Berger, and Wile (2000) reported that self-pacing during off-road biking results in participants selecting an intensity of approximately 68.5% VO2max if performing the exercise for a moderate duration. The mean heart rate for the ascent in this study corresponded to approximately 70-75% VO2max (Powers & Howley, 2004). This value is roughly equivalent to the study of Mastroianni et al. (2000), who examined a relatively fit population (army recruits).

The mean blood lactate value associated with the ascent portion of the ride was significantly higher than the resting level. The mid-ride concentration of 6.49mmol/L is above the 4mmol/L value that is commonly assigned to the onset of blood lactate accumulation (OBLA) or lactate threshold (LT) (Heck, Mader, Hess, Mucke, Muller, & Hollmann, 1985; Astrand & Rodahl, 1986). The actual number assigned to the OBLA and LT is controversial and the theory of a specific threshold has not been proven (Brooks, 1985). It has been found that individuals may maintain levels of effort that produce lactate concentrations in excess of 4mmol/L for extended durations, and that other individuals may fatigue rapidly at lower blood lactate concentrations (Astrand & Rodahl, 1986).
Within the current study design, the exact kinetics of lactate production from the start to the finish of the ascent is not known. The heart rate patterns during the ascent were consistent indicating that a steady-state level of effort was maintained. Whether or not this resulted in a steady-state balance of lactate production and removal or a non-steady state lactate production that peaked at the end of the ascent is also not known. It is probable that the lactate kinetics varied between individuals given the range of lactate concentrations observed and individual differences in lactate clearance rates.

Normally there is a strong relationship between heart rate and blood lactate concentration, however no significant correlation was found between ascent blood lactate and individual mean ascent heart rate. This may have been due to the participant group having a wide range of fitness levels. Individuals of higher endurance fitness status are generally able to exercise at the same or higher intensity with minimal increases in blood lactate as compared to individuals who are not endurance trained (Taoutaou et al., 1996). Specific training also tends to improve the ability to clear lactate faster through oxidative pathways (Taoutaou et al., 1996). In the context of this study, this would mean that a higher average heart rate would not necessarily be related to a higher blood lactate concentration.

The range of blood lactate values associated with the ascent (2.7 - 10.8 mmol/L) was quite substantial. This was an expected result due to the self-paced nature of the observed ride and the relatively heterogeneous mixture of participants involved in the study. Had this investigation involved competitive athletes (of the same performance caliber) and a race format, the blood lactate values could have been expected to be more similar as the participants would have been working at close to the same relative
intensity. The heart rates recorded during the ascent were also fairly widely distributed, again indicating that the level of effort expended by each individual was based upon their own personal motivation and fitness level.

The mean individual heart rates recorded during the ascent were found to be moderately correlated with the RPE. This was expected given the linear relationship between perceived exertion and submaximal heart rate seen in many previous studies (Gamberale, 1972; Astrand & Rodahl, 1986; Noble, Borg, Jacobs, Ceci, & Kaiser, 1983; Shephard, 1994). RPE appears to be highly related to muscle sensations as well as to “central” factors such as heart rate and ventilation (Lollgen, Graham, & Sjogaard, 1980; Shephard, 1994; Noble et al., 1983). Since the ascent was completed primarily with the use of the upper leg muscles, sensations of muscular effort would have been localized and easily identified by the participants.

A higher RPE value is typically reported by participants exercising with legs only compared to the same power output performed with the arms and legs combined (Hoffman, Kassay, Zeni, & Clifford, 1996; Sagiv, Rotstein, Ben-Sira, Grodjinovsky, Fisher, & Kaufmann, 1991). Hoffman et al. (1996) and Sagiv et al. (1991) both speculate that the higher RPE values with lower-body only exercise are due to greater muscle sensations and increased metabolic load per unit of muscle mass.

Perceived exertion during a FMB ascent tends to underestimate exercise intensity as measured by heart rate. The original intent of the RPE scale was to present a numerical series that was equivalent to one tenth of the exercising heart rate (Borg, 1998; Shephard, 1994). In this study, the mean ascent heart rate was 159bpm and the mean ascent RPE was 14.55. Based on Borg’s original scaling, this equates to a discrepancy
between the recorded heart rate and the mean RPE of approximately 14.5 “bpm”.

Shephard (1994) states that although the linear relationship between intensity of work and RPE is robust, the slope of the line appears to vary depending on the nature of the activity. He further states that specific training in a certain mode of exercise leads to a decrease in perceived exertion relative to workload.

The accuracy of Borg’s RPE scale in terms of defining effort or work is also influenced by the participants’ experience level with the tool, the specific instructions given by the researcher, and the environment in which the scale is used. For the participants in the current study, this was their first exposure to the RPE scale. The principal researcher explained to each participant how to use body sensations (including muscle, breathing, and overall sensations of fatigue or strain) to correctly identify the level of effort they were experiencing. The scale was used in a non-competitive setting in this study as each individual was assessed discretely upon their arrival at the mid-ride and post-ride points.

In spite of the small discrepancy between the two measures, the RPE values support the heart rate data in that a significant level of effort is indicated. Not only are RPE and heart rates related to each other, they accurately predict energy expenditure over a wide range of exercise modes and intensities (Okura & Tanaka, 2001; Vuori, 1998; Keylet et al., 2005; Londeree et al., 1995). The average RPE score of 14.55 is one half point below the “hard/heavy” descriptor on Borg’s Scale (Borg, 1998). The average ascent heart rate of 159bpm (approximately 80% PHRmax) is significantly above the American College of Sports Medicine’s minimum intensity (70% HRmax for healthy individuals) for improving cardiovascular fitness (ACSM, 2000). The data on the
intensity of the ascent, combined with the typical duration indicate that this portion of the ride is likely to positively impact upon cardiovascular health and fitness with regular participation.

_Descent_

The mean heart rate of the participants during the descent was not significantly different from the mean ascent heart rate. Stapelfeldt et al. (2004) found that heart rate response in XC riders is not diminished during descents over technically challenging terrain. The authors of that study proposed that the heart rates seen during the descent were the result of both energetic factors (muscular work) and non-energetic factors such as the influence of the sympathetic nervous system. It is possible that both energetic and non-energetic factors influenced heart rates during the descent involved in the current study.

It is well documented that there is significant muscular work involved in downhill mountain-biking over rough terrain and it is reasonable to assume that this effort drives the majority of the cardiovascular response during the descent. Several authors have reported that extensive upper body and lower body muscle action occurs during rough descents (Burke, 1996; Impellizzeri et al., 2002; Seifert et al., 1997). This muscular work is quite different than the cyclic pedaling of the ascent. Pedal power outputs are typically low when riding downhill due to the terrain supplying forward momentum (Stapelfeldt et al., 2004; Impellizzeri et al., 2002). Short sections of trail included in the descent route necessitated pedaling although those cases were rare.
The extended time that is spent out of the saddle during the descent requires body weight to be supported by the lower body, torso, and upper body musculature. The absorption of gravitational forces as riders drop off steps, roots, and rocks in the trail necessitates multiple eccentric and isometric muscle actions of the lower and upper extremities (Seifert et al., 1997; Burke, 1996). Biomechanical loading analysis of mountain bikers descending over moderately challenging terrain indicates that 90% of the body weight is supported on the pedals (Wang & Hull, 1997) and vertical forces at the wheel hubs may exceed 5 times that of the rider’s weight per wheel (De Lorenzo & Hull, 1999). On bicycles with front suspension alone, these forces would be similar to those encountered by the muscles of the lower body (Warner, Shaw, & Dalsky, 2002).

Steeper terrain with higher drop-offs and greater velocities as encountered in the observed trail route may be associated with even greater forces. The front and rear suspension systems of a typical Freeride mountain bike act to suppress some of these forces (Seifert et al., 1997), however the arms and legs are still required as shock absorbers (eccentric actions) and vibration dampeners (isometric actions) (Wang & Hull, 1997).

The energetic cost of eccentric and isometric work is generally less than the same intensity of concentric muscle actions but static and yielding work still demand the delivery of substrates and oxygen to the working tissue. During an extended descent a large amount of muscle mass is active in a semi-isometric state for a significant duration. The level of intensity of work for each involved muscle may be quite low, indicating that energy could be supplied primarily through oxidative pathways. The demand for oxygen and substrates at the periphery combined with the need for removal of cellular metabolic
wastes drives the cardiovascular response. This response can be partially measured by heart rate as demonstrated in the current study.

Measurement of oxygen uptake and ventilation would have been ideal additions to this project, especially given the novelty of defining the cardiovascular strain during downhill mountain biking. The requirement for practical measures of cardiovascular strain necessitated the use of heart rate as the major indicator of work during the ascent and descent. A number of previous investigations have indicated that heart rate is a reliable predictor of work and energy expenditure during submaximal continuous (Vuori, 1998; Keytel, Goedcke, Noakes, Hiilloskorpi, Laukkanen, Van Der Merwe, & Lambert, 2005; Londeree, Thomas, Ziogas, Smith, & Zhang, 1995) and intermittent work (Bot & Hollander, 2000).

The descent performed during the observed ride was performed in a continuous fashion although the nature of the terrain dictated that the muscular work was acyclic and varied in terms of type, duration, and intensity of contraction. Prior mountain biking studies have utilized heart rate to measure work during the ascent portion of the ride but have questioned the nature of the cardiovascular response during the descent as to whether it is purely indicative of the energetic requirements of riding downhill (Stapelfeldt et al., 2004).

The blood lactate measurement at the end of the descent was intended to bolster the heart rate data by providing another measure of the intensity of work performed. This was confounded by the lack of a blood lactate value immediately prior to the participants leaving the mid-ride point. The absence of that measure precluded the observation of any
change in blood lactate specifically caused by the descent. Several theories as to the 
kineti cs of lactate during the descent can be put forth and related to heart rate and RPE.

The mean blood lactate value following the descent was significantly different 
than the ascent value, but not the resting (pre-ride) value. At first glance, these statistics 
indicate that there was very little muscular work performed during the descent. However 
a closer look at the range of blood lactate values following the descent (2.0 – 6.1 mmol/L) 
compared to rest (1.4 – 3.1 mmol/L) indicates that there was a trend towards higher 
concentrations of blood lactate after the ride. The relatively small subject number for this 
measure (12) may have contributed to a lack of statistical power in finding a difference 
between pre- and post-ride measures.

The participants may also not have been at a true resting state when the pre-ride 
measurement was taken. Prior to arriving at the testing area the participants had to push 
their bicycles 1 km uphill from a designated parking area. This exertion most likely 
resulted in accumulation of blood lactate that may not have dissipated prior to the pre- 
ride measurement being taken. As discussed in the methodology, the participants 
performed the muscular testing immediately upon their arrival, followed by a 10 minute 
rest period. This resulted in a time lag of 15 to 20 minutes between participant arrival 
and blood lactate sampling.

Astrand & Rodahl (1986) suggest that a normal resting blood lactate 
concentration is around 1 mmol/L. The mean value obtained from the participants in the 
current study was 2.15 mmol/L with a range of 1.4 to 3.1 mmol/L. A number of factors 
that influence the production and clearance of blood lactate may have also caused lower 
values in spite of the performance of significant muscular work during the descent.
Defining the exact amount of work performed during the descent using blood lactate is impossible given the methodological limitations of this study. The range of blood lactate values obtained after the descent was expected as individual differences in riding styles, competency, motivation to ride fast/hard, and the variability of bike specifications all influence the effort expended. Also, differences in physical fitness and/or genetic makeup can affect the speed of lactate clearance and utilization for fuel through oxidative pathways (Brooks, 1985; Taoutaou et al., 1996).

