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Physiological and anthropometric profiles of elite teen-age cyclists

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Physiological and Anthropometric Profiles of Elite Teen-Age Cyclists

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Dedication

I would like to dedicate my thesis to my family and all of my friends who have supported me during my time in graduate school. Your overwhelming generosity has given me every opportunity to succeed and I will be forever thankful for all that you have done.

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I would like to acknowledge Dr. Michael Saunders for his influence as a mentor during my time at James Madison University. Dr. Saunders has inspired me to be a stronger critical thinker and has consistently been available in times of need. This project would not have been possible without your direction and support.

I would like to acknowledge Dr. Nick Luden and Dr. Chris Womack as members of my thesis committee and past professors. I would like to thank you both for helping me become a more well-rounded student and for your input during the writing process of this project. I have undoubtedly become a better writer as a result of your guidance.

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Abstract

Lenzi D. N., N. D. Luden, C. J. Womack, and M. J. Saunders. Physiological and anthropometric profiles of elite teen-age cyclists. **Purpose:** Previous research has demonstrated that maximal oxygen consumption (VO_{2max}), lactate threshold (LT), aerobic/anaerobic power output, and several anthropometric characteristics are related to elite cycling performance in adults. These values also improve during maturation in children. However, there is little research examining how these values differ between elite teen-age cyclists and their adult counterparts. Previous literature has also reported low bone mineral density (BMD) in adult cyclists when compared to recreationally active controls. This study sought to characterize the aerobic, anaerobic, and anthropometric profiles of elite U.S.-based teen-age cyclists and compare these values to high-level junior Italian cyclists and professional cyclists in the literature. This study also sought to characterize BMD in elite teen-age cyclists and compare them to age-specific normative data. **Methods:** Eight competitive male cyclists (age 16.8 ± 1.4 y; height 175 ± 5.8 cm, weight 61.5 ± 5.0) completed a DEXA scan (Body fat %, BMD), graded exercise test (VO_{2max}, LT, W_{max}), anaerobic power test, and muscle function test (isokinetic peak torque) in consecutive order. Descriptive data (means and standard deviations) were reported for all dependent measures and were qualitatively compared to existing data from the literature. **Results:** Elite U.S.-based teen-age cyclists possess comparable relative/absolute VO_{2max} and W_{max} values to high-level junior Italian cyclists, with inter-study differences likely explained by differing rider specializations and competitive-levels, and potentially methodological differences between studies. Our sample of teen-aged cyclists were smaller, lighter, and presented lower peak aerobic capacity (4.6 ± 0.7 vs. 5.4 ± 0.5 L) and power outputs (375 ± 67 vs. 432 ± 43 W) in comparison to professional cyclists. The teen-age cyclists had site-specific BMD values above the 50th percentile for age/sex, which may be attributable to MTB/running cross-training completed by these athletes. **Conclusion:** Our results are consistent with prior data in elite youth cyclists, and suggest that with further maturation and development, some of these riders have the potential to achieve physiological profiles equal to those required to reach the professional level. **Keywords:** CYCLING, PERFORMANCE, ELITE, TEEN-AGE, BONE MINERAL DENSITY.

Chapter 1

Introduction

Competitive cycling is a physically demanding sport that includes diverse riding conditions, incorporating variable racing distances, terrain, and elevation changes, both within and between competitive events. These diverse conditions impose varied physiological demands and, consequently, high-level cyclists usually possess individualized riding specializations such as uphill/climbing, flat terrain/time-trialing