LABORATORY AND FIELD-BASED CORRELATES

OF OFF-ROAD CYCLING PERFORMANCE

By

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The following individuals read and discussed the thesis submitted by student Joshua M. Adams, and they evaluated his presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

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ABSTRACT

The aims of this study were to identify physiologic characteristics among trained off-road cyclists and correlate them with a field-based time trial to determine predictors of live performance. Fourteen trained male off-road cyclists were recruited for this study, and measured for maximum aerobic capacity (VO_{2max}), peak aerobic power (W_{peak}), maximum anaerobic power (W_{max}), time trial performance (sec), and climbing ability (vertical feet per second – VFS). VO_{2max} and W_{peak} were measured during an incremental cycling test to exhaustion, W_{max} was measured during a 30-second Wingate test and time trial, and VFS were measured during a live 1.65 mile uphill mountain bike course. Laboratory and field test variables were taken as absolute values as well as relative values when scaled to body mass and correlated to identify their relationship. Significant correlations ($p = 0.01$) were seen between relative peak power ($W \cdot kg^{-1}$) and time trial performance ($r = -0.803$), absolute VFS ($r = 0.828$), and relative VFS ($r = 0.843$). Relative maximum aerobic capacity ($ml \cdot kg \cdot^{-1} min^{-1}$) was also highly and significantly correlated ($p = 0.01$) with time trial performance ($r = -0.773$), absolute VFS ($r = 0.790$), and relative VFS ($r = 0.775$). Moderate correlations ($p = 0.05$) were demonstrated between absolute peak power and time trial ($r = -0.595$) and absolute VFS ($r = 0.603$). The present results suggest that relative peak power ($W \cdot kg^{-1}$) and relative maximum oxygen consumption ($ml \cdot kg \cdot^{-1} min^{-1}$) are highly predictive of uphill climbing time trial efforts.

Keywords: Aerobic capacity, maximum power, time trial, climbing ability

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CHAPTER 1: INTRODUCTION

Mountain biking, also known as off-road cycling, is any cycling event that takes place off-road on trails, gravel or dirt roads, or in open fields. The sport consists of several events including cross-country, short track, and downhill races, each with their own set of unique characteristics and demands. Over the past two and a half decades, mountain biking has seen large increases in the number of participants starting from 112 registered members in 1983 and growing to over 11,900 registered members in 2007 (USA Cycling, Retrieved April 30th, 2009, from http://www.usacycling.org/news/user/story.php?id=938). Despite the increasing number of competitions and competitors nationally as well as internationally, relatively few studies have investigated predictors of success in off-road cycling performance, especially when compared to traditional road cycling. Part of the challenge posed to researchers attempting to identify various parameters of off-road cycling is that replication in a laboratory setting is nearly impossible. Many factors that make mountain biking unique, also make it difficult to study (i.e., highly variable mountainous terrain, crowded trails and wide variations in exercise intensity). All of the aforementioned factors differ greatly from course to course and from event to event.

Cross-country mountain biking, which became an Olympic event during the Summer Games of 1996 in Atlanta, Georgia, has quickly become the most popular of all off-road cycling events (Baron, 2001). Races are characterized by significant amounts of ascending and descending vertical distances ranging anywhere from 1000 to 2000 feet over the course of a race (Impellizzeri & Marcora, 2007). Contrary to road cycling, the terrain of these courses is typically highly technical and includes large rocks, roots, or logs that must be avoided or negotiated, testing not only physical ability but a rider's bike- handling skills as well (Lee, Martin, Anson, Grundy, & Hahn, 2002). From beginning to end, competitive cross-country races are completed in 2-3 hours and are won by riders posting times of roughly 120-135 minutes (men) and 105-120 minutes (women) over courses ranging from 25-40 kilometers (Gregory, Johns, & Walls, 2007; Impellizzeri & Marcora, 2007; Wilber, Zawadzki, Kearney, Shannon, & Disalvo, 1997). Racing format varies from co-ed to men's and women's races only with men generally covering more distance if separated, explaining the differences in duration.

Other mountain biking competitions include short track and downhill races. Short-track mountain biking closely mimics road cycling criteriums in that the races are much shorter in duration (approximately 20-30 minutes) and typically require the completion of several laps on a three-quarter mile track (USA Cycling, Retrieved May 1st, 2009, from http://www.usacycling.org/news/user/story.php?id=946). Like a road race, competitions begin with a mass start and usually contain a tightly packed group of riders contending for the lead throughout the competition with the overall winner sprinting to the finish. Unlike cross-country, however, short-track courses generally do not include large climbing or downhill portions and more closely resemble bicycle motocross (BMX) tracks with several sharp turns around banked corners and designed jumps.

Downhill courses are an exclusive "gravity race" requiring a single rider to navigate the course as quickly as possible from top to bottom (USA Cycling, Retrieved May 1st, 2009, from http://www.usacycling.org/news/user/story.php?id=946). As a timed event, downhill competitors are often staged and riders generally do not have to worry about encountering any other riders during competition. The duration of a typical downhill race varies from 4-8 minutes and the course includes portions of rapid descents and highly technical obstacles (USA Cycling, Retrieved May 1st, 2009, from http://www.usacycling.org/news/user/ story.php?id=946).

Previous studies have examined factors related to performance in mountain biking. Success during any cycling event is highly dependent on the athlete's ability to meet the demands unique to each competition (Anton et al., 2007). Mass starts, steep climbs, and finishing sprints are present in nearly every cycling event and must be considered when evaluating cycling ability. Several studies have examined correlates of success in road events; however, research into the unique demands of off-road cycling is relatively sparse.

Of the research that does exist, scholars believe that in order to compete at an elite level, mountain bike athletes must display higher than average values for maximum heart rate (HR_{max}), maximum aerobic capacity (VO_{2max}), and aerobic power measured in watts (W). Additionally, off-road cyclists often compete at or above their lactate threshold (LT) and at intensities beyond the point of the onset of blood lactate accumulation (OBLA). Lactate threshold is defined as the point at which exercise induces a 1 $mmol \cdot L^{-1}$ increase in blood lactate above baseline and OBLA is defined as an exercise intensity inducing a blood lactate concentration of 4 $mmol \cdot L^{-1}$ or higher (Padilla, Mujika, Orbananos, & Angulo, 2000). Exercise intensity can also be described in terms of where an individual's LT and OBLA are reached as a percentage of their maximum power output. In other words, how close to maximum effort can an individual work until he or she reaches these metabolic thresholds?

Maximum heart rate, VO_{2max}, and aerobic power (W) are measureable in either a laboratory or field-test setting and include the use of metabolic carts to measure gas exchange (VO_{2max}), portable lactate analyzers (LT and OBLA), reliable heart rate monitors (average or peak HR), and either a manually braked cycle ergometer or an on-bike cyclometer with a rear hub powermeter (average or peak power). The advantage to using a "real time" powermeter when assessing an athlete's power output is that it is possible to get second by second power readings, which can then be used to determine an athlete's mean power output (W_{mean}), maximum power output (W_{max}), and average heart rate (HR_{mean}) during peak power and at points during an event when power demands are highest. This type of equipment makes data collection during competition possible and data collected using mobile ergometers may more effectively demonstrate field conditions, more closely approximating competitive performance (Faria, Parker, & Faria, 2005; Paton & Hopkins, 2001).

Although some authors have suggested that specific measures of performance are better indicators of success (i.e., relative peak power), further investigations into exactly what tests should be performed is crucial (Gregory et al., 2007). Several characteristics including anthropometric measures (weight, lean body mass, and body composition), percentage of energy system contribution during training or competition (aerobic and anaerobic), and specific exercise intensity, all seem to contribute to the success of a mountain biker (Baron, 2001; Gregory et al., 2007; Impellizzeri, Sassi, Rodriguez-Alonso, Mognoni, & Marcora, 2002; Impellizzeri et al., 2005a; Impellizzeri et al., 2005b; Lee et al., 2002; Prins, Terblanche, & Myburgh, 2007; Wilber et al., 1997).

Given that minimal data on these parameters exist among off-road cyclists, more information is needed. Specifically, of the studies conducted, focus has primarily been on nationally and internationally competitive MTB riders and not on locally or regionally competitive riders. This narrow scope only describes the characteristics of an extremely small sample of off-road cyclists and ignores the much larger population of competitors at lower competition levels.