Another possibility is that blood lactate concentration may not be directly indicative of the muscular effort involved in the FMB descent due to the dynamics associated with the production, accumulation, and removal of lactate in the muscles and bloodstream. Unlike the ascent portion of the ride, FMB descents are characterized by a distribution of muscular work across the upper and lower extremities and torso. The localization of work in the upper legs during the ascent acts to intensify the metabolic stress on those muscles, requiring a higher level of work than if the same relative workload were distributed amongst several different muscle groups (Sagiv et al., 1991).

Reybrouck, Heigenhauser, and Faulkner (1975) observed that participants exercising arms and legs simultaneously had a higher lactate threshold than participants strictly exercising legs or arms. This indicates that the addition of muscle mass either reduces the accumulation of lactate or enhances the removal rate, both of which would result in a decreased blood lactate concentration. An intensification of muscular work on one group of muscles leads to significantly more muscle (and therefore blood) lactate accumulation (Sagiv et al., 1991). It is reasonable to assume that the muscles involved
during the descent were working in an acyclic fashion at a lower individual capacity due to the sharing of workload and, therefore, produced less lactate.

The rate of oxidation of lactate for fuel is enhanced at lower relative intensities of muscular work, especially in individuals who have an endurance training background (Taoutaou et al., 1996). A reduced production of lactate through a sharing of workload and an increased oxidation of existing lactate could well have combined to create low levels of lactate concentration during and following the descent.

RPE was not significantly related to individual heart rate or blood lactate concentration for the descent portion of the ride. This is in contrast to the relationship observed during the ascent between blood lactate and mean heart rate. Consistent with the ascent data is the underestimation of intensity of work (as indicated by heart rate) by RPE during the descent. The average perceived exertion reported by the participants upon completing the descent was 14.2, which slightly "underestimates" the mean descent heart rate of 155bpm. A lower RPE with greater muscle mass involvement is supported by the previously mentioned work of Hoffman et al. (1996). Several other factors could have contributed to this discrepancy, including the influence of non-energetic influences on cardiovascular response or affective factors such as dissociation with physical sensations during the enjoyment of the ride.

The mean heart rate and RPE for the descent support each other in the assertion that work is performed both during the ascent and descent portions of the ride. Both of these measures have been proven to be reliable in determining energy expenditure and oxygen uptake. Their combined indication of significant physical effort is important in this study due to the absence of other measures of cardiovascular strain. Consistency was
seen between RPE and heart rates for the ascent and descent portions of the ride. This indicates that both perceived effort and cardiovascular strain are similar despite significant differences in muscle action, riding posture, and nature of the terrain.

Several non-energetic factors linked to excess sympathetic nervous system activation may have caused an increased heart rate response during the descent portion of the observed ride. An increase in non-exercise generated sympathetic outflow to the heart can elevate heart rate in excess of the level required for metabolic processes during exercise (Stebbins, Walser, & Jafarzadeh, 2002). The extensive isometric muscle actions, upper body involvement, and/or psychological factors associated with the descent may all have contributed to non-exercise-related sympathetic response.

Repeated or sustained isometric actions are associated with increased sympathetic activity (Seals, 1989; Seifert et al., 1997; Bot & Hollander, 2000), especially if the upper body or a large muscle mass is involved (Seals, 1989; Franke, Boettger, & McLean, 2000). As the amount of active muscle mass increases during isometric exercise, a rise in heart rate is observed (Seals, 1989; Franke et al., 2000). A doubling in the amount of active muscle mass does not result in an equal increase in sympathetic nerve activity as there appears to be a neural inhibitory affect on this process (Seals, 1989). The semi-isometric muscle action of the upper and lower extremities and torso during the FMB descent would provide a strong stimulus for an increase in heart rate given the above research. This may have resulted in the descent heart rate being elevated above the level required for the support of metabolic processes, however the extent of this increase (if present) is not known.
Muscle damage resulting from isometric and/or repeated eccentric actions also
can increase sympathetic response, leading to increased heart rate (Ishii et al., 2000;
Seifert et al., 1997). Damage from these types of muscle action is more pronounced with
intensities or durations of exercise that are unfamiliar to the individual involved (Seifert
et al., 1997). Repeated exposure to the same intensities and/or durations of exercise
creates a physiological resistance to those patterns of exercise. The participants in the
present study were experienced mountain bikers, indicating that they would be less
vulnerable to this type of trauma. It is also difficult to categorize the extent of eccentric
muscle action during FMB, although observations by the principal researcher and other
data (Burke, 1996; Wang & Hull, 1997; De Lorenzo & Hull, 1999) indicate extensive
absorption of forces with downhill riding.

The terrain encountered on the descent portion of the observed ride was
challenging and steep, and may have been associated with increased psychological
arousal and subsequent sympathetic response. It appears that psycho-physiological
responses tend to be greatest when individuals encounter novel or especially large stimuli
(Herd, 1991; Bunting, Tolson, Kuhn, Suarez, & Williams, 2000), which would not have
been the case in the current study. As stated previously, the participants were skilled in
FMB with specific experience on the trails making up the descent route. A higher level
of fitness and greater experience with a mode and intensity of exercise also tends to blunt
the effects of psychological and emotional variables on heart rate response (Bunting et
al., 2000; Acevedo, Dzewaltowski, Kubitz, & Kraemer, 1999).

The effects of psychological factors on heart rate response during exercise also
appear to be more pronounced during low to moderate intensity exercise (Bot &
Hollander, 2000; Szabo, Peronnet, Gauvin, & Furedy, 1994). The intensity of work observed during the FMB ride may fall under the category of moderate to intense depending on the classification system used. Certainly in terms of the RPE values reported by the participants, the FMB ascent and descent could both be considered to be of moderate to high intensity. The mean RPE level for the descent of 14.2 is three quarters of a point below the descriptor of “heavy” exercise and one and a quarter points above the descriptor of “somewhat hard”. The group mean heart rate associated with the descent is towards the upper end of the spectrum in terms of prescription for cardiovascular exercise for healthy individuals (ACSM, 2000).

The high level of familiarity with the trail network, experience and skill of the participants, and intensity of exercise all indicate that psychological influences on cardiovascular response can be assumed to be minimal. This indicates that there was significant muscular effort during the descent and that the majority of the heart rate response was driven by the metabolic requirements of that work.

**Implications for Health and Fitness**

Beyond describing the acute physiological response during a typical FMB ride, the purpose of this study was to attempt to predict health and fitness benefits from regular participation. The acute cardiovascular and neuromuscular fatigue data combined with information on riding patterns allows for the prediction of chronic effects. The indication from this study is that regular involvement in this form of mountain biking will increase levels of cardiovascular health and fitness. It is possible also that FMB can impact positively on muscular endurance.
The American College of Sports Medicine (ACSM) (2000) recommends participating in activities that involve large muscle groups in rhythmic exercise for twenty to sixty minutes per session, three to five times per week, at an intensity of 70 to 85% of HR max in order to improve cardiovascular health and fitness. The survey responses gathered from the participants indicate that the majority of these individuals satisfy the duration and frequency guidelines. The vast majority (94.7%) of the participants in the current study reported riding frequencies of two or more days per week. Almost one third of all participants ride four to seven times a week. For the individuals with an average riding frequency of 3 days per week or more, the minimum standard set out by the ACSM is achieved. For the other participants, regular FMB outings can significantly contribute to their weekly exercise regimens and add to the benefits gained from other cardiovascular activities.

All of the participants reported average ride durations of greater than one hour, with 79% typically spending two or more hours on the mountain per outing. This is well above the 20-60 minute threshold recommended by the ACSM. It is probable that some of the reported duration is not spent in active participation in mountain biking. Small periods of time may be spent resting at the top of the ascent and preparing for the descent, taking breaks to allow slower riders to catch up, or simply stopping to enjoy the surroundings. Several of the participants also mentioned riding particular sections of trails more than once. Typically these sections involve traversing narrow wooden bridges ("skinnies") or negotiating other man-made and natural obstacles. These "rest" breaks aside, the average FMB ride must satisfy the ACSM duration guidelines as the ascent alone is typically 45 minutes or longer.
The last requirements for improvement in cardiovascular fitness are the intensity and mode of the exercise. The ascent portion of the ride is well aligned with the rhythmic, large muscle group activity that is recommended by the ACSM. The intensity of the ascent and descent as shown by the high average heart rates (>80% PHRmax) in this study is towards the upper end of the recommended range of percent maximum heart rate for improving cardiovascular fitness. The mean RPE value for the whole observed ride and (14.4) also indicates that FMB involves a significant intensity of work.

It is probable that the descent contributes to the overall physiological demand of the ride given the large amount of muscle mass involved, the requirements of the terrain, and the perceived exertions reported by the participants. At this time, it is impossible to state definitively whether or not this contribution is significant in terms of increasing health and fitness levels. The intensity as defined by heart rate may not be completely representative of the demands of the exercise but rather artificially increased by non-exercise influences on sympathetic response. The RPE values reported by the participants support the heart rate data which warrants further investigation into the exact cardiovascular strain associated with the descent.

Although the descent involves a large amount of muscle mass, the activity of that muscle is by nature acyclic and this may not satisfy the guidelines provided by the ACSM. It is important to define the nature of the descent more completely as there are increasing numbers of mountain bikers who are pursuing lift-accessed or “shuttle” trails, which involve traveling to trailheads by motorized transportation. Future research should address whether or not these patterns of riding will contribute to increases in cardiovascular health and fitness.
The neuromuscular fatigue in the upper and lower body associated with the FMB ride was significant statistically but perhaps not enough of a stimulus for improving muscular fitness. A certain minimum threshold of intensity must be reached for increasing muscular strength or endurance levels. The sustained uphill cycling that defines the ascent portion of the ride consists of low intensity concentric actions which have been shown not to be related to muscular power and strength measures (Warner et al., 2002).

The isometric and eccentric actions of the descent seem to be of a fairly high intensity. De Lorenzo & Hull (1999) noted forces at the wheel hubs were five times the weight of the rider’s body mass. On a bike with front suspension only, these forces would be similar to what the rider would have to absorb through the upper and lower extremities (Warner, Shaw, & Dalsky, 2002). This would provide a significant stimulus for muscular strength improvements if this pattern of movement were repeated frequently during the ride. It is uncertain at this time whether or not this intensity of force absorption is a regular occurrence and if it may contribute to increases in muscular strength or endurance.

It is likely that the loading patterns in FMB have other beneficial health effects on the body. Warner et al. (2002) found that competitive XC mountain bike racers had significantly higher total body, femur, and spinal bone density than either road cyclists or normally-active controls. The authors concluded that this difference was directly related to the loads imposed by the rough terrain encountered during mountain biking and the extra requirements for control of the bike and rider’s body. The mean weekly riding time of the XC riders in that study (11 hours) was higher than the average weekly ride time of
the FMB participants (8 hours), however the intensity of the forces involved in FMB may compensate for the difference in exposure time. It remains to be seen whether or not lower levels of participation in either FMB or XC mountain biking will result in these beneficial effects (Warner, Shaw, & Dalsky, 2002).