Specific attention has recently been paid to the use of absolute vs. relative measures that are scaled to body mass (Gregory et al., 2007; Impellizzeri et al., 2002; Impellizzeri & Marcora, 2007; Impellizzeri et al., 2005a; Impellizzeri et al., 2005b; Lee et al., 2002; Prins et al., 2007; Wilber et al., 1997). From their findings, researchers have subsequently suggested that relative measures of aerobic capacity and power, and anaerobic power may correlate more closely with success in off-road cycling. Interestingly, these measures have exclusively been scaled to overall body mass and not to fat free mass (FFM), even though body composition among mountain bikers has been reported in the literature (Lee et al., 2002; Wilber et al., 1997). Since laboratory measures are often the most convenient and controllable methods of assessment, identifying the most accurate measures is of utmost importance to sports scientists, coaches, and athletes.

Given the apparent influence of the aforementioned variables on MTB success and the lack of information about these variables in regionally competitive mountain bikers, the purposes of this study are to (a) describe peak aerobic power output, maximum aerobic capacity, maximum anaerobic power, and off-road cycling climbing ability (vertical feet per second) in absolute terms as well as relative to body mass (BM) and (b) to examine the correlation between these variables and race performance time in regionally competitive mountain bike racers. By scaling relative performance measures to body mass, this study aims to add evidence to the sparse data that exist on this growing population.

To achieve the purposes of this study, laboratory and field-based measures are used to describe physiological characteristics of off-road cyclists. Body composition (including body mass, percent body fat, and fat free mass) of each athlete is also determined and used to establish relative values for tests obtained in the lab or in the field. Finally, all measures, relative and absolute, are correlated with field measures obtained through completion of a closed time trial and presented in the results.

Research Questions

The first research question is: What are the sport physiological and anthropometric characteristics of non-elite male mountain bike racers? Secondly, are laboratory-based methods of assessment highly correlated with field-based methods of assessment ($r \geq 0.70$)? Thirdly, are relative measures of fitness better predictors of off-road cycling performance versus absolute measures?

Hypotheses

Based on previous studies conducted with trained off-road cyclists, it is hypothesized that:

1. Compared to other cyclists, regionally competitive mountain bike riders will possess elevated levels of both aerobic and anaerobic fitness as evidenced by their performance in an incremental cycling test to exhaustion, and an anaerobic power test (Wingate test).
2. Climbing ability, determined by a field-based time trial, will significantly and positively correlate with laboratory-based physiological parameters ($r \geq 0.70$).
3. Relative values for all measures (field and laboratory-based) will correlate more highly with overall race performance time than will absolute values.

Delimitations

It is assumed that all participants are in good physical condition and have spent the necessary time training for such cycling-specific tests. Subjects are also assumed to have completed the questionnaire as fully and as accurately as possible and put forth maximal effort during all tests and events. A total of fourteen regionally competitive mountain bike riders with a minimum of 12 months off-road cycling experience were recruited for this study.

Limitations

Given the relatively few number of participants, this study provides one piece of information that builds on prior studies, and aids in the development of future research. Secondly, the sample of cyclists is only a small representation of ability found in not only regional riders, but national and international as well. Cyclists will choose their own equipment to conduct the field test, which will inevitably lead to discrepancies in size, weight, geometry, and suspension of the bicycle.

Definitions

Lactate Threshold

The exercise intensity that elicits an increase in blood lactate concentration of 1 $mmol \cdot L^{-1}$ above baseline (LT).

Maximum Aerobic Capacity

The point at which an individual can no longer increase the amount of oxygen consumption (VO_{2max}).

Maximal Anaerobic Power

The highest observed power output (in watts) produced during a Wingate test (W_{max}).

Onset of Blood Lactate Accumulation

The exercise intensity that elicits a blood lactate concentration of 4 $mmol \cdot L^{-1}$ or greater (OBLA).

Peak Aerobic Power

The highest calculated power (in watts) determined by an incremental cycling test to exhaustion (W_{peak}).

Vertical Feet per Second

This was our method of assessing how quickly participants ascend a simulated cross-country course (VFS). It is also known as “climbing ability.”

CHAPTER 2: LITERATURE REVIEW

The purpose of this literature review was to examine the research related to the study of cross-country mountain biking. Sections of this literature review include: (a) a description of the levels of competition in off-road cycling (i.e., categories), (b) anthropometric profiles of off-road cyclists, (c) physiological profiles of off-road cyclists and (d) positive correlates (predictors) of off-road cycling performance. Special attention was paid to the methodology, results, and implications of prior works, along with a small amount of information gathered from similar studies with road cyclists. This information not only serves as the basis of investigation but also as comparative information to the current study.

Race Categories

Road Racing

In order to assure races with riders of similar ability, road cyclists are grouped by category depending on experience and prior performance. Typically, beginning racers are placed in the Category 5 group until they have accumulated ten races considered mass start (NOTE: This excludes time trials, triathlons, etc.). In order to move up to a Category 4 racer, each rider must submit a record of their starts and results, which are reviewed by a USA Cycling official who then determines their upgrade eligibility. This process is repeated as riders progress through Categories 3, 2, and 1; each with higher prerequisites for upgrading (i.e., performance in national or international events).

<u>Mountain Bike Racing</u>

Unlike road racing, riders entering off-road cycling competitions generally have the ability to choose in which discipline they race. Additionally, there are usually only three levels of MTB racing (beginner, sport, and expert), with varying distances for each group. It is thus up to the competitor to self select their race category based either on desired length of race or competition level.

Anthropometric Profiles of Off-Road Cyclists

Compared to traditional road bikers, male off-road cyclists are significantly lighter, in terms of mass (kg), and leaner in terms of body composition (percent body fat). Lee et al. (2002) found that the average body mass of elite mountain bike competitors was 65.3 kg ± 6.5kg, compared to 74.7 ± 3.8kg among professional road cyclists. In addition, mountain bikers were leaner with an average skin fold sum of 33.9 ± 5.7mm compared to 44.5 ± 10.8mm in road cyclists (Lee et al., 2002). These skin fold values yielded mean body fat estimates of 6.1 ± 1.0% and 7.9 ± 1.8% for mountain and road cyclists, respectively. All three of these anthropometric measurements (e.g., body mass, sum of skin folds, and body fat) were significantly different between road and off-road cycling groups with reported absolute percent differences of 14%, 31%, and 29%, respectively.

Wilber et al. (1997) compared elite male and female riders from both the United States National Off-Road Bicycle Association (NORBA) and the Unites States Cycling Federation (USCF) teams and found that the off-road cyclists were lighter with an average mass of 71.5 ± 7.8kg and 57.5 ± 4.7kg for men and women respectively, compared to 72.6 ± 6.4kg and 60.4 ± 3.6kg for USCF men and women respectively.

When examining lean body mass (LBM), NORBA men and women had 67.3 ± 7.0kg and 49.9 ± 3.8kg of LBM, respectively, compared to 68.4 ± 7.2kg and 53.2 ± 3.0kg for USCF men and women, respectively. Differences in body mass and LBM, however, were statistically non-significant, suggesting that the anthropometric measures between elite road and off-road cyclists are less relevant; even though they may be practically important.

Physiological Profiles of Off-Road Cyclists

Maximal Aerobic Capacity

Previous cycling research is dominated by studies focusing on the attributes, characteristics, and physiological profiles of road cyclists (Glaister, Stone, Stewart, Hughes, & Moir, 2006; Lucia, Joyos, & Chicarro, 2000; Mujika & Padilla, 2001). Research examining these same parameters among off-road cyclists suggests that there are significant and important differences between mountain bikers and other athletes as well as other cyclists. In a study comparing National and World Cup competition level male off-road cyclists to a control group of male sports students, Baron (2001) demonstrated that when compared to non-cycling athletes, mountain bikers had significantly higher values for both aerobic and anaerobic measures. Maximum aerobic capacity (VO_{2max}) for male off-road cyclists was 68.4 ± 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$, whereas values for the control athlete group averaged 53.2 ± 6.4 $ml \cdot kg^{-1} \cdot min^{-1}$ (Baron, 2001). Additionally, the mountain bikers possessed a significantly higher maximal aerobic power index (38% compared to 32%), determined by dividing the average peak power (W_{max}) obtained aerobically through an incremental cycling test, by the average maximum power ($IsoW_{peak}$) obtained anaerobically through repeated bouts of isokinetic cycling and multiplying the result by 100 (Baron, 2001). Mean anaerobic power output during the same isokinetic cycling test was significantly higher in mountain bikers for all cadences (e.g., 50-140 revolutions per minute) compared to the control group (Baron, 2001).

Higher and lower values for aerobic capacity have been reported in other studies examining physiological profiles of off-road cyclists. Impellizzeri et al. (2005a) reported a mean VO_{2max} of 76.9 ±5.3 $ml\cdot kg^{-1}\cdot min^{-1}$ in internationally competitive male mountain bikers, whereas Gregory et al. (2007) demonstrated a maximum aerobic capacity of 64.8 ± 8.2 $ml\cdot kg^{-1}\cdot min^{-1}$ for trained but non-elite male mountain bikers. This VO_{2max} range is common throughout the literature and is useful when identifying the performance level of subjects due to the historical acceptance of aerobic capacity as a positive determinant for success in endurance events.

Incremental Cycling Tests (Peak Power Output)

As previously mentioned, peak power output (W) is a second measurement that is often considered when testing cycling ability. One method of obtaining peak power is through an incremental cycling test on an ergometer, in which the individual is required to maintain a particular cadence (pedal revolutions per minute) while power requirements are increased by predetermined increments, often ranging from 1 $W\cdot kg^{-1}$ every 3 minutes to 30 $W\cdot min^{-1}$ (Anton et al., 2007; Bentley, McNaughton, Thompson, Vleck, & Batterham, 2001). The test is completed when the subject falls below the preset cadence, and final peak power is derived mathematically from the time spent in the last and most demanding stage. These equations are found throughout the cycling literature and vary only slightly depending on the specific protocol. Incremental cycling tests are typically highly reliable among participants unfamiliar with a protocol when given two familiarization sessions (Glaister, Stone, Stewart, Hughes, & Moir, 2003)

Table 1 presents peak power data among male off-road cyclists obtained through incremental cycling tests. Gregory et al. (2007) and Impellizzeri et al. (2005a) reported peak aerobic power among highly trained male riders ranging from 367 to 426 watts. Similar results were reported by Impellizzeri et al. (2005b), Lee et al. (2002), and Prins et al. (2007) who demonstrated a range of peak power among male cross-country MTB riders of 372 to 413 watts. When scaling these measures relative to body mass, power output varies even less among the same subjects with reported figures ranging from 5.1 to 6.6 $W \cdot kg^{-1}$ (Gregory et al., 2007; Impellizzeri et al., 2005a). This level of relative power places these subjects in a performance category ranging from high or elite, to national or international caliber cyclists.

Some authors have compared off-road cyclists and their road counterparts to determine if any differences exist (Table 1). When comparing seven internationally competitive Australian male cross-country riders with seven fully sponsored male professional road cyclists, Lee et al. (2002) found absolute peak power outputs for MTB riders and road cyclists as 413 ± 36 and 431 ± 12 watts, respectively. Absolute maximal oxygen consumption was also higher among road cyclists ($5.4 \pm 0.1\ l \cdot min^{-1}$) compared to MTB riders ($5.1 \pm 0.05\ l \cdot min^{-1}$) (Lee et al., 2002). Interestingly, however, this study also revealed that relative values (scaled to body mass), for power at maximal exercise, lactate threshold, and during a timed laboratory trial of 30-minutes, were higher among off-road cyclists than road cyclists despite higher absolute values among road cyclists; suggesting higher relative aerobic power among mountain bikers than road cyclists (Lee et al., 2002). These data also suggests that in mountain biking, relative measures may be more indicative of off-road cycling ability. It appears as if high power-to-weight ratios are critical for cross-country racing success (Lee et al., 2002).

Table 1 Summary of Incremental Test Results for Male Off-Road Cyclists

Author	Subjects	Method of peak power determination and protocol	Results
Gregory et al. (2007)	N= 11; male elite CC riders	Progressive exercise test $100W + 50W{\cdot}5min^{-1}$	W_{peak} 367.5 (32) $W{\cdot}kg^{-1}$ 5.1 (0.4)
Impellizzeri et al. (2005a)	N=12; male international CC riders	Incremental exercise test $100W + 25W{\cdot}min^{-1}$	W_{peak} 426 (40) $W{\cdot}kg^{-1}$ 6.4 (0.6)
Impellizzeri et al. (2005b)	N=13; male U23 UCI* riders	Incremental exercise test $100W + 40W{\cdot}4min^{-1}$	W_{peak} 392 (35)
Lee et al. (2002)	N=12 male Australian national CC riders	Incremental exercise test $100w + 50W{\cdot}5min^{-1}$	W_{peak} 413 (36) $W{\cdot}kg^{-1}$ 6.3 (0.5)
Prins et al. (2007)	N=8; male CC riders w/2 years experience	Incremental exercise test $3.33W{\cdot}kg^{-1} + 30W{\cdot}2.5min^{-1}$	W_{peak} 372 (37) $W{\cdot}kg^{-1}$ 5.1 (0.4)

*Union Cycliste International

Wingate Test (Average and Maximal Power Output)

The Wingate test is performed using a mechanically braked cycle ergometer on which the individual performs an all-out-effort for 30 seconds; a modified test of 15 seconds is also used (Del Coso & Mora-Rodriguez, 2006). Typically, researchers are able to quantify maximal power, average power, and a fatigue index using the Wingate protocol. Tanaka, Basset, Swensen, & Sampedro (1993) found variations in maximal power based on racing category. For example, male category 2 racers averaged 994.07 W_{max} while category 3 and 4 racers averaged 985.17 and 923.41 W_{max}, respectively (Tanaka et al., 1993). Relative measures of maximal power ($W_{max}{\cdot}kg^{-1}$) also increased with an increase in competition level (e.g., 13.86, 13.55, and 12.80 $W{\cdot}kg^{-1}$ for categories 2 through 4, respectively) (Tanaka et al., 1993). This trend in power differences, although consistent among subjects, was not statistically significant. When examining relative average power (W_{mean}) over the duration of the test, significant differences were seen between category 2 and category 4 cyclists with groups averaging 11.22 and 10.4 $W \cdot kg^{-1}$, respectively (Tanaka et al., 1993). Lastly, fatigue index, described as the amount that power decreased during the trial, was similar between all categories with average percent fatigue values of 34.25, 33.46, and 36.65% for categories 2 through 4, respectively (Tanaka et al., 1993).

Typical maximal power in highly trained athletes from other sports ranges from 10.0 $W \cdot kg^{-1}$ in middle-distance runners to 13.5 $W \cdot kg^{-1}$ in volleyball players (MacDougall, Menger, & Green, 1991). Above average values for anaerobic power in cyclists may be due to one of two conditions: (1) The Wingate test is a highly sport-specific performance test, and (2) certain cycling training protocols, such as high intensity interval training, have been shown to improve all-out sprint performance (Tanaka et al., 1993). Also, the Wingate test is suggested as an acceptable and "important tool for assessing the relative potential of sub-elite competitive cyclists" (Tanaka et al., 1993).

Energy System Considerations

As an activity that extends beyond two hours from start to finish, mountain biking heavily utilizes the aerobic energy system for the production of energy. It is also imperative, however, to consider anaerobic pathways for energy production needed during sudden increases in force requirements (i.e., rapid steep ascents, mass starts, and passing efforts around other riders). Few studies have quantified these contributions in athletes, and to our knowledge only one study describes these contributions among off-road cyclists. Baron (2001) tested 25 elite mountain bikers and 60 control non-cyclist sport students for maximal anaerobic power during several 10-second all-out isokinetic cycling tests at different cadences; a maximal aerobic (incremental) power test was also conducted. Using the power index, calculated by dividing the average maximum aerobic power (W_{max}) by the average maximum anaerobic power ($IsoW_{peak}$) and multiplying the result by 100, Baron (2001) found that this aerobic contribution ranged from 55-60% in the trained group. The power index, which may be a better predictor of aerobic and anaerobic contributions rather than physical fitness levels, considers both aerobic and anaerobic abilities of an individual and presents the data as a ratio. This value helps to identify which energy system an athlete needs to train more, depending on their specific event or sport (Baron, 2001). It was suggested that for optimal performance in off-road cycling events, riders should have a power index of 40-45% (Baron, 2001). In other words, an off-road cyclist should be able to produce 40-45% of their maximum anaerobic power, through aerobic pathways or during aerobic tests (Barron, 2001). Ratios outside of that range require improvements in either maximal power output, or in sustainable aerobic work loads.