Conclusions

This investigation was intended as a preliminary examination of the physiological demand of Freeride Mountain Biking. As discussed above, significant neuromuscular and cardiovascular strain is associated with an ascent and descent typical to the FMB experience. The acute physiological data combined with the ride pattern information gathered in this study indicate that regularly participating in this form of mountain biking could have beneficial effects on cardiovascular health and fitness. It is possible that FMB may also improve muscular fitness and bone density if practiced regularly.

The results of this study are applicable to experienced individuals participating in FMB on a regular basis and who ride intermediate to expert trails in a continuous fashion. Caution should be exercised when attempting to predict health and fitness benefits for populations outside of this group. Further research using more intensive measures is needed to clarify the nature of the neuromuscular fatigue and cardiovascular strain associated with FMB. In particular, the acute physiological effects of descent portion of the ride alone represent an area of research that should receive more attention.
References


Appendix A

Review of Literature
Outdoor sporting and adventure activities have experienced a rapid growth over the past two decades. Many people are looking for more and different ways to explore and enjoy the outdoors while increasing fitness and health. Mountain biking in particular has seen a large rise in popularity; the US National Bicycle Dealers Association’s (NBDA) 2004 survey showed that 33% of all bicycle sales were mountain bikes, representing the largest single category of bicycles sold. Other sources quote figures as high as 50 to 60% of bike purchases being some form of off-road bicycle (Burke, 1996; Stapelfeldt, Schwitz, Schumacher, & Hillebrecht, 2004). 47.3 million Americans participated in off-road cycling in 2000, with 94.5% of those individuals riding for recreation and/or fitness goals (NSRE, 2000; NBDA, 2006).

One of the most rapidly growing sub-groups of mountain biking is Freeride Mountain Biking (FMB), a recreational form of primarily downhill riding. FMB can be considered to be a cross between downhill riding and cross country mountain biking (Bader, 2006). Freeriding incorporates much more technical and downhill terrain than cross-country biking with the negotiation of man-made and natural obstacles requiring less speed and more finesse than strictly downhill riding (Bader, 2006). In contrast to the recognized fitness activities of road cycling and cross country mountain biking, FMB has not received attention as a potential fitness and health enhancing activity, in spite of appearing to have significant physical demands due to traversing rough and sometimes undulating terrain.

In a North American population where levels of obesity and inactivity – related diseases are ever increasing, the requirement for a wider range of health and fitness enhancing activities cannot be understated. The purpose of this paper is to review the
physiology literature pertaining to the area of off-road cycling, with a particular focus on exploring the possible health and fitness benefits of participation in Freeride Mountain Biking.

*Cycling for Fitness and Health*

Cycling is a recognized fitness – and health – enhancing activity. The American College of Sports Medicine (ACSM) recommends bicycling to improve cardiovascular fitness and health (ACSM, 2000). Cardiovascular fitness can be defined as the ability of the heart, lungs, and blood vessels to deliver oxygen to the exercising muscles in amounts sufficient to meet the demands of the workload (Greenberg et al, 2000).

The ACSM guidelines encourage participation in activities that involve large muscle groups in rhythmic exercise for twenty to sixty minutes per session, three to five times per week, at an intensity of 70 to 85% of HR max (ACSM, 2000). Increased levels of cardiovascular fitness are associated with numerous health benefits, including protection against several hypokinetic and obesity-related diseases such as cardiovascular disease, some forms of cancer, and diabetes (ACSM, 2000; Greenberg et al, 2000). Cycling involves the synchronized recruitment of seven major lower body muscles and some trunk musculature, in addition to being a low – impact form of exercise (ACSM, 2000).

The ACSM also has recommendations for the development and maintenance of muscular fitness. The two components identified within these guidelines are muscular strength and muscular endurance (ACSM, 2000). Improving muscular fitness enhances bone density, fat-free mass (affecting metabolic rate), glucose tolerance, protection
against musculoskeletal injury, and the performance of activities of daily living (ACSM, 2000). It is unlikely that cycling provides the necessary intensity of stimulus to enhance muscular strength, however the repeated concentric contractions necessary in the pedal stroke significantly impacts upon muscular endurance (Burke, 1996). Specific characteristics associated with mountain bike riding, and downhill riding in particular, may also represent additional stimuli for muscular adaptations in the torso and upper extremity musculature (Burke, 1996; Rhyan, 2005).

*Mountain Biking for Fitness and Health*

Cross-country mountain biking is a common form of off-road cycling that satisfies the ACSM’s criteria for involving a large muscle mass in a rhythmical fashion. This type of off-road cycling has been studied from both fitness and performance perspectives, although not nearly to the extent of road cycling (Stapelfeldt et al, 2004; Lee, Martin, Anson, Grundy, & Hahn, 2002). The Compendium of Physical Activities is a classification system for different exercises by predicted energy expenditure, and expresses the average intensity of various physical activities by Metabolic Equivalents (METS) (Ainsworth et al, 1993). Mountain biking (in general) is equated with an average intensity of 8.5 METS, approximately equivalent to road bicycling at a moderate intensity (18 to 21 kph) (Ainsworth et al, 1993). More aggressive forms of mountain bike riding, such as technical cross-country riding may well have energy expenditures beyond this value.

Cross-country riding involves traversing undulating terrain that incorporates low to moderate levels of technical difficulty and has large recreational and competitive
participation (Lee et al., 2002; Bader, 2006). In comparison to road cycling, cross-country mountain biking may offer more strength benefits through the increased upper body involvement and bike handling skills (Cinque, 1987; Burke, 1996; Impellizzeri et al., 2002). In terms of energy requirements, riding a bicycle for 1-2 hours in a technical off-road setting may be equivalent to riding a road bike for 3 to 4 hours on a smooth surface (Cinque, 1987).

Comparisons of elite cross-country mountain bike riders and elite road bike racers reveal that the mountain bikers typically maintain higher average heart rates during race conditions (Stapelfeldt et al., 2004). In road bike races, heart rates tend to follow the contours of the course – rising on climb portions and falling during descents (Stapelfeldt et al., 2004). Cross-country racing involves a more consistent heart rate response, with no significant decrease seen during downhill sections (Stapelfeldt et al., 2004). This is most likely due to muscle action in both the lower and upper body as a result of descending over rough ground, as pedaling power is lowest when riding downhill (Stapelfeldt et al., 2004). These results tend to indicate that unlike descending on a smooth surface, riding downhill over rough ground requires significant energy expenditure.

In spite of several similarities existing between cross-country mountain biking and FMB, the latter has not yet been evaluated in terms of its acute or chronic physiological effects on the body. The following sections discuss how acute physiological demands can be assessed and applied to the study of Freeride Mountain Biking as a potential fitness and health-enhancing activity.
Defining Physiological Strain

The term "physiological strain" is a label typically used to describe a range of physiological demands on the body as a result of exercise. Used interchangeably with physiological demand and physical demand, physiological strain is commonly referred to in heat-stress literature, where it is often a composite of circulatory measures (heart rate and blood pressure) and various internal and external body temperatures (Baker, 2000). Physiological demand measurements have also been conducted in various forms of exercise in attempts to identify minimum levels of physical capacity, performance criteria (Vuorimaa, Vasankari, & Rusko, 1999; Roecker et al, 2002), and possible fitness and health outcomes from regular participation (Ainsworth et al, 1993; Noakes & Durandt, 2000). Percent VO2 max, heart rate response, alterations in muscle force production, Ratings of Perceived Exertion (RPE), and blood lactate concentrations are common measures used for assessing physiological strain in sporting and work-related tasks (Vuorimaa et al., 1999; Roecker et al, 2002).

For the purposes of this paper, physiological strain will be considered to be a composite of the acute cardiovascular strain and neuromuscular fatigue resulting from participation in exercise. All physical activities incorporate the cardiovascular and neuromuscular systems to some degree, and thus represent a certain level of strain to both components. The exact nature and primary locations of the physical demand vary with the type, duration, and intensity of exercise as well as numerous categorical variables including gender, age, and fitness level. Measures of cardiovascular strain are common (as listed above), however measures of neuromuscular fatigue in work-related or sporting
tasks are much rarer. The following sections discuss cardiovascular and neuromuscular fatigue in terms of the effects of exercise and typical methods of assessment.

*Acute Cardiovascular Strain*

In the context of physiological strain measures of exercise and sports performance, cardiovascular strain can be considered as the product of the acute activity-related demands on the cardiovascular and respiratory systems. Rest-to-exercise transitions involve rapid and pronounced increases in both cardiovascular and respiratory variables in response to increased demands for oxygen and substrates in the working muscles (Powers & Howley, 2004). Cardiac output is increased through the combined actions of increased heart rate and stroke volume, and is accompanied in exercise by pronounced increases in respiration rate, minute ventilation, and oxygen consumption (Powers, & Howley, 2004). Central command theory suggests that the initial response to exercise is a centrally-generated cardiovascular motor signals which are then modified by feedback from several groups of chemo-, baro-, and mechanoreceptors (Powers & Howley, 2004). The magnitude and nature of cardiovascular strain is governed by the intensity, duration, and type of exercise, in addition to numerous inter-individual variables (including age, sex, and fitness level) (Powers & Howley, 2004).

The acute measurement of the cardiovascular strain associated with different forms of exercise gives insight into potential fitness and health benefits that may result from chronic participation (Vuori, 1998). A certain minimum level of strain is associated with improvements in cardiovascular fitness. The ACSM guidelines suggest a minimum intensity of 60% of estimated maximum heart rate (HRmax) to increase cardiovascular
fitness (ACSM, 2000, Roecker et al, 2002). For healthy individuals with average levels of fitness, this minimum threshold is raised to 70% of HRmax (ACSM, 2000). Attainment of this level with appropriate frequency and duration will result in cardiovascular fitness and health benefits. The accurate measurement of the acute strain of various activities is therefore a key component in predicting chronic adaptations.

Measurement of Cardiovascular Strain

Any measure of cardiovascular or respiratory function can be utilized to predict overall cardiovascular strain. This includes measures of central delivery capacity (such as heart rate), measures of energy metabolism and cardiovascular efficiency (blood lactate and VO2) and psychological inventories of exertion (RPE) (Lollgen, Graham, & Sjogaard, 1980; Vuorimaa, 1993; Roecker et al, 2002). Although the majority of studies in this area examine more than one of these components, the main assumption is that for most tasks, measures of cardiovascular function are proportional to work rate and energy expenditure (Montoye, Kemper, Saris, & Washburn, 1996; Roecker et al, 2002). In addition, there is a high degree of correspondence between discrete measures of cardiovascular and respiratory function (Bot & Hollander, 2000). The strong relationship between cardiovascular variables allows for predictions of total energy expenditure as well as amongst each variable without direct measurement.

The most common measure is heart rate, in particular the percentage of maximum heart rate (HRmax) or percentage of heart rate reserve (HRR). Heart rate has been found to be proportional to work rate, VO2max, and energy expenditure both incremental and intermittent-type exercise (Bot & Hollander, 2000; Montoye et al., 1996). The typically
linear relationship between VO2max and heart rate is used in many predictive testing situations for submaximal incremental tests, and has been shown to be robust (Crouter, Albright, & Bassett, 2004; Keytel et al, 2005; Bot & Hollander, 2000). The relationship of heart rate to VO2 and workload during intermittent exercise appears to be the result of similar response times to changes in exercise intensity (Bunc, Heller, & Leso, 1988; Bot & Hollander, 2000). Results can be expressed as peak heart rate attained, average heart rate, or time spent in particular heart rate zones (expressed as percentage of maximum or predicted maximum heart rate), with the latter two variables useful in predicting fitness and health benefits through chronic exposure (Vuori, 1998).

Using heart rate to assess cardiovascular strain is widespread due to its accuracy, reliability, and inexpensive nature (Vuori, 1998; Bot & Hollander, 2000; Keytel et al, 2005). In particular, Polar brand heart rate monitors have been assessed in various types of exercise (including cycling) and have been shown to be highly accurate and reliable (Crouter et al, 2004; Karvonen, Chwalbinska-Moneta, & Saynajakangas, 1984; Leger & Thivierge, 1998). Heart rate response using telemetric heart rate monitors can be measured non-invasively, in adverse environmental conditions, and for long periods of time (Vuori, 1998).

There are several factors that may affect the accuracy of the relationship between heart rate response and work rate. In particular, physical activities which involve significant levels of psychological stress (which may include steep and technical FMB descents) have an effect on heart rate that may obscure the true cardiovascular strain resulting from the energetic requirements of the body (Stapelfeldt et al, 2004; Crouter et al., 2004; Herd, 1991; Seifert, Luetkemeier, Spencer, Miller, & Burke, 1997). The
influence of psychological stress to heart rate during these types of tasks contributes to overall strain, however when attempting to isolate the actual demands of the physical activity in question, this may become a confounding variable. It appears that in such psychologically demanding activities such as sky-diving and various adventure sports, higher levels of experience and fitness tend to blunt the psychological stress response (Schedlowski & Tewes, 1992; Bunting, Tolson, Kuhn, Suarez, & Williams, 2000).

Repetitive exposure to the same stimulus, such as riding certain technical trail features regularly, is also associated with a decreased psycho-physiological stress response (Herd, 1991).

Adverse climatic conditions, in particular hot and humid environments, also have a significant effect on exercise heart rates (Crouter et al., 2004). Cardiovascular strain in such environments is accentuated due to a combination of factors, with the most influential being competition for blood flow between the muscles and skin and loss of blood volume due to dehydration (Green, 1997). The influence of heavy or protective clothing (for example firefighting equipment) can also increase the cardiovascular strain associated with physical tasks (Baker, 2000). The protective gear worn by FMB riders, in particular full-face helmets and body armor may act in a similar fashion by increasing body temperature and increasing cardiovascular strain.

Other intervening factors affecting the relationship between heart rate and workload include level of fitness, dehydration, gender, and the nature of the actual exercise task (Bot & Hollander, 2000; Crouter et al., 2004). Utilizing large versus small, upper body versus lower body, intermittent versus continuous, and static versus dynamic forms of exercise all have been shown to have an impact on the HR response to exercise.
(Bot & Hollander, 2000; Seifert et al, 1997). In particular, upper body exercise and isometric exercise are associated with increased sympathetic activity (Seifert et al, 1997), which may cause an increased heart rate response not necessarily associated with greater energetic demands.

Exercise forms that produce muscle damage through high loading or repeated loading (in particular eccentric) also tend to increase sympathetic outflow and subsequent heart rate response (Seifert et al, 1997). However, the ease of use and high correspondence of heart rate and various measures of work rate and energy expenditure make this measure a valid and important tool in assessing cardiovascular strain.

Blood lactate is another common method of examining the response and efficiency of the cardiovascular system during exercise. The concentration of blood lactate can reveal information about the balance of anaerobic and aerobic energy production and is inherently tied to other measures of cardiovascular strain (Brooks, 1985; Powers & Howley 2004). Blood lactate accumulation is also strongly related to acute neuromuscular fatigue, which will be discussed in the following section. Lactate production and clearance from the muscles and blood follow predictable paths, dependent on the intensity and nature of exercise (continuous vs. intermittent), and fitness level.

At rest, blood lactate levels are stable at around 1 mmol/L of blood. As moderate intensity exercise is initiated, blood lactate begins to accumulate due to a time lag between rest and steady-state oxygen consumption (Powers & Howley, 2004). This acute increase reverses as aerobic respiration adapts to the demands of the exercise, and blood lactate levels return to approximately resting values. In higher intensities of exercise, anaerobic energy production may take a larger role due to the inability of aerobic energy
processes to keep up with energetic demands. This results in an increased level of blood lactate for the duration of the exercise bout (Powers & Howley, 2004). At even higher intensities, anaerobic energy production predominates, resulting in a continuous increase in lactic acid until fatigue.

Researchers have identified blood lactate concentration transitions to define the contribution of anaerobic processes to energy production, using these values both to assess physiological demand and to prescribe exercise training intensities (Brooks, 1985).

Assessing changes in blood lactate concentrations resulting from exercise give insight into the specific energetic demands of a particular physical activity. Monitoring blood lactate shifts during rest, exercise, and recovery after exercise is a common method of assessing energetic demands and the efficiency of the cardiovascular system in supporting aerobic means of energy production. Blood samples are usually collected by means of a finger prick, a relatively non-invasive yet highly reliable technique (Pyne, Boston, Martin, & Logan, 2000).

The major assumption with collecting and analyzing blood lactate samples is that concentrations at the periphery (i.e. finger) are representative of concentrations at the level of the working muscle(s). A strong relationship is evident between blood and muscle lactate concentrations however a delay effect may be apparent between alterations at the muscle level and subsequent expression in the location of the measurement. In addition, muscle lactate concentrations appear to increase at a greater rate than blood lactate values at higher intensities of exercise (Noble, Borg, Jacobs, Ceci, & Kaiser, 1983).
Maximal oxygen uptake (VO2max) is the gold standard in terms of assessing cardiovascular fitness. VO2max is proportional to the product of cardiac output and arterio-venous O2 difference (Powers & Howley, 2004; Montoye et al, 1996). Since variation in a-vO2 difference is minimal during exercise, and stroke volume stabilizes around 40% of VO2max in moderately trained individuals, the strong relationship between VO2 and heart rate becomes apparent (Powers & Howley, 2004).

VO2 measurement during exercise allows for the assessment of the efficiency of the cardiovascular system to deliver and utilize oxygen, and is affected by both alterations in cellular respiration and the hemodynamic changes that occur with exercise (Sietsma, Daly, & Wasserman, 1989). Testing for absolute VO2max is common for assessing fitness in sports performers whereas expressing work rate as a percentage of VO2max gives direct insight into the nature of the demands of different activities. In particular, the workload demands of various forms of cardiovascular exercise are often measured via VO2max due to its ability to reliably and accurately assess total acute cardiovascular strain (Vuorimaa, 2000).

Cross-country mountain bikers have been evaluated in terms of their VO2 response to race conditions in several studies (Impellizzeri, 2005; Lee et al, 2002; Stapelfeldt et al, 2004). These responses are difficult to apply to recreational FMB riders in general as the terrain, fitness level, and characteristics of technique and equipment are quite different to cross-country mountain biking. However, the initial ascent and bursts of uphill cycling associated with FMB may produce similar magnitudes of VO2 response.

In comparison to heart rate, VO2 is less affected by psychological stress (Herd, 1991), however the measurement of VO2 during aggressive outdoor activities is limited
by the availability and cost of equipment. In situations where the use of VO2 testing is not feasible, the strong relationship between oxygen and heart rate indicate that predictive values derived from heart rate and other cardiovascular variables is a reasonable alternative.

Rating of Perceived Exertion (RPE) scales assess workload through an individual’s subjective rating of effort. RPE is not exclusive to assessing cardiovascular strain, however most research using perceived exertion has been conducted with endurance/cardiovascular exercise modes. The original scale and subsequent variations developed by G.V. Borg have been shown to reliably correspond to exercise intensity, heart rate, VO2, and energy expenditure in a wide range of exercise tasks (Borg 1998; Noble et al, 1983; Powers & Howley, 2004).

Two main scales are in use currently; the original categorical scale from 6 to 20 was designed to correspond with approximate resting and maximum heart rates (6 = 60bpm, 20 = 200bpm), with a category ratio scale from 0 to 10 developed later with improved word association and scaling (Borg, 1998; ACSM, 2000). RPE is a valid measurement regardless of fitness level, age and gender, and is a simple, non-invasive method for monitoring exercise (ACSM, 2000; Powers & Howley, 2004).

The exact mechanism of the interaction between intensity of effort and perception of effort appears to be a complex combination of cardiovascular and peripheral muscular sensations (Lollgen, Graham, & Sjogaard, 1980). In particular, sensations due to anaerobic byproducts have been shown to be both strong and weak predictors of RPE (Noble et al., 1983; Lollgen, Graham, & Sjogaard, 1980). In a study by Noble et al (1983), blood lactate and RPE were strongly related over different intensities of cycling.
Muscle lactate accumulation followed a more exponential trend than RPE and blood lactate, indicating that lactate concentration in the blood is more related to perceived exertion. In contrast, Lollgen et al (1980) observed no significant relationship between RPE and several cardiovascular variables. These researchers suggested that a number of factors influenced RPE and no one variable was the sole cause of fluctuations in perceived exertion (Lollgen et al, 1980).

The signals for sensation of effort may also vary with mode of exercise, as RPE has been shown to be an effective intensity assessment tool in both resistance and endurance training exercise (Borg, 1998). Researchers have identified the importance of receptor cues in contributing to exercise-induced perceptions of effort. Afferent information from chemoreceptors and mechanoreceptors at the periphery may play an important role in signaling effort (Lollgen et al, 1980).

The overall strong interaction between RPE and exercise intensity, combined with the measure’s ease-of-use and non-invasive nature support the use of this exertion scale for assessing physiological strain, and cardiovascular strain in particular.

*Acute Neuromuscular fatigue*

Acute neuromuscular fatigue can be defined as an acute decrease in the force-producing capabilities of a muscle (Gandevia, 2001). Most often studied in the context of resistance training, neuromuscular fatigue is believed to be affected by both central and peripheral alterations resulting from exercise (Gandevia, 2001; Kawakami, 2000; Millet & Lepers, 2004). The exact locations and mechanisms of neuromuscular fatigue have yet to be definitively identified however most researchers suggest that disruption in the
excitation-contraction (EC) coupling within the muscle cell is a key component (Gandevia, 2000; Fitts, 1994).

Much like cardiovascular strain, a certain threshold of acute demands on the neuromuscular system is required for improvements in muscular strength and/or endurance. The ACSM (2000) lists general guidelines for the improvement of muscular strength as percentages of 1 repetition maximum (1RM). The forces regularly encountered during cycling do not approximate the intensities required for gains in muscular strength, which typically has a minimum threshold of 60% 1RM (ACSM, 2000).

The ACSM defines muscular endurance as the ability of a muscle group to sustain repeated contractions until fatigue (ACSM, 2000). Their prescription for improving muscular endurance does not incorporate a minimum stimulus but instead refers to duration of activity. Over extended periods of time, submaximal contractions can provide adequate stimulus, which is primarily why the concentric actions of the lower body encountered during cycling are considered to be beneficial in enhancing muscular endurance (Burke, 1996). The muscular requirements of mountain biking, and FMB in particular, may differ substantially in terms of loading patterns to less aggressive forms of cycling (Burke, 1996). The objective assessment of the acute neuromuscular fatigue associated with FMB may help to indicate the extent and intensity of the muscular activity, in turn improving the prediction of any potential muscular endurance benefits from regular participation.
Mechanisms of Acute Neuromuscular fatigue

Central influences on fatigue are considered to be alterations in the signaling for muscular contraction that occur proximal to (and including) the neuromuscular junction (Kawakami, 2000). Often linked to alterations in mental arousal or voluntary effort, central fatigue influences neuromuscular fatigue by decreasing the number or rate of firing activated motor units (MU's) (Gandevia, 2001). This process is generally described as a decreased neural drive to the musculature (Gandevia, 2001; Millet & Lepers, 2004).