Exercise Intensity during Off-Road Cycling

Despite the reported significant aerobic contributions required for successful mountain biking, as well as the extended duration of an event, off-road cyclists typically compete at high percentages of their maximum heart rate (HR_{max}) and aerobic capacity (VO_{2max}). As previously mentioned, this is a testament to the high level of aerobic power possessed by off-road cyclists and to the anaerobic contributions needed to sustain such work rates. Impellizzeri et al. (2002), in a study examining five elite mountain bikers, demonstrated an average working percentage of 90% of HR_{max} over the course of four races ranging from 133-148 minutes in length. Also, the percentage of time spent in the "moderate" or "hard" zone, defined as intensities between the lactate threshold (LT) and the onset of blood lactate accumulation (OBLA), and above OBLA respectively, ranged from 74-88% of the total race time (Impellizzeri et al., 2002). In terms of percentage of VO_{2max}, the same five cyclists recorded an average $\%VO_{2max}$ over the course of four races of 84 ± 3% (Impellizzeri et al., 2002). Such high work rates suggest that elite mountain bikers are exceptionally well trained, both aerobically and anaerobically, and that they are able to sustain near maximum efforts for over two hours.

Wirnitzer and Kornexl (2008) found similar results when examining exercise intensities among seven amateur off-road cyclists during an 8-day marathon cross-country race. Prior to competition, incremental cycling tests were used to determine peak power, VO_{2max}, and heart rates associated with four fixed intensities. Exercise intensities were defined as low, moderate, high, and very high based on blood lactate thresholds of 2, 4, 6, and greater than 6 $mmol^{\cdot L-}1$, respectively (Wirnitzer and Kornexl, 2008). Results from competition illustrated that subjects spent 27-36% of the race at an exercise intensity defined as high and very high as evidenced by heart rates maintained at 79% of laboratory maximum, and 85% of maximum HR during competition (Wirnitzer and Kornexl, 2008). Such evidence suggests that regardless of competition level, work loads specifically in terms of a percentage of maximum are comparable among mountain bikers, and indicative of the significant metabolic demands of cross-country cycling.

Positive Correlates (Predictors) of Performance

With the ultimate goal of exercise scientists and coaches being the assessment of an athlete's current condition and prediction of his or her future performance, many authors have correlated physiological attributes to competition results. Gregory et al. (2007) tested eleven elite male off-road cyclists using a progressive exercise laboratory test and a field-based 15-km time trial. With an average peak aerobic power output of 367.5 ± 32.0 (W) obtained in the lab and an average time trial completion time of 61:33 ± 6:12 (min:sec), variables were correlated to identify their relationship. Absolute measures of power output (W) correlated positively with time trial performance time (r=0.64). When scaled to body mass, however, a much higher correlation was found between relative peak power ($W \cdot kg^{-1}$) and overall time to complete the time trial (r=0.93) (Gregory et al., 2007). Additionally, relative VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) was more highly correlated with TT performance (r=0.80) than was absolute VO_{2max} ($L \cdot min^{-1}$) (r=0.66) (Gregory et al., 2007). The authors therefore suggested that a rider's ability to produce elevated work loads relative to his or her mass may better predict performance compared to absolute measures.

Similar studies have also shown a relationship between lab measures and field-based tests. Impellizzeri et al. (2005b) demonstrated significant relationships between cross-country competition performance (time) and relative physiological variables, including relative peak oxygen uptake ($ml \cdot kg^{-1} \cdot min^{-1}$) (r=0.62), overall peak power (W) (r=0.76), power at OBLA (W_{OBLA})(r=0.89), and power at LT (W_{LT}) (r=0.86). These findings are further evidence of the importance of examining physiological measures relative to body mass as well as metabolic intensity levels when assessing off-road cycling ability. These same physiological variables were further correlated with performance time when scaled to body mass raised to a factor of 0.79, which takes into account weight differences among individuals. Accounting for this difference in body mass, correlations between competition time and peak oxygen uptake ($ml \cdot kg^{-1} \cdot min^{-1}$), overall peak power (W), power at OBLA, and power at LT (W_{LT}) increased to $r = 0.68$, $r = 0.87$, $r = 0.94$ and $r = 0.90$, explaining 80% of the variance in time trial performance (Impellizzeri et al., 2005b). Scaling to a body mass raised to a factor of 0.79 is thought to enhance relationships based on allometric scaling of energy requirements during uphill cycling (as cited in Impellizzeri et al., 2005a).

In highly elite MTB riders, correlations between physiological measures and performance are not always as clear. Impellizzeri et al. (2005a) demonstrated only moderately significant correlations between laboratory variables and cross-country performance when examining fifteen internationally competitive male mountain bikers. Most notably, relative power output ($W \cdot kg^{-1}$) and oxygen consumption ($ml \cdot kg^{-1} \cdot min^{-1}$) at the respiratory compensation point (RCT) showed correlations of $r = -0.63$ and $r = -0.66$, respectively (Impellizzeri et al., 2005a). The respiratory compensation point was defined as “an increase in Ve/Vo_2 and Ve/Vco_2, the second sustained rise in excess CO_2, and the second increase in the slope of the Vco_2 v Vo_2 plot” and was included in data collection due to its significance among gas exchange thresholds (Impellizzeri et al., 2005a). Relatively low correlations, explaining only 40% of the variance, were attributed to the high level of homogeneity among participants. Moreover, it was suggested that the aerobic-anaerobic transition be further examined, with special attention paid to the anaerobic contributions to off-road cycling performance (Impellizzeri et al., 2005a).

In order to more accurately predict performance, the development of sport-specific tests is essential. Early studies have attempted to develop cycling tests that would more accurately predict mountain bike performance. Unlike road cycling, cross-country mountain biking contains a much higher level of variability in both terrain and intensity. Prins et al. (2007), in an effort to develop such a test, compared both field and laboratory tests to competition performance in eight competitive male MTB riders. Subjects competed in an outdoor competition, and performed an incremental cycling test, a 1-kilometer time trial, and two variable fixed intensity conditions. Variable fixed-intensity trials were designed using each subject's maximum heart rate and peak power output obtained via the incremental cycling test. Subsequently, a simulated course was designed and implemented using relative percentages of each participant's HR and peak power. The course was also designed to include "rest periods" (portions of lower intensity), which are expected features during a mountain bike competition (Prins et al., 2007). Finally, the simulation was modeled after the average time for participants to complete one lap of the original competition course (26 minutes). The first condition required a single simulated lap, while the second condition required two laps (52 total minutes).

There was no significant difference between competition lap times and time trial lap times (Prins et al., 2007). Additionally, relative peak aerobic power ($W \cdot kg^{-1}$), when scaled to body mass was highly correlated with live competition time (min) (r=-0.83) and time trial performance (min) (r=0.83), which accounted for 70% of the variance (Prins et al., 2007). Of note, however, neither absolute nor relative values for maximal oxygen consumption (VO_{2max}) were significantly related to competition or time trial performance (outdoor tests). These findings suggest that when assessing MTB ability, it may be more important to consider measures of peak aerobic power output during an incremental cycling test than values of maximum oxygen consumption. Therefore, maximum oxygen consumption, though important, may contribute less to performance prediction in outdoor tests than the peak aerobic power output during the same test, despite the documented high aerobic demands of cross-country cycling.

Although there are several studies that assess relative physiological variables scaled to overall body mass in off-road cyclists, there are no studies to date that scale measures to fat free mass (FFM) or lean body mass (LBM). Since body composition among mountain bikers has been reported in the literature, along with the belief that body weight affects a cyclists climbing ability, it stands to reason that relative measures scaled to LBM may also demonstrate significant relationships with other variables.

Climbing ability itself is another variable that has received virtually no attention among mountain biking research. As previously discussed, a vast majority of time spent competing in a typical cross-country mountain bike race is ascending great vertical distances, yet to the best of our knowledge, no studies have assessed this ability directly among the MTB population. Tests that provide information on a cyclist’s ability to ascend a vertical distance at a given rate may prove useful in mountain bike research and athlete assessments. From the previous literature review, no such tests were found. Due to this oversight in the existing literature, a “vertical feet per second” (VFS) assessment is included in the current study in an attempt to describe climbing ability within our subjects.