Sources of peripheral changes in neuromuscular activation appear to be metabolic, energetic and/or structural in origin (Fitts, 1994; Green, 1997; Hamlin & Quigley, 2001). During more intense forms of exercise, increased reliance on anaerobic means of energy production causes an increased concentration of lactate, H⁺ ions, and a concomitant decrease in muscle pH. A strong negative correlation exists between concentration of blood/muscle lactate and decreases in force production (Fitts, 1994). The resulting increase in H⁺ ion concentration and decreased pH are more likely the cause of acute neuromuscular fatigue (Fitts, 1994; Hamlin & Quigley, 2001).

High H⁺ concentrations in muscle cells have been shown to inhibit force production more than increased levels of lactate, most likely due to the multiple sites within the EC coupling process that can be negatively affected by H⁺ ions (Fitts, 1994; Green, 1997). Low pH has been associated with reduced force per cross bridge and inhibition of the excitation-contraction coupling through interference with Ca²⁺ processes within the muscle. Specifically, H⁺ ions compete for troponin binding sites and inhibit Ca²⁺ release and reuptake to the sarcoplasmic reticulum through disrupting local ATPase
action (Green, 1997). Force for any given concentration of Ca\(^{++}\) is decreased, along with a slowing of muscle relaxation due to the inability to re-sequester Ca\(^{++}\) ions to the sarcoplasmic reticulum (Fitts, 1994).

Energetic processes within the muscle may also influence force production via protective feedback mechanisms. Similarly to lactate and pH, a strong negative correlation exists between concentration of inorganic Phosphate (Pi) and force following exercise (Fitts, 1994). This higher concentration of Pi would result from high rates of energy usage and has been linked to interference in the transition of cross bridges from the weakly-bound to strongly-bound positions (Fitts, 1994). In addition, Pi may contribute to slowing of the relaxation in muscle cells by interfering with Ca\(^{++}\) reuptake to the sarcoplasmic reticulum. Some researchers have suggested that this influence of Pi is part of a protective mechanism to avoid the excessive depletion of ATP within the muscle cell. However, the concentration of ATP rarely falls below 70% of the normal level, even with intense exercise, and never below the required amount to produce peak force (Fitts, 1994).

Exercise for longer durations (2 to 3 hours) and at moderate intensities (65 to 85% of VO2 max) leads to depletion of muscle glycogen that is significantly related to decreases in muscular force production (Fitts, 1994; Green, 1997). The depletion of muscle glycogen and concomitant reduction in blood glucose has been shown to be a major limitation to endurance exercise performance. This may be through energetic means or through signaling and protective feedback loops through higher centers, as the maintenance of blood glucose to the brain and heart are highly regulated. In addition, low muscle glycogen may affect force production in ways other than its role in energy
production, perhaps through influencing structural changes in the SR and other cell organelles (Fitts, 1994).

Structural influences on neuromuscular fatigue are associated with both high loading and high volume exercise involving eccentric, isometric and concentric muscle actions (Hakkinen, 1993). Most often, structural damage is the result of a substantial eccentric component, which may be manifested in the form of a heavy load applied relatively briefly, or through lighter loads applied repetitively (Green, 1997; Noakes & Durandt, 2000; Hamlin & Quigley, 2001). Significant muscle damage can result from endurance exercise, particularly activities involving impact, such as distance running (Millet & Lepers, 2004). Regardless of the principal mechanism, high-load or repetitive-load strains have the potential to disrupt the contractile components of muscle tissue, leading to acute decrements in muscle force (Green, 1997; Hamlin & Quigley, 2001). This muscle damage to the sarcolemma and contractile myofilaments, in addition to local tissue edema, may represent a major aspect of acute neuromuscular fatigue (Green, 1997; Hamlin & Quigley, 2001).

Assessing Acute Neuromuscular Fatigue

The energetic, metabolic, neuronal, and structural influences on acute neuromuscular fatigue can be assessed to identify the key variable(s) responsible for neuromuscular fatigue in different types of activities. Typically, pre and post-intervention measures are used to assess changes resulting from a controlled bout of exercise (Millet & Lepers, 2004), with decrements in force and alterations in muscle electrical activity significantly related to neuromuscular fatigue. Common methods of
examining the various components of neuromuscular fatigue are described below, with a particular focus on acute neuromuscular fatigue associated with endurance cycling exercise.

Electromyography (EMG) and Interpolated Twitch (ITT) measures are common means of examining the neural influences on acute neuromuscular fatigue and reductions in central drive (Knaflitz, 2003; Gandevia, 2001; Millet & Lepers, 2004; Vuorimma et al, 2006). EMG measures the electrical activity of a muscle group resulting from depolarizations associated with motor unit recruitment and summation (Gandevia, 2001; Thiery et al, 2001). Increased EMG level during exercise may be associated with neuromuscular fatigue as it represents the requirement to recruit more motor units in compensation for the fatigue of other motor units (Gandevia, 2001). Muscle activation as measured by EMG typically changes due to exposure to different forms of exercise, but may occur independent of changes in force production (Gandevia, 2001). In terms of pre to post intervention, decreased EMG levels indicate a lower level of neural drive or increased inhibition of supraspinal signals to the target musculature (Gandevia, 2001).

Recent research in the area of endurance exercise indicates that there is a reduction in central drive as assessed by EMG following running and cycling for durations of 30 minutes to several hours (Millet & Lepers, 2004). Both marathon running and cross-country skiing are associated with decreased EMG during an MVIC post-exercise (Millet & Lepers, 2004). Larger decrements in EMG post-exercise are associated more with running as opposed to cycling, which may primarily be a result of the increased muscle damage associated with distance running (Millet & Lepers, 2004). FMB may represent a different category of cycling exercise with regard to muscle
damage due to marked differences in terrain encountered and riding technique (see
Potential Sources of Physiological Strain in Freeride Mountain Biking, below), which
may in turn impact upon alterations in central drive following a FMB ride.

The measurement of ITT provides information on the proportion of muscle tissue
that can be activated voluntarily in comparison to involuntary (electrical) stimulation. A
reduction in the voluntary twitch response in comparison to the electrically – generated
response would tend to indicate a reduction in central drive (Gandevia, 2001). Unlike
EMG, ITT measurements appear to be more closely linked to changes in muscular force
production (Gandevia, 2001), however very little research in the area of the
neuromuscular fatigue associated with cycling has incorporated this measure.

Maximum voluntary contraction (MVC) measures are useful in assessing basic
alterations in the maximum force production of a muscle group. MVC measures may
utilize isometric, concentric, and/or eccentric muscle actions. Running and cycling
studies typically evaluate the knee extensor muscle group through a dynamic or isometric
half squat (Millet & Lepers, 2004; Vuorimaa, 2006). As an indication of neuromuscular
fatigue, MVCs are limited in that the mechanism behind any changes cannot be
identified, and may be the result of peripheral factors, central factors, or a combination of
the two influences (Vuorimaa, 2006).

Several studies have examined the acute effects of cardiovascular exercise on
series of studies and found that participation in cycling for 30 minutes to 5 hours resulted
in decrements in MVC force ranging from 9 to 20%. Four primary trends are evident in
the reduction of MVC force following endurance exercise. Force decrements follow a
non-linear pattern with exercise time such that the reductions in MVC tend to decrease with increasing exercise duration (Millet & Lepers, 2004). This may be due to the increased intensity associated with shorter exercise durations. The second trend evident in the data is that concentric MVC’s tend to show smaller decrements than either isometric or eccentric muscle actions (Millet & Lepers, 2004).

The third trend indicates that continuous exercise is associated with greater decrements in knee extensor MVC than intermittent exercise (Vuorimaa, 2006). Continuous versus intermittent exercise – continuous associated with much higher levels of acute neuromuscular fatigue (Vuorimaa, 2006). This may be due in part to the different energetic and metabolic requirements between continuous and intermittent exercise protocols, and indicates a different progress of neuromuscular fatigue (Vuorimaa, 2006). Lastly, exhaustive cardiovascular performance was predictably associated with the largest MVC decrements. In addition, it appears that non-exhaustive sustained exercise may increase knee extensor MVC in runners of moderate fitness (Vuorimaa, 2006).

The use of EMG, ITT, and MVC assessments in combination offers the most promise in terms of accurately assessing the location and extent of acute neuromuscular fatigue. Running for extended periods in a continuous fashion is associated with the greatest alterations in electrical activity and maximum voluntary contraction, possibly due to the higher degree of muscle damage as compared to conventional cycling (Millet & Lepers, 2004). As mentioned above, the specific demands of FMB appear to be quite different to those of conventional cycling and may similar in some ways to higher impact activities such as jogging. The following section describes potential sources of
physiological strain in FMB with specific regard to comparisons with conventional cycling.

Potential Sources of Physiological Strain in Freeride Mountain Biking

Movement analysis has been conducted on the general area of mountain bike riding that applies to the more specific area of FMB (Burke, 1996). Freeride Mountain Biking incorporates some similar terrain features as cross-country mountain biking, so some of the muscular and energetic requirements inherent to competitive cross-country cycling will apply to FMB. As mentioned previously, the physical demands of riding downhill may be substantial in terms of energy and muscular force requirements (Rhyam, 2005). Riding uphill and downhill over rough terrain requires dynamic (concentric/eccentric) and isometric muscle actions (Seifert et al, 1997; Burke, 1996).

Much of the dynamic activity in cross-country mountain biking comes from the concentric cyclic actions of the legs, which are used in both endurance and power capacities (Stapelfeldt et al, 2004; Burke, 1996). In FMB and other types of downhill mountain biking, the terrain supplies much of the forward momentum, so pedaling is often not required except to adjust speed to traverse obstacles (jumps, drops, logs) and ascend relatively short uphill stretches (Rhyam, 2005). However, as much as 80 to 90% of the descent portion of the ride will be spent standing in the pedals (not using the saddle) (Bader, 2006), which places a load-bearing stress on the musculature of the lower body.

Preliminary video analysis and pilot work by the author of Freeride Mountain Biking indicates that the legs appear to act in a semi-isometric manner, with small range
concentric and eccentric actions occurring with shifts in weight, manipulation of the 
bicycle, and absorption of downward forces. These actions affect the knee extensors and 
flexors, the hip extensors and flexors, and the ankle flexors. FMB riders typically 
maintain fairly consistent knee, hip, and ankle angles while riding to stabilize the body 
over the bike, with larger ranges of movement occurring with especially large downward 
forces (such as absorbing impact after a step in the trail), losses of balance, or when 
negotiating especially challenging sections (Bader, 2006).

Typically inherent to the FMB experience is a prolonged ascent to the Freeride 
trailhead. This involves riders pedaling and/or pushing their bikes uphill for upwards of 
45 to 60 minutes (Bader, 2006). This duration and muscle action corresponds highly with 
the ACSM guidelines of large muscle group use in cyclic activity, for duration of 20 to 60 
minutes (ACSM, 2000). Many of the lower body energetic requirements associated with 
cross-country riding are applicable, with some alteration due to the special characteristics 
of Freeride mountain bikes and equipment. Given similar or greater energetic costs to 
those encountered during regular uphill cycling, this initial ascent would appear to be a 
significant contributor to both acute physiological demand and fitness/health benefits 
from chronic participation.

Traversing rough terrain both uphill and downhill involves the production and 
absorption of forces by the torso and upper extremities, with the muscles of the shoulder 
girdle and arm flexors/extensors acting in isometric, concentric, and eccentric fashions 
(Burke, 1996; Seifert et al., 1997; Rhyan, 2005). In FMB and other forms of downhill 
mountain biking, upper body action may be even more accentuated, as the terrain 
traversed during FMB is typically rougher, more diverse, and more technically
challenging than what is encountered on cross-country mountain biking trails (Bader, 2006; Rhyne, 2005). The absorption of bumps and continuous vibrations from the trail surface also impact upon muscle activation and are associated with elevated muscle damage (Ishii, Umemura, & Kitagawa, 2000; Seifert et al, 1997).

Descending over this type of ground involves eccentric actions of the serratus anterior, pectoralis muscle group, anterior deltoid, and elbow extensors through resisting transverse abduction at the shoulder and protraction of the scapulae (Burke, 1996). Ascending and manipulating a bike uphill or over obstacles involves the recruitment of the scapular musculature (trapezius, rhomboids, levator scapulae), latissimus dorsi, posterior deltoid, and elbow flexors in both concentric and isometric actions (Burke, 1996).

The wrist and hand muscles are a particular area of muscular demand in all types of off-road cycling. The finger and thumb flexors are required to exert low to high concentric and isometric forces when braking and gripping the handlebars (Burke, 1996). Due to the primarily downhill nature of FMB trails, the use of the finger and hand muscles for braking and steering over and around obstacles may continue for extended periods of time.

In cross-country mountain biking, the primary function of the trunk musculature is to maintain body position against the force of gravity (Burke, 1996). Preliminary video analysis indicates that FMB tends to incorporate larger and more aggressive movements of the bicycle, increasing the need for the torso to act as an active link between the upper and lower extremities. Dynamic balance becomes more of a factor when covering rougher terrain, indicating the requirement for involvement of the torso musculature as
riders shift their weight and manipulate the bicycle (Bader, 2006; Seifert et al, 1997; Rhyan, 2005). Many times, FMB riders must hold the bike on a certain line while moving their body to balance, and vice versa (Bader, 2006). These adjustments of position require coordinated, repeated, powerful, and sometimes prolonged levels of muscular activation, centered in the muscles of the torso. These muscle actions could considerably increase the neuromuscular fatigue of FMB in comparison to riding on smoother surfaces.

*Special Characteristics of Freeride Mountain Bikes and Equipment*

The challenging nature of the terrain encountered during FMB requires the use of special riding and protective equipment. In particular, the bicycle design and characteristics both offer benefits and drawbacks in terms of physical demand. Typical Freeride mountain bikes weigh 35 to 45 pounds, with an average of six inches of front and rear wheel suspension travel (Bader, 2006). This is in contrast to cross-country bicycles, which commonly weigh 20 to 30 pounds, have an average of 3 to 4 inches of front and rear suspension (although a significant number of cross-country bikes are a “hardtail” design, incorporating no rear wheel travel).

In addition, freeride mountain bike tires often feature enlarged tread patterns in widths upwards of 2.4 inches, and tend to be run with relatively low pressure (~20 to 35psi) (Burke, 1996). This is contrasted with the less pronounced tread and narrower tire width (1.75-2.2”) and typically higher tire pressures seen with cross country bicycles (Burke, 1996).
The specific characteristics of Freeride mountain bikes are designed to benefit the rider on the descent portions of the ride. Larger suspension travel smooths vibrations, steps, and impacts from drops in the trail, possibly resulting in decreased energetic requirements on the part of the rider, and more consistent tire contact with the trail (Ishii et al, 2000; Seifert et al, 1997). Wider, softer tires with larger air volume increase traction over roots, rocks, and other obstacles, aiding in stability and traction. Heavier bikes also tend to be less sensitive to impacts from rocks that would otherwise throw riders off balance.

These same characteristics are detrimental to Freeride mountain bikers when traversing flat or uphill terrain. Rolling resistance is a major factor in energy expenditure while cycling, and is the sum of surface roughness, tire pressure, wheel load, and tire materials and construction (Burke, 1996). Controlling for surface, the equation for rolling resistance is the product of the weight on a tire multiplied by a friction coefficient (Burke, 1996). It has already been established that there is a significant difference in the weight borne by the tires in Freeride and cross-country bicycles. It also appears that the softer pressures and wider tread of a tire result in a substantial increase in friction; a moderate tread width of 2.25" and lower tire pressure are associated with a friction coefficient more than four times that of a 1.75" tire with higher pressure (Burke, 1996).

Investigations into the effect of suspension travel on energy expenditure while riding have indicated several trends. In particular, it appears that rear suspension systems may interfere with the direct application of power to the pedal through the dissipation of forces (Seifert et al, 1997; Ishii et al, 2000). This absorption of pedal forces by the suspension system is not counterbalanced by increased rear-wheel contact with the trail.
(Ishii et al, 2000). With larger (and softer sprung) rear wheel travel, it would be reasonable to presume that this dissipation effect would become magnified. Given these factors, the ascent portion of a FMB ride may present a more substantial challenge to FMB riders than to riders on cross-country bicycles. This challenge would be manifested as increased cardiovascular strain and neuromuscular fatigue during the initial ascent.

The suspended and rotating weight of the bicycle and tires are added to by the protective gear worn by FMB riders. Leg, arm, and frequently chest and shoulder protection are common essentials for Freeride Mountain Biking (Bader, 2006). In addition, many riders choose to wear full-face helmets and carry food, emergency supplies and bike repair equipment on their rides (Bader, 2006). These extra items not only add to the total weight of the bicycle and rider, but also may constitute a substantial challenge to heat regulation and hydration during exercise. The added weight may substantially add to the physical demands of a FMB ride, and in warmer temperatures, the combined insulating and evaporation-limiting properties of the protective gear may significantly impact upon physiological strain through disruption of heat regulation.

*Frequency and Duration Patterns in Freeride Mountain Biking*

Two of the key components of the ACSM’s guidelines for increasing cardiovascular fitness are the frequency and duration of exercise. The ACSM recommends activity for 20 to 60 minutes on 3 to 5 days per week (ACSM, 2000). The Trail User Survey conducted by the North Shore Mountain Bike Association (NSMBA) in July and August, 2003, reveals several trends regarding participation patterns in FMB in North Vancouver hiking and biking trails that pertain to the ACSM’s guidelines.
Of the 695 mountain bikers polled, 51.7% spend 2 to 3 hours on the trails, with 24.7% spending 3 to 5 hours in the trail network (NSMBA, 2003). These durations of activity are in excess of those recommended by the ACSM for improving cardiovascular fitness, although an assumption must be made that this length of time is not spent in continuous motion. A substantial allotment of that time must be attributed to the primary ascent to the trailheads, which may last as long as 60 minutes (Bader, 2006). This ascent involves riders either pedaling or pushing their bicycles up low to moderate inclines (commonly fire access roads), both of which could be considered to be rhythmic activities involving large muscle groups. Descent times vary with skill level and number of rest stops, with some riders choosing to perform several loops of ascents and descents within each ride (Bader, 2006).

The descent portion of the ride is completed in a continuous or interval-type fashion. Some riders prefer to keep in constant motion, whereas others tend to take regular breaks and re-ride portions of the trail (Bader, 2006). The latest recommendations from the ACSM suggest that performing several discrete and shorter periods of exercise offers similar benefits to exercising continuously for the same total time (ACSM, 2000). This indicates that regardless of the interval or continuous nature of the ride, fitness and health benefits would apply, given a minimum level of exercise intensity. Further analysis is needed in this area to accurately assess the proportion of the reported ride time that is dedicated to intensities of exercise sufficient to elicit gains in cardiovascular fitness.

The Trail User Survey also polled mountain bike riders for riding frequency. 82% of riders visit the trail network at least once every two weeks, with 46.1% riding weekly
and 24.4% visiting the trails to ride multiple times a week (NSMBA, 2003). Considering the ACSM guideline of 3 to 5 sessions per week (ACSM, 2000), this reported frequency of riding indicates that the multiple-weekly riders may satisfy those recommendations through their participation in FMB. For less frequent riders, FMB may still represent a significant contributor to their cardiovascular training frequency, as long as a minimum threshold of training intensity is achieved.

The missing component in this physical description of FMB is an examination of the common intensity of exercise associated with a typical Freeride Mountain Biking ride. The objective and valid measurement of the acute physiological strain of FMB, with a focus on intensity of exercise, will give more insight into how these frequency and duration patterns may translate into significant health and fitness benefits for FMB riders.

**Summary and Recommendations**

Freeride Mountain Biking is a popular recreational form of downhill off-road biking with a wide demographic of participants. Movement analysis research indicates that there is significant demand placed on the upper body, lower body, and trunk musculature while riding downhill over rough terrain (Burke, 1996). The full extent of the acute neuromuscular fatigue resulting from this activity has not yet been assessed. Additionally, the typical FMB experience incorporates a substantial initial ascent to the trailhead. This ascent (riding or walking) involves large muscle groups working in a rhythmical fashion satisfying two of the requirements for cardiovascular exercise as recommended by the ACSM (2000). Ride frequency and duration information reported
by the NSMBA indicate that participation in FMB may help participants gain in cardiovascular health and fitness, given a minimum threshold of exercise intensity.

No research has yet been conducted to accurately assess the physiological strain of FMB with a focus on determining the acute neuromuscular fatigue and cardiovascular strain. The objective examination of both the cardiovascular strain and neuromuscular fatigue associated with a typical FMB ride will help to identify how FMB affects the body in an acute sense. This assessment, combined with riding frequency and duration information, may help to predict chronic health and fitness adaptations associated with regular participation in Freeride Mountain Biking.
References


Appendix B

Informed Consent
PARTICIPANT CONSENT FORM

You are invited to participate in a study entitled **Physiological Strain of Freeride Mountain Biking: A health-related approach** that is being conducted by Cam Birtwell.

Cam Birtwell is a graduate student in the department of Physical Education at the University of Victoria and you may contact him if you have further questions by email at birtwell@uvic.ca.

As a graduate student, I am conducting this research as part of the requirements for a degree in Physical Education. It is being conducted under the supervision of Dr. David Docherty. You may contact my supervisor at (250) 721-8375.

**Purpose and Objectives**
The purpose of this research project is to evaluate how Freeride Mountain Biking (FMB) affects the cardiovascular and muscular systems of the body. The aim is to assess physical changes in your body as you ride to define FMB as a potential fitness and health-related activity.

**Importance of this Research**
Research of this type is important because FMB is an activity which is rapidly rising in popularity. Through this research study, I hope to increase awareness of FMB in the public eye, especially in terms of any potential fitness and health benefits. Defining physical activities in terms of such potential benefits is important to provide activity options for an increasingly inactive society. Also, no prior research has been conducted in this area making this study an important first step from which further studies may build upon.

**Participants Selection**
You are being asked to participate in this study because you replied to bulletin board postings on North Shore Mountain Biking online magazine (www.NSMB.com) or to posters distributed throughout North Vancouver.

**What is Involved**
If you agree to voluntarily participate in this research, your participation will include an observed ride during which specific physiological measurements will be taken. This meeting will take place at a pre-specified time at the first gate on Fromme Mountain in North Vancouver, BC. This meeting will involve filling out surveys and obtaining preliminary readings of your resting heart rate, grip strength, leg strength, and blood lactate (a measure of exercise intensity which involves a finger-prick sampling technique). Following these pre-ride measures, you will ascend to Seventh Secret trailhead while heart rate monitors assess your heart rate on a minute-by-minute basis.