CHAPTER 3: METHODS

Subjects

Subjects participating in the Coyote Classic mountain bike race in Boise, Idaho were recruited to participate in this study via emails and a list-serve notification of this project. Male off-road cyclists (N=14) ranging in age from 20-55 years with a minimum of 12 months of training experience were selected for this study. Each participant was part of a local club or team and regionally competitive, participating in a minimum of two events during the previous cycling season and finishing within the top 30% of their respective class in at least one race. Also, average weekly training volume was considered (minimum of 5 hrs per week) when selecting subjects, and all testing was done within the competitive season. All participants were fully informed of the aims of the study, laboratory and field-testing procedures, and the potential risks and benefits incurred through testing. This project was approved by the Institutional Review Board of Boise State University, and informed consent was obtained from each subject.

Experimental Design

Data collection for this study was separated into four days during which either laboratory testing or field testing was performed. Each testing session was separated by 48 hours during which subjects were asked to (a) refrain from vigorous activity, (b) maintain a normal diet, and (c) sustain adequate hydration levels. Subjects were encouraged to put forth maximal effort during all tests and allowed to withdraw from testing at any point and for any reason. All anthropometric testing was performed on the Boise State University campus (Boise, ID) in the Human Performance Laboratory. Incremental cycling tests as well as Wingate Tests were conducted at the Idaho Sports Medicine Institute (Boise, ID). The field-based time trial was completed in the Boise City foothill trail system on a section of the Homestead trail (#12).

Procedures

Day 1 - Anthropometric and Training Information

On day one, subjects reported to the Boise State University campus Human Performance Laboratory for anthropometric measurements, including height (cm), weight (kg), and body composition (% body fat). Both height and weight of each subject were measured using a standing physician scale and stadiometer (Healthometer, Healthometer Inc, Bridgeview, Illinois, USA). All participants were measured without shoes and in minimal clothing.

Body composition was determined using under water weighing techniques described by Hoeger & Hoeger (2008). Subjects were instructed to wear bathing suits or compression shorts that were form-fitting and limited the trapping of air within the suit. After entering the under-water weighing device (EXERTECH Body Density Measurement Systems), participants submerged themselves completely while in a seated position and exhaled fully and completely. Once the subject was unable to expel any more air, a hand signal was used to notify researchers. Once the signal was given, body weight measurements were taken and used to calculate body composition. Eight to ten trials were completed, with the average under-water weight between the three heaviest trials being used for body composition determination. Percent body fat (%BF) was then calculated using the Siri equation (Hoeger & Hoeger, 2008):

$$\%BF = [495\text{-}BD] - 450$$

where BD (body density) was determined by the formula:

$$BD = \frac{BW}{\frac{BW-UW}{WD} - RV - .1}$$

where BW is body weight in kilograms, UW is the calculated average underwater weight in kilograms, WD is water density calculated from its temperature during testing, and RV is estimated residual lung volume (Hoeger & Hoeger, 2008). All calculations were performed using attached software (EXERTECH Weighing and Densitometry Program. Version 2), which displayed both underwater weight for each trial and %BF based on the calculated average of the 3 heaviest trials.

After all anthropometric measurements were recorded, each subject was asked to complete a questionnaire detailing their training habits. This survey provided information concerning the frequency, duration, intensity, and mode of training. Data collected here were used to more accurately describe the current subject sample and their training habits.

Day 2 - Maximum Aerobic Capacity

Maximal oxygen consumption has long been the gold standard in determining success in endurance athletes (Bentley, Wilson, Davie, & Zhou, 1998; Bjorklund, Pettersson, & Schagatay, 2007). To determine VO_{2max}, an incremental cycling test was conducted on a mechanically braked cycle ergometer (Lode, Excalibur Sport, Netherlands) at the Idaho Sports Medicine Institute (Boise, Idaho). Proper adjustments were made to the set up of the bike in order to match each rider's normal riding position. Subjects began by warming up for a period of ten minutes at a self-selected pace. Initial load was set to 100 W and increased by 50 W every two minutes until volitional exhaustion or the subject was unable to maintain their cadence. Cadence, load starting point, and increase requirement selection was based on previous studies by Impellizzeri et al. (2005b) and Wilber et al. (1997) who suggested that mountain bikers prefer, and often utilize, higher pedaling rates because they cause less neuromuscular fatigue. Failure to maintain a selected cadence during the test resulted in termination of the test.

Direct gas analysis was performed using a ParvoMedics Truemax 2400 Metabolic Measurement System (ParvoMedics, Sandy, UT), which continuously measured inspiration of oxygen (VO_2) and the expiration of carbon dioxide (VCO_2). Calibration of the metabolic cart was conducted prior to each trial using standard gas, and the pneumotach flowmeter was calibrated with a 3-liter calibrating syringe. Subjects were required to wear a mask and nose clips to ensure that all expired air was collected. Heart rate was monitored using a wireless wrist unit with chest belt (Polar, USA), and heart rates were recorded during the last 10 seconds of each stage.

Automated direct gas analysis results were calculated by an on-line computer and a cumulative test report was generated. Participants were assumed to have reached their peak oxygen consumption based on meeting two of three criteria: (a) a heart rate (HR) equal to or greater than 90% of their age predicted maximum HR, (b) a respiratory exchange ratio (RER) greater than 1.1 (indicating anaerobic metabolism), and (c) an oxygen consumption plateau, defined as "<150 ml·min^{-1} difference in oxygen consumption, for the final two stages" (Prins et al., 2007). When an individual was unable to complete a stage during the incremental test, peak power was calculated using the following equation:

$$W_{peak} = W_f + (t/120 \cdot 50)$$

where W_f is the last completed stage in watts, and *t* is the time (sec.) spent in the final stage (adapted from Impellizzeri et al., 2005b).

Day 3 - Maximum Anaerobic Power

Maximum power output is produced through stored ATP, phosphorcreatine (PCr) utilization, and glycogenolysis resulting in the production of lactate (Faria et al., 2005). The Wingate test, one of the mostly widely accepted and used determinants of anaerobic power, was used to obtain values for maximum power (W_{max}), average power (W_{mean}), and fatigue rate (expressed as a percentage of power lost from peak power over the duration of the protocol) (Del Coso & Mora-Rodriguez, 2006). Validity and reliability of the Wingate Test, a well-accepted measure of anaerobic power, have been described by Minahan, Chia, & Inbar (2007).

All tests were performed on the same mechanically braked cycle ergometer (Lode, Excalibur Sport, Netherlands). Prior to each test, the ergometer was adjusted according to each individual's height, and modifications in geometry were made to mimic the dimensions of each subject's respective bicycle. The cycle ergometer was fitted with clipless pedals of each athlete's preference, competition handle bars, and a racing saddle to closely resemble most participants' own equipment.

Testing procedures followed the protocol described by Del Coso and Mora-Rodriguez (2006) in which each subject began by warming up at a resistance of 0.5kg for five minutes. After the warm-up period, a load equal to 0.075kg per kg of body mass was rapidly added. As the load was added, each participant produced an all-out-effort for a period of thirty seconds. Verbal encouragement was provided to aid in a maximum effort of each subject. During the trial, power outputs were recorded every five seconds and used to determine maximum anaerobic power, average power, and fatigue rate (described as the decrease in watts per second for the duration of the test).

Day 4 - Vertical Feet per Second (VFS)

On day 4, each subject completed a 2.72-kilometer (1.65 mile) time trial on their own selected mountain bike. A detailed profile of the course, including distance and change in elevation, is presented in Figure 1. Development of the course was conducted through the use of three mock trials using a Garmin Forerunner 405HR GPS unit. Careful consideration was given to technical aspects of the course to eliminate the confounding effects of difference in bike-handling skills of each rider. In other words, an effort was made to utilize a moderately smooth course without obstacles that would require riders to dismount their bicycle. This is not to say, however, that the course was completely void of obstacles. Easy to moderately technical portions were included to serve as a consistent representation of how a typical cross-country ascent may look. Course length was designed to elicit both aerobic and anaerobic metabolic pathways with an estimated time of completion ranging from 14-18 minutes.

Figure 1 **Time trial profile (** Device: Garmin Forerunner 405Hr. Version 2.15*)**

On the fourth day of testing, all subjects arrived at the TT site and were briefed on the testing protocol. Each rider was allowed to select his own bicycle and to make all adjustments (tire pressure, suspension changes, etc.) that he felt necessary with the assumption that each rider would post his best finishing time possible based on his own preferences. The warm up routines were also unique to each cyclist. To limit the possibility of any rider blocking another on a narrow section of single-track, riders were staged 2 minutes apart. Overall completion time was recorded in seconds.