At the top of the ascent, your blood lactate level will be assessed again, and will be followed by minute-by-minute heart rate recordings as you continuously ride 7th Secret, Leopard, Kirkford, Crinkum Crankum, Cedar, and Roadside Attraction trails. Participants will be staggered at 20 minute intervals, with the fastest riders entering the trail network first (to help prevent clumping and possible collisions between riders). At the end of Roadside Attraction trail, your grip strength will be assessed immediately upon your arrival, followed by a leg strength measure and post-ride blood lactate assessment. You will be asked to rate your level of exertion by using a standardized number scale. Your time commitment for this portion of the study will be approximately 3 hours.

**Inconvenience**
Participation in this study may cause some inconvenience to you, including exposure to adverse environmental conditions (rain/snow, cold temperatures). The principal researcher will work in concert with the NSMBMA to ensure that the trails are free of ice/snow in advance of the ride portion taking place. If the NSMBMA determines that adverse weather/trail conditions pose a threat to participant safety, the ride portion of the study will be postponed. The study will be designed to run as smoothly and efficiently as possible, but stated time commitments are only estimates and may vary due to extenuating circumstances. Due to the nature of physical activity, a certain level of fatigue may result from participating in this study.

The finger-prick blood lactate sampling method does involve piercing the skin and may result in some discomfort and sensitivity of the fingertips.

Risks
There are some potential risks to you by participating in this research. Physical risks during the ride portion of the study may include (but are not limited to) serious physical injury (broken limbs, head injuries, and internal/external injuries) and/or death. To prevent or to deal with these risks, the following steps will be taken. An inspection of your safety gear and bicycle will precede the ride portion of the study. Secondly, a sweep of the trails will be made prior to the ride portion to ensure no obstacles are present that are not part of the usual trail format. A first aid attendant will be stationed at the bottom of Crinkum Crankum trail to respond quickly to any potential injuries. Volunteers will be posted at key trail junctions, linked by hand-held radios, and will work with riders to ensure all risks are minimized as much as possible. Lastly, all study volunteers will have contact numbers for the North Shore Search and Rescue team, RCMP, and local fire department and paramedic services. In the event of an injury, all costs will be covered by the participant. For this reason, proof of medical coverage must be supplied before participation in the observed ride.

There are additional risks due to the finger-prick blood sampling technique, which will be addressed through the researcher’s adherence to stringent guidelines as laid out by the University of Victoria Biosafety Committee. Such risks may include exposure to harmful and potentially fatal blood-borne pathogens such as (but not limited to) Hepatitis and HIV. To minimize any risk, trained Registered Nurses will be on hand to take the samples and ensure that all procedures are sterile and safe.

Benefits
The potential benefits of your participation in this research include furthering the knowledge of the physical requirements and impact of FMB. This will in turn increase awareness of FMB in the public eye and help define it in terms of any potential health/fitness benefits. Your participation in this first study of FMB will set the basis for future research in the area.

Voluntary Participation
Your participation in this research must be completely voluntary. If you do decide to participate, you may withdraw at any time without any consequences or any explanation. If you do withdraw from the study your data will be removed from the database and not be used for subsequent analyses, unless your express permission is granted.

Anonymity
In terms of protecting your anonymity, the researcher will assign you a participant number which will be used during the analysis of the data. None of your personal or experimental information will be shared or disseminated.
Confidentiality
Your confidentiality and the confidentiality of the data will be protected by the assignment of a participation number and the securing of your personal and experimental information in a locked filing cabinet in the office of the principal researcher’s Supervisor (Dr. David Docherty). Upon the transfer of the paper-based files to computer-based files, the paper files will be shredded. The computer-based files will be kept on a password-protected computer accessible only to the principal researcher. None of your personal or experimental information will be disseminated or shared until the final analysis, wherein your participant number will be used. Due to the ride portion of the study involving participants as a group, confidentiality in terms of participation in the study will be limited, however the steps detailed above will ensure confidentiality of questionnaire responses and data from the observed ride.

Dissemination of Results
It is anticipated that the results of this study will be shared within a published research article, presentations to physiology graduate students at the University of Victoria, and at a physiology conference. Since this is the basis for the principal investigator’s Master’s thesis, the results will be analyzed and written up for this purpose. Print/Internet media and formal reports to Health Canada and the District of North Vancouver are also possible avenues of dissemination. Additionally, the results will be disseminated directly to participants in the study.

Disposal of Data
Paper-based files will be shredded upon the transfer of data to a password-protected computer accessible only to the principal researcher. The computer based files will be kept secure up to a maximum period of 5 years.

Withdrawal from the Study
At any time during the study, you may withdraw without penalty simply by notifying the principal researcher by phone, email, or in person. Your data will not be used in the study analysis.

Contacts
Individuals that may be contacted regarding this study include:

Cam Birtwell, Principal Researcher
E-mail: Birtwell@uvic.ca
Phone: (250) 477-0978

Dr. David Docherty, Supervisor
E-mail: Docherty@uvic.ca
Phone: (250) 721-8375

In addition, you may verify the ethical approval of this study, or raise any concerns you might have, by contacting the Associate Vice-President, Research at the University of Victoria (250-472-4545). Your signature below indicates that you understand the above conditions of participation in this study and that you have had the opportunity to have your questions answered by the researchers.

Name of Participant __________________________ Signature __________________________ Date __________________________
Appendix C

Participant Questionnaire
Freeride Mountain Biking Physiology Study

Participant Questionnaire

Principal Researcher: Cam Birtwell (Birtwell@uvic.ca)

University of Victoria | School of Physical Education
Freeride Physiology Study Questionnaire

Subject #

Age: _______ Gender: _______

Years Mountain Bike Riding: _______

* For the following questions, please check the most relevant answer (unless otherwise specified)

1. Which category best defines your level of riding skill?
   ___ Beginner  ___ Intermediate  ___ Expert

2. What style of mountain biking takes up the majority of your riding time?
   ___ Cross Country  ___ Downhill (racing/training)
   ___ Freeride  ___ Urban

3. What are the main reasons why you participate in mountain biking (tick all that apply)?
   ___ Fitness  ___ Thrills  ___ Stress Release  ___ Enjoyment of Nature
   ___ Challenge  ___ Social (riding with friends)
   Other _______________________

4. What best defines your riding frequency?
   ___ Daily  ___ 4-5 times/wk  ___ 2-3 times/wk  ___ 1 time/wk
   ___ Biweekly  ___ Monthly  Other (please specify): ___________________

5. How long does an average ride last?
   ___ <1 hour  ___ 1 to 2 hours  ___ 2 to 3 hours  ___ 3 to 4 hours
   ___ >4 hours
6. How do you typically get to the trailhead?
   __ Shuttle up   __ Ride up   __ Walk/push bike up

7. If you ride or walk to the trailhead, what Rating of Perceived Exertion (see scale on page 4) do you associate with:
   Walking up ___ RPE   Riding up ___ RPE

8. Do you feel fatigued while riding?
   __ Never   __ Rarely   __ Sometimes   __ Regularly

9. Using the Rating of Perceived Exertion Scale (page 4), what value would you assign to your level of effort while freeriding?
   RPE level: ______

10. Do you feel fatigued after a ride?
    __ Never   __ Rarely   __ Sometimes   __ Regularly

11. What muscle groups do you feel are involved in freeride mountain biking (please tick all that apply)?
    __ Lower Legs   __ Forearms   __ Upper Arms   __ Shoulders
    __ Upper Legs   __ Trunk/Core   __ Upper Back   __ Lower Back

12. Which best describes the physical requirements of freeride mountain biking?
    __ Low   __ Moderate   __ High

*Thank you for completing this survey. Your response will be kept confidential as per the details outlined in the Informed Consent form*
**BORG’S RATINGS OF PERCEIVED EXERTION SCALE**

Adapted from:


<table>
<thead>
<tr>
<th>Rating</th>
<th>Descriptor</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>No exertion at all</td>
</tr>
<tr>
<td>7</td>
<td>Extremely light</td>
</tr>
<tr>
<td>8</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Very light</td>
</tr>
<tr>
<td>10</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Light</td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>Somewhat hard</td>
</tr>
<tr>
<td>14</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>Hard (heavy)</td>
</tr>
<tr>
<td>16</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Very hard</td>
</tr>
<tr>
<td>18</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>Extremely hard</td>
</tr>
<tr>
<td>20</td>
<td>Maximal</td>
</tr>
</tbody>
</table>
Appendix D

Statistical Analyses
Quarter Squat MVIC Pre-Post Paired Comparison

Paired Samples Statistics

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1 Preride Isometric Squat</td>
<td>58.9125</td>
<td>20</td>
<td>12.02937</td>
<td>2.68985</td>
</tr>
<tr>
<td>Postride Isometric Squat</td>
<td>56.7875</td>
<td>20</td>
<td>11.57820</td>
<td>2.58852</td>
</tr>
</tbody>
</table>

Paired Samples Correlations

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1 Preride Isometric Squat &amp; Postride Isometric Squat</td>
<td>20</td>
<td>.934</td>
<td>.000</td>
</tr>
</tbody>
</table>

Paired Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Paired Differences</th>
<th>t</th>
<th>df</th>
<th>Sig. (2tail)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
<td>95% Confidence Interval of the Difference</td>
</tr>
<tr>
<td>Pair 1 Preride Isometric Squat - Postride Isometric Squat</td>
<td>2.12500</td>
<td>4.30460</td>
<td>.96254</td>
<td>.11038</td>
</tr>
</tbody>
</table>
# Handgrip MVIC Pre-Post Comparisons

## Paired Samples Statistics

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>Preride Grip Right</td>
<td>51.9605</td>
<td>19</td>
<td>6.04397</td>
</tr>
<tr>
<td></td>
<td>Postride Grip Right</td>
<td>47.8684</td>
<td>19</td>
<td>6.02735</td>
</tr>
<tr>
<td>Pair 2</td>
<td>Preride Grip Left</td>
<td>48.1818</td>
<td>22</td>
<td>9.20215</td>
</tr>
<tr>
<td></td>
<td>Postride Grip Left</td>
<td>46.1364</td>
<td>22</td>
<td>8.36793</td>
</tr>
</tbody>
</table>

## Paired Samples Correlations

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>Preride Grip Right &amp; Postride Grip Right</td>
<td>19</td>
<td>.733</td>
</tr>
<tr>
<td>Pair 2</td>
<td>Preride Grip Left &amp; Postride Grip Left</td>
<td>22</td>
<td>.910</td>
</tr>
</tbody>
</table>

## Paired Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Paired Differences</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tail)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
<td>95% Confidence Interval of the Difference</td>
</tr>
<tr>
<td>Pair 1</td>
<td>Preride Grip Right - Postride Grip Right</td>
<td>4.0921</td>
<td>4.41054</td>
<td>1.01185</td>
</tr>
<tr>
<td>Pair 2</td>
<td>Preride Grip Left - Postride Grip Left</td>
<td>2.0454</td>
<td>3.82398</td>
<td>.81528</td>
</tr>
</tbody>
</table>
Blood Lactate