Each subjects' absolute vertical feet per second variable was determined by the rate at which they climbed the total elevation by the equation:

$$VFS = X \cdot t^{-1}$$

where X is the total vertical feet ascended, and *t* is the time in seconds to complete the ascent. Relative measures of VFS were calculated using the equation:

$$VFS = [X \cdot t^{-1}] \cdot kg^{-1}$$

where X is the total vertical feet ascended, *t* is the time in seconds to complete the ascent, and kg is the subject's body mass in kilograms.

Statistical Analysis

All anthropometric, physiological, and competition variables were entered into the Statistical Package for the Social Sciences (SPSS for Windows version 19.0, SPSS Inc.). To answer research question one, descriptive statistics and variance were calculated and displayed as means ± standard deviations (SD) for anthropometric and physiological characteristics of all subjects. To answer research question two, Pearson's correlations were determined between all predictor variables (anthropometric data and lab tests) and the criterion variable (time trial). Research question three was answered based on which of the field tests most highly correlated with time trial performance when compared to all other variables. Finally, all variables were correlated with each other to identify any relationships that existed between tests.

CHAPTER 4: RESULTS

Subjects

A total of 14 subjects were recruited to participate in laboratory and field-based cycling tests. Self assessment of these athletes was gathered through a pre-study questionnaire detailing cycling ability (determined by race category), as well as training habits (determined by hours trained per week), including cycling-specific training, cross training, etc., over the course of the previous year. Cycling experience was then determined based on years spent competing and by races completed per year (see Table 2).

Results of the questionnaire showed that six cyclists were designated as professional or expert (Level 1), seven reported intermediate or sport (Level 2), and one cyclist was determined to be beginner (Level 3). The average time spent racing in a minimum of one off-road cycling event was 5.86 $\pm$ 3.72 years, with a minimum of 1 year and a maximum of 13 years racing experience. Participants spent an average of 11.29 $\pm$ 2.87 hrs per week training, and 3 individuals utilized a coach regularly. This volume of training was considered “peak training hours,” which took place during the spring and summer months. The majority of riders (e.g., 11 out of 14 subjects) reported year round training; however, all participants indicated maintaining at least moderate activity during the months not spent actively training.

Table 2 Race Category and Training Habits

Subject	Category	Years Racing	Hours Training/Wk	Use of Coach	Year Round Training
1	expert	7	10	Yes	Yes
2	beginner	1	9	No	Yes
3	expert	3	14	Yes	No
4	sport	3	8	No	Yes
5	expert	6	15	No	Yes
6	sport	10	12	No	Yes
7	sport	1	11	No	Yes
8	sport	7	8	No	Yes
9	sport	5	10	No	No
10	sport	4	14	No	No
11	expert	12	10	No	Yes
12	sport	4	15	No	Yes
13	expert	6	7	No	Yes
14	expert	13	15	Yes	Yes
Mean		5.86	11.29		
SD		3.72	2.87		
Min		1	7		
Max		13	15		

Full anthropometric data are presented in Table 3. Two subjects (numbers 7 and 10) failed to complete body composition testing. The average participant age was 37.86 $\pm$ 9.06 y (range = 25 to 53 y). Average height (cm) was 179.43 $\pm$ 6.17 (range = 170 to 191) with an average body mass (kg) of 75.08 $\pm$ 7.48 (range = 66.1 to 86.8). Calculated average body composition (% body fat) was 13.3 $\pm$ 6.41 (range = 2.1 to 23.6) with an average lean body mass (kg) of 63.4 $\pm$ 5.4 (range = 52.25 to 72.54).

Table 3 Descriptive Characteristics of the Sample

Subject	Hgt (cm)	Wgt(kg)	LBM(kg)	% BF	Age
1	175	66.8	61.92	7.3	31
2	184	74.3	63.68	14.3	46
3	180	72	60.48	16	29
4	178	67	65.59	2.1	27
5	170	66.1	58.23	11.9	32
6	188	68.4	52.26	23.6	25
7*	183	84.5	-	-	44
8	175	79.1	60.59	23.4	50
9	175	84.1	69.30	17.6	38
10*	191	86.8	-	-	31
11	179	77.5	66.50	14.2	36
12	185	74.5	67.57	9.3	53
13	171	67	62.11	7.3	47
14	178	83	72.54	12.6	41
Mean	179.43	75.08	63.40	13.30	37.86
SD	6.17	7.48	5.40	6.41	9.06
Minimum	170	66.1	52.25	2.1	25
Maximum	191	86.8	72.54	23.6	53

* Subjects not completing body composition analysis

Laboratory Tests

Maximum Aerobic Capacity

Full incremental cycling test results for VO_{2max} are presented in Table 4. The average absolute maximum aerobic capacity ($L \cdot min^{-1}$) was 4.82 $\pm$ 0.53 (range = 4.14 to 5.81). When scaled to body mass, participant average relative aerobic capacity was 64.33 $mL \cdot kg^{-1} \cdot min^{-1}$ $\pm$ 6.31 (range = 52.8 to 74.10). The average maximum metabolic equivalent (MET) obtained during VO_{2max} testing was 18.39 $\pm$ 1.81 (range = 15.10 to 21.20) across subjects.

Table 4 VO_{2max} Results for the Sample

Subject	Absolute VO_{2max} (L/min)	Relative VO_{2max} (ml/kg/min)	Mets
1	4.82	72.10	20.60
2	4.50	60.50	17.30
3	5.34	74.10	21.20
4	4.76	71.00	20.30
5	4.25	64.30	18.40
6	4.14	60.50	17.30
7	4.92	58.20	16.60
8	4.17	52.80	15.10
9	4.72	56.10	16.00
10	5.81	66.90	19.10
11	5.49	70.20	20.10
12	4.64	62.30	17.80
13	4.43	66.00	18.90
14	5.44	65.60	18.70
Mean	4.82	64.33	18.39
SD	0.53	6.31	1.81
Minimum	4.14	52.80	15.10
Maximum	5.81	74.10	21.20

Peak Aerobic Power

Full aerobic peak power results are presented in Table 5. Average peak aerobic power in watts (W) during the incremental cycling test was 390.64 $\pm$ 42.32 (range = 333-481) with an average relative peak power ($W \cdot kg^{-1}$) of 5.22 $\pm$ 5.22 (range = 4.21-6.21).

Table 5 Aerobic Power Results for the Sample

Subject	Absolute Peak Aerobic Power (W)	Relative Peak Aerobic Power (W/kg)
1	415	6.21
2	356	4.79
3	430	5.97
4	362	5.4
5	363	5.49
6	350	5.12
7	395	4.67
8	333	4.21
9	385	4.58
10	481	5.54
11	442	5.65
12	387	5.19
13	350	5.22
14	420	5.06
Mean	390.64	5.22
SD	42.32	0.55
Minimum	333	4.21
Maximum	481	6.21

Maximum Anaerobic Power

Full Wingate results are presented in Table 6. Average maximum power in watts (W) during the Wingate test was 991.79 $\pm$ 147.61 (range = 760 to 1203) with an average relative maximum power ($W \cdot kg^{-1}$) of 13.21 $\pm$ 1.46 (range = 11.30 to 16.80). Average mean power (W) over the duration of the test was 653.79 $\pm$ 76.72 (range = 566 to 804) with an average relative mean power ($W \cdot kg^{-1}$) of 8.73 $\pm$ 0.69 (range = 7.60 to 9.90). Average decline in power output ($W \cdot sec^{-1}$), described as a fatigue index (drop in power from peak power to the completion of the test), was 18.97 $\pm$ 5.94 (range = 8.9 to 30.7).

Table 6 Maximum Power Results for the Sample

Subject	Max Power (W)	Mean Power (W)	Fatigue Index ($W \cdot sec^{-1}$)	Rel. Max Power ($W \cdot kg^{-1}$)	Rel. Mean Power ($W \cdot kg^{-1}$)
1	899.00	596.00	14.20	13.50	8.90
2	914.00	566.00	18.00	12.30	7.60
3	921.00	610.00	17.80	12.80	8.50
4	1123.00	660.00	26.60	16.80	9.90
5	870.00	579.00	17.60	13.20	8.80
6	777.00	594.00	11.10	11.40	8.70
7	1143.00	707.00	25.30	13.50	8.40
8	1010.00	605.00	19.50	12.80	7.60
9	1120.00	787.00	18.60	13.30	9.40
10	1146.00	701.00	21.90	13.20	8.10
11	1203.00	710.00	30.70	15.50	9.20
12	891.00	636.00	14.50	12.00	8.50
13	760.00	598.00	8.90	11.30	8.90
14	1108.00	804.00	20.90	13.30	9.70
Mean	991.79	653.79	18.97	13.21	8.73
SD	147.61	76.72	5.94	1.46	0.69
Minimum	760.00	566.00	8.90	11.30	7.60
Maximum	1203.00	804.00	30.70	16.80	9.90

Notes:
Rel. Max Power – Relative maximum power when scaled to body mass
Rel. Mean Power – Relative average power when scaled to body mass

Field Test

Time Trial

All participants who attempted the time trial did so without any report of mechanical or technical problems. Two subjects failed to attempt the time trial due to injury outside of testing. Course conditions were noted as being both dry and without compromise. Additionally, no rider reported the need to dismount during the time trial for any reason; thus, all attempts were completed without interruption.

Full time trial results are presented in Table 7. Average participant time to complete the time trial (seconds) was 944.17 $\pm$ 126.60 (range = 746 to 1206). The average for absolute vertically ascended feet ($ft \cdot sec^{-1}$) was 0.93 $\pm$ 0.12 (range = 0.72-1.16) with an average relative VFS ($ft \cdot sec^{-1} \cdot kg^{-1}$) of 0.0126 $\pm$ 0.0022 (range = 0.0096 to 0.073).

Table 7 Time Trial Results for the Sample

Subject	Time Trial (sec)	Absolute VFS ($ft \cdot sec^{-1}$)	Relative VFS ($ft \cdot sec^{-1} \cdot kg^{-1}$)
1	746.00	1.16	0.0173
2	1206.00	0.72	0.0096
3*	-	-	-
4	946.00	0.91	0.0136
5	927.00	0.93	0.0141
6	982.00	0.88	0.0128
7*	-	-	-
8	1087.00	0.79	0.0100
9	1054.00	0.82	0.0097
10	886.00	0.97	0.0112
11	820.00	1.05	0.0136
12	953.00	0.91	0.0122
13	891.00	0.97	0.0145
14	832.00	1.04	0.0125
Mean	944.17	0.93	0.0126
SD	126.60	0.12	0.0022
Minimum	746.00	0.72	0.0096
Maximum	1206.00	1.16	0.0173

*Subjects not completing time trial

Correlations

Full correlation data between laboratory and field tests are presented in Table 8. Most notably, relative peak power was most highly correlated with all measures of time trial performance with r-values of -0.803, 0.828, and 843, for time trial, absolute VFS, and relative VFS, respectively. Additionally, relative maximum aerobic capacity (VO_{2max}) and METS were significantly correlated with Time Trial (r = -0.773 and -0.770, respectively), absolute VFS (r = 0.790 and 0.787, respectively), and relative VFS (r = 0.775 and 0.778, respectively. Correlations between absolute VO_{2max} and time trial, absolute VFS, and relative VFS were lower than the aforementioned correlations for relative values. Significant correlations were also seen between absolute peak power and time trial (r=0.595) and absolute peak power and absolute VFS (r=0.603). Absolute VO_{2max} and relative mean power during the Wingate were moderately correlated with time to complete the time trial, though these values were statistically insignificant.

Table 8 Correlations Between Laboratory and Field Tests in the Sample(r)

	Time Trial	AbsVFS	RelVFS
AbsVO2	-.519	.521	.032
RelVO2	-.773**	.790**	.775**
Mets	-.770**	.787**	.778**
AbsPPower	-.595*	.603*	.138
RelPPower	-.803**	.828**	.843**
Max Power	-.132	.115	-.299
Mean Power	-.254	.218	-.254
Fatigue Index	-.103	.090	-.169
RelMaxPower	-.276	.263	.184
RelMeanPower	-.543	.495	.441

** Correlation is significant at the 0.01 level (2-tailed)
*Correlation is significant at the 0.05 level (2-tailed)
Notes:
AbsVO2 – Absolute $VO2_{max}$ ($L \cdot min^{-1}$)
RelVO2 – Relative VO_{2max} ($mL \cdot kg \cdot min^{-1}$)
Mets – Metabolic Equivalents
AbsPPower – Peak aerobic power during incremental cycling test
RelPPower – Relative peak aerobic power during incremental cycling test
Max Power – Maximum power output during Wingate Test (W)
Mean Power – Average power output during Wingate Test (W)
Fatigue Index – Percent decline in power output from beginning to end of Wingate
RelMaxPower – Maximum power scaled to body mass (W/kg)
RelMeanPower – Average power scaled to body mass (W/kg)

CHAPTER 5: DISCUSSION

The purpose of this study was to examine the physiological and anthropometric characteristics of non-elite male mountain bike racers, compare lab-based testing methods to field-based methods, determine which measures are the best predictors of time trial success, and examine whether relative measures of fitness are better predictors of cycling performance compared to absolute measures. The most important findings of this study were that: (a) these athletes were comparable to previously studied samples and demonstrated high absolute and relative aerobic capacity and power, as well as anaerobic power, (b) time trial (seconds) was significantly correlated with relative VO_{2max} and METS, and both absolute and relative peak aerobic power, meaning that relative VO_{2max}, METS, absolute peak power, and relative peak power are effective predictors of performance on field tests that simulate racing conditions, and (c) relative VO_{2max} and relative peak aerobic power were better predictors of off-road cycling performance on a time trial compared to absolute VO_{2max} and absolute peak aerobic power.

The 14 non-elite riders in this sample who had been racing an average of more than 5 years and who trained approximately 11.29 $\pm$ 2.87 hours per week were similar to previous samples of non-elite riders (age = 37.86y; height = 179.43cm weight = 75.08kg; %bf = 13.3). When reviewing anthropometric data specifically, all participants demonstrated values for height, weight, lean body mass, and body composition that were consistent with a high level of training. This is in agreement with Lee et al. (2002) who has described both physical and physiological characteristics of competitive mountain bikers. These results confirm an appropriately selected subject pool such that valid measures were taken and results can be generalized accordingly. This study also provides additional data describing the anthropometric uniqueness of off-road cyclists.

The application of laboratory tests to determine athletic ability in endurance athletes has been a mainstay of assessment for some time now. The challenge, however, has been linking lab results to competitive performance. In off-road cycling, specifically cross-country mountain biking, measures of maximum aerobic capacity, peak aerobic power output, maximum anaerobic power and the relative expression of these numbers based on rider weight have been identified as useful assessment tools (Gregory et al., 2007; Impellizzeri et al., 2002; Impellizzeri & Marcora, 2007; Impellizzeri et al., 2005a; Impellizzeri et al., 2005b; Lee et al., 2002; Prins et al., 2007; Wilber et al., 1997). The common finding of many recent studies has been that relative measures (when scaled to body mass), rather than absolute values are more valuable for determining cycling ability (Gregory et al., 2007). This is, in part, thought to be the result of improved exercise economy or efficiency in the case of higher relative lab values. Despite this evidence, it is a challenge to apply lab findings to live competition. This investigation was designed to include a field cycling test and determine its usefulness in assessing off-road cycling ability, and what its relationship was to laboratory test values.

Although time trial formats are often used in stage races on the road, similar competitions are rarely, if ever, completed by cross country mountain bike riders. Of those that do occur, to our knowledge, they are primarily executed by downhill mountain bikers and assess a rider's ability to descend rather than ascend. Thus, this study included an uphill time trial to provide rationale for its use.

Both mean values for absolute and relative VO_{2max}, 4.82 $L \cdot min^{-1}$ and 64.33 $ml \cdot kg^{-1} \cdot min^{-1}$, respectively, are similar to prior studies that used an incremental cycling test to exhaustion. Specifically, Baron (2001) demonstrated a mean relative VO_{2max} of 68.4 $\pm$ 3.8 $ml \cdot kg^{-1} \cdot min^{-1}$ among a group of National and World Cup mountain bikers, and Gregory et al. (2007) studied a sample of trained but non-elite male mountain bikers and reported their VO_{2max} as 64.8 $ml \cdot kg^{-1} \cdot min^{-1}$.