1. Original data descriptives and boxplot

<table>
<thead>
<tr>
<th>Group</th>
<th>Valid</th>
<th>N</th>
<th>Percent</th>
<th>Missing</th>
<th>N</th>
<th>Percent</th>
<th>Total</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>original Blood Lactate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-ride</td>
<td>16</td>
<td>16</td>
<td>69.6%</td>
<td>7</td>
<td>7</td>
<td>30.4%</td>
<td>23</td>
<td>100.0%</td>
</tr>
<tr>
<td>Mid-ride</td>
<td>15</td>
<td>15</td>
<td>68.2%</td>
<td>7</td>
<td>7</td>
<td>31.8%</td>
<td>22</td>
<td>100.0%</td>
</tr>
<tr>
<td>Post-ride</td>
<td>14</td>
<td>14</td>
<td>77.8%</td>
<td>4</td>
<td>4</td>
<td>22.2%</td>
<td>18</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Original Blood Lactate

2. Blood lactate descriptives, boxplot, and ANOVA with extreme scores removed

<table>
<thead>
<tr>
<th>Group</th>
<th>Valid</th>
<th>N</th>
<th>Percent</th>
<th>Missing</th>
<th>N</th>
<th>Percent</th>
<th>Total</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood lactate minus extremes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre-ride</td>
<td>15</td>
<td>15</td>
<td>65.2%</td>
<td>8</td>
<td>8</td>
<td>34.8%</td>
<td>23</td>
<td>100.0%</td>
</tr>
<tr>
<td>Mid-ride</td>
<td>14</td>
<td>14</td>
<td>63.6%</td>
<td>8</td>
<td>8</td>
<td>36.4%</td>
<td>22</td>
<td>100.0%</td>
</tr>
<tr>
<td>Post-ride</td>
<td>12</td>
<td>12</td>
<td>66.7%</td>
<td>6</td>
<td>6</td>
<td>33.3%</td>
<td>18</td>
<td>100.0%</td>
</tr>
</tbody>
</table>
Blood lactate minus extremes

![Graph showing distribution of blood lactate minus extremes across groups]

**Oneway**

**Descriptives**

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>95% Confidence Interval for Mean</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower Bound</td>
<td>Upper Bound</td>
<td></td>
</tr>
<tr>
<td>Pre-ride</td>
<td>15</td>
<td>2.1533</td>
<td>0.41208</td>
<td>0.10640</td>
<td>1.9251</td>
<td>2.3815</td>
<td>1.40</td>
</tr>
<tr>
<td>Mid-ride</td>
<td>14</td>
<td>6.4929</td>
<td>3.70726</td>
<td>0.99081</td>
<td>4.3523</td>
<td>8.6334</td>
<td>2.70</td>
</tr>
<tr>
<td>Post-ride</td>
<td>12</td>
<td>3.3833</td>
<td>1.10769</td>
<td>0.31976</td>
<td>2.6795</td>
<td>4.0871</td>
<td>2.00</td>
</tr>
<tr>
<td>Total</td>
<td>41</td>
<td>3.9951</td>
<td>2.90370</td>
<td>0.45348</td>
<td>3.0786</td>
<td>4.9116</td>
<td>1.40</td>
</tr>
</tbody>
</table>

**ANOVA**

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Groups</td>
<td>142.716</td>
<td>2</td>
<td>71.358</td>
<td>13.938</td>
<td>.000</td>
</tr>
<tr>
<td>Within Groups</td>
<td>194.543</td>
<td>38</td>
<td>5.120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>337.259</td>
<td>40</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### Post Hoc Tests

#### Multiple Comparisons

Dependent Variable: Blood lactate minus extremes

<table>
<thead>
<tr>
<th>(I) Group</th>
<th>(J) Group</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
<th>95% Confidence Interval</th>
<th>Lower Bound</th>
<th>Upper Bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-ride</td>
<td>Mid-ride</td>
<td>-4.33952(*)</td>
<td>.84083</td>
<td>.000</td>
<td>-6.0417</td>
<td>-2.6374</td>
<td></td>
</tr>
<tr>
<td>Post-ride</td>
<td></td>
<td>-1.23000</td>
<td>.87632</td>
<td>.169</td>
<td>-3.0040</td>
<td></td>
<td>.5440</td>
</tr>
<tr>
<td>Mid-ride</td>
<td>Pre-ride</td>
<td>4.33952(*)</td>
<td>.84083</td>
<td>.000</td>
<td>2.6374</td>
<td></td>
<td>6.0417</td>
</tr>
<tr>
<td>Post-ride</td>
<td></td>
<td>3.10952(*)</td>
<td>.89012</td>
<td>.001</td>
<td>1.3076</td>
<td></td>
<td>4.9115</td>
</tr>
<tr>
<td>Post-ride</td>
<td>Pre-ride</td>
<td>1.23000</td>
<td>.87632</td>
<td>.169</td>
<td>-5.440</td>
<td></td>
<td>3.0040</td>
</tr>
<tr>
<td>Mid-ride</td>
<td></td>
<td>-3.10952(*)</td>
<td>.89012</td>
<td>.001</td>
<td>-4.9115</td>
<td></td>
<td>-1.3076</td>
</tr>
</tbody>
</table>

* The mean difference is significant at the .05 level.
## RPE Pre-Post Paired Comparison

### Paired Samples Statistics

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>Ascent RPE</td>
<td>14.5533</td>
<td>18</td>
<td>1.53832</td>
</tr>
<tr>
<td></td>
<td>Descent RPE</td>
<td>14.2000</td>
<td>18</td>
<td>1.43372</td>
</tr>
</tbody>
</table>

### Paired Samples Correlations

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Correlation</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1</td>
<td>Ascent RPE &amp; Descent RPE</td>
<td>18</td>
<td>.122</td>
</tr>
</tbody>
</table>

### Paired Samples Test

<table>
<thead>
<tr>
<th></th>
<th>Paired Differences</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>Std. Deviation</td>
<td>Std. Error Mean</td>
<td>95% Confidence Interval of the Difference</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pair 1</td>
<td>Ascent RPE - Descent RPE</td>
<td>.6388</td>
<td>1.9692</td>
<td>.46408</td>
</tr>
</tbody>
</table>
Heart Rate Repeated Measures ANOVA

Within-Participants Factors

Time (22 levels x Heart Rate group)

Between-Participants Factors

<table>
<thead>
<tr>
<th>Value Label</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ascent, Descent, and pHRmax Averages</td>
<td></td>
</tr>
<tr>
<td>Individual Ascent HR</td>
<td>19</td>
</tr>
<tr>
<td>Individual Descent HR</td>
<td>15</td>
</tr>
<tr>
<td>70% Predicted Heart Rate Maximum</td>
<td>19</td>
</tr>
</tbody>
</table>

Multivariate Tests

<table>
<thead>
<tr>
<th>Effect</th>
<th>Value</th>
<th>F</th>
<th>Hyp. df</th>
<th>Error df</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Obs. Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>time</td>
<td>Wilks' Lambda</td>
<td>0.042</td>
<td>32.775</td>
<td>21.000</td>
<td>0.000</td>
<td>0.958</td>
<td>1.000</td>
</tr>
<tr>
<td>Time*HRGroup</td>
<td>Wilks' Lambda</td>
<td>0.015</td>
<td>10.154</td>
<td>60.000</td>
<td>0.000</td>
<td>0.877</td>
<td>1.000</td>
</tr>
</tbody>
</table>

a Computed using alpha = .05
b Exact statistic
c The statistic is an upper bound on F that yields a lower bound on the significance level.
d Design: Intercept+HRGroup
Within Participants Design: time

Tests of Within-Participants Effects

Measure: MEASURE_1

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Obs. Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>time</td>
<td>Sphericity Assumed</td>
<td>39870.774</td>
<td>21</td>
<td>1898.608</td>
<td>47.194</td>
<td>0.000</td>
<td>0.486</td>
</tr>
<tr>
<td>time*HRGroup</td>
<td>Sphericity Assumed</td>
<td>23324.042</td>
<td>42</td>
<td>555.334</td>
<td>13.804</td>
<td>0.000</td>
<td>0.356</td>
</tr>
<tr>
<td>Error(time)</td>
<td>Sphericity Assumed</td>
<td>42241.339</td>
<td>1050</td>
<td>40.230</td>
<td></td>
<td></td>
<td>1.000</td>
</tr>
</tbody>
</table>

a Computed using alpha = .05
Tests of Between-Participants Effects

<table>
<thead>
<tr>
<th>Source</th>
<th>Type III Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
<th>Partial Eta Squared</th>
<th>Observed Power(a)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1152047.224</td>
<td>1</td>
<td>1152047.2</td>
<td>9911.49</td>
<td>.000</td>
<td>.995</td>
<td>1.000</td>
</tr>
<tr>
<td>HRGroup</td>
<td>6846.793</td>
<td>2</td>
<td>3423.396</td>
<td>29.453</td>
<td>.000</td>
<td>.541</td>
<td>1.000</td>
</tr>
<tr>
<td>Error</td>
<td>5811.674</td>
<td>50</td>
<td>116.233</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

a. Computed using alpha = .05

Estimated Marginal Means

1. Ascent, Descent, and pHrmax Averages

<table>
<thead>
<tr>
<th>Ascent, Descent, and pHrmax Averages</th>
<th>Mean</th>
<th>Std. Error</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual Ascent HR</td>
<td>156.343</td>
<td>2.473</td>
<td>151.375 - 161.310</td>
</tr>
<tr>
<td>Individual Descent HR</td>
<td>156.152</td>
<td>2.784</td>
<td>150.560 - 161.743</td>
</tr>
<tr>
<td>70% Predicted Heart Rate Maximum</td>
<td>132.558</td>
<td>2.473</td>
<td>127.590 - 137.526</td>
</tr>
</tbody>
</table>

Post Hoc Tests

Ascent, Descent, and pHrmax Averages

Multiple Comparisons

<table>
<thead>
<tr>
<th>(I) Ascent, Descent, and pHrmax Averages</th>
<th>(J) Ascent, Descent, and pHrmax Averages</th>
<th>Mean Difference (I-J)</th>
<th>Std. Error</th>
<th>Sig.</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual Ascent HR</td>
<td>Individual Descent HR</td>
<td>.1911</td>
<td>3.72377</td>
<td>.959</td>
<td>-7.2883 - 7.6705</td>
</tr>
<tr>
<td>70% Predicted Heart Rate Maximum</td>
<td>Individual Ascent HR</td>
<td>.1911</td>
<td>3.72377</td>
<td>.959</td>
<td>-7.2883 - 7.2883</td>
</tr>
<tr>
<td>Individual Descent HR</td>
<td>Individual Ascent HR</td>
<td>-23.7847(*)</td>
<td>3.49787</td>
<td>.000</td>
<td>16.7590 - 30.6104</td>
</tr>
<tr>
<td>70% Predicted Heart Rate Maximum</td>
<td>Individual Descent HR</td>
<td>-23.7847(*)</td>
<td>3.49787</td>
<td>.000</td>
<td>30.6104 - -16.7590</td>
</tr>
<tr>
<td>Individual Descent HR</td>
<td>Individual Descent HR</td>
<td>-23.5936(*)</td>
<td>3.72377</td>
<td>.000</td>
<td>31.0730 - -16.1142</td>
</tr>
</tbody>
</table>

Based on observed means.
* The mean difference is significant at the .05 level.
Profile Plots

Estimated Marginal Means of MEASURE_1

Ascent, Descent, and
pHRmax Averages
- Individual Ascent HR
- Individual Descent HR
70% Predicted Heart
Rate Maximum
Appendix E

Observed Ride Route