Peak aerobic power obtained during the same incremental cycling test is consistent with previous research as well. From the sample, an average absolute peak power of 390.64 W was observed. This most closely mirrors Impellizerri et al. (2005b) who reported an average peak power among 13 male U23 UCI riders of 392 W. Additionally, our sample demonstrated an average relative peak aerobic power of 5.22 $W \cdot kg^{-1}$, which is in accordance with research done by both Gregory et al. (2007) and Prins et al. (2007) who showed average relative peak power of 5.1 $W \cdot kg^{-1}$ among 11 elite cross-country riders and 8 cross-country riders with 2 years racing experience respectively (see Table 1).

Maximum anaerobic power, when obtained through a Wingate test, was also in agreement with earlier research. Among the current sample, subjects had an average maximal power output of 991.79 W, which most closely resembles the values obtained by Tanaka et al. (1993) who demonstrated an average max power of 994.07, 985.17, and 923.41 among category 2, 3, and 4 cyclists, respectively. Relative max power reported by Tanaka et al. (1993) was also closely related to the current sample averaging 13.21

$W \cdot kg^{-1}$, compared to 13.86, 13.55, and 12.80 $W \cdot kg^{-1}$ among category 2, 3, and 4 cyclists, respectively (Tanaka et al., 1993).

The second finding of this study was that lab-based values positively correlated with field-based measures of cycling performance. More specifically, results show that relative values for maximum aerobic capacity ($ml \cdot kg^{-1} \cdot min^{-1}$) and peak aerobic power ($W \cdot kg^{-1}$) were more highly correlated with time trial performance measures (time in seconds, absolute VFS, and relative VFS) than was absolute VO_{2max} ($L \cdot min^{-1}$) and absolute peak power (W). Of these relationships, relative peak power ($W \cdot kg^{-1}$) when correlated with relative VFS ($ft \cdot sec^{-1} \cdot kg^{-1}$), absolute VFS ($ft \cdot sec^{-1}$), and time trial (sec) demonstrated the highest coefficients (r=0.843, r=0.828, and r=-0.803, respectively). Relative VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$) and absolute VFS ($ft \cdot sec^{-1}$) also demonstrated a significantly high correlation (r=0.790). Looking at relative VO_{2max} and its relationship to time trial (seconds) and relative VFS, correlations of -0.773 and 0.774 were observed. Absolute VO_{2max} was moderately correlated with time trial (seconds) and absolute VFS, r = -0.519 and 0.521 respectively, although this relationship was lower and not statistically significant. There was essentially no relationship between absolute VO_{2max} and relative VFS (r=-0.030).

These findings suggest two unique implications. First, improvements in relative aerobic capacity and peak power may improve cross-country race performance. Second, that assessing a rate of ascent (VFS) may effectively demonstrate a mountain bikers climbing ability. Specifically, improvements in relative aerobic values (VO_{2max} and peak power), either through increasing aerobic performance or through losing body mass while maintaining a given aerobic capacity/power may improve a cyclists exercise economy and thus climbing ability. Therefore, the assessment and development of improved relative aerobic variables should be a priority when training or evaluating cyclists.

The use of a climbing assessment (i.e., VFS) may be an appropriate tool for researchers, coaches, and athletes. Although the concrete value of VFS may show little promise, correlational data does demonstrate a positive relationship between lab values and TT performance. Therefore, athletes and coaches may want to consider utilizing a pre-determined course of their choosing to assess improvements in fitness when laboratory measurements are unavailable. This is particularly useful for coaches and athletes who do not have access or the means to conduct laboratory testing.

An interesting and somewhat unique finding of this study was that relative mean power output ($W \cdot kg^{-1}$) as determined throughout the duration of the Wingate test was more highly correlated with all measures of time trial performance than relative maximum power during the Wingate. When correlations between relative mean power output and overall time trial performance (r=-0.543), absolute VFS (r=0.495), and relative VFS (r=0.441) were examined, correlations were low to moderate. In contrast, correlations between relative maximum power output and time trial performance, absolute VFS and relative VFS were -0.276, 0.263, and 0.186, respectively. This result suggests that a cyclist's ability to maintain high levels of relative power output for a given amount of time (30-seconds) is a more important factor in determining time trial performance than relative peak power during the same test. This finding is in agreement with studies that have suggested higher sustained intensity levels are required of more successful mountain bikers (Impellizzeri et al., 2002; Wirnitzer and Kornexl, 2008).

It is worth noting that absolute VFS was more highly related to relative maximum power output (r=0.263) and relative mean power output (r=0.495) than was relative VFS when scaled to body mass (r = 0.186 and 0.441, respectively). These findings do not concur with studies that have shown higher correlations when lab values are scaled to body mass, rather than taken absolutely (Impellizzeri et al., 2005b). This is also contradictory to the hypothesis of this study, which had assumed that values relative to body mass would more effectively predict field test performance. Ultimately this study shows that the fastest time trial is the fasted ascent, regardless of body mass or body composition.

This evidence then lends itself to the idea that in addition to training cyclists to their upper limit of power output (maximum power), attention should be paid to developing their ability to maintain the highest level of power over a given time (aerobic and anaerobic power). This would make sense, due to the highly variable nature of off-road racing with courses containing several sections requiring a cyclist to utilize a large amount of power for short bursts of time (i.e., short repeated climbs).

Conclusions

In the world of coaching and training, the search for an ideal assessment of athletic ability is often sought. For most sports or competitions, however, the complexity of the event does not lend itself to a single measure of performance other than outcome (winning or losing). This is without a doubt a concept consistent within the sport of off-road cycling.

With the environment of sports science rapidly evolving and new testing methods becoming available, it is not only important to continue searching for these tools but also to validate and use them in conjunction with tests that have proven successful in the past. One conclusion made by this research is that no single test can absolutely define a cyclists ability to perform in a given race or event. Rather, tests must be viewed collectively in order to gain a more global view of an athlete's strengths and weaknesses. With that knowledge in hand, it may be beneficial to train all aspects of cycling ability to include maximum power and the ability to maintain and repeat similar efforts.

A second conclusion that can be made from the current study is that a tool, such as a time trial (VFS), may be useful in determining in part a cyclist's ability outside of the laboratory. Moreover, it may be more useful to determine improvements in fitness or from training when repeated and compared to previous results. For example, in addition to tracking time of VFS, it would be useful to calculate heart rate during this activity to observe changes in heart rate that might occur with consistent training. It may also be helpful to track VFS/HR average during the trial as another measure of fitness that might effectively predict field test performance of off-road cyclists. It is recommended that if a time trial (or similar protocol) is to be used in the assessment of an athlete's ability, it must be frequently performed in order to gauge progress from his or her current training regimen.

Lastly, when looking practically at VFS, both absolutely and relatively, the usefulness is brought into question. Due to the fact that time is the ultimate factor in a race, and the small scale of relative VFS measurements, its value may be difficult to apply to training or assessment. However, it was demonstrated that when compared to lab values, absolute VFS was more highly correlated than was relative VFS, most likely due to the fact that absolute VFS most closely represents overall outcome (time to finish).

The one exception demonstrated in this study was seen when comparing r-values of relative and absolute VFS with relative peak power. Of the two, relative VFS was more highly correlated with relative peak power than was absolute VFS (0.843 and 0.828, respectively), potentially due to the comparison of two relative measures.

One possible solution to the small expression of VFS would be to extrapolate it to a vertical distance over the period of an hour rather than by minute. By doing this, coaches and athletes may have a more practical measure of ability, while correlations should be maintained. This could also allow for a longer time trial (or test efforts), and more general application of the information gathered. Another way to apply VFS may be to use it to judge fatigue or recovery. If prior to a race an athlete has a given VFS on a particular course, and that measure is repeated, faster or slower times may indicate a increased need to recover before the competition. In other words, if before a live competition a cyclist's VFS is decreased, that rider may benefit from a break in training to allow adequate recovery.

Future research into the world of off-road cycling performance may benefit from continued investigations into time trail efforts. If they are utilized, coaches and athletes should carefully evaluate not only the characteristics of the course, but also the characteristics of upcoming races. If possible, it may be most advantageous to perform such tests on the race course itself so as to perfectly match "practice" with "performance." Finally, cross-country race courses offer an extremely high degree of variability from course to course. For this reason, testing and training should follow this principle to develop a wider array of cycling ability, which should theoretically translate to more successful outcomes during competition.

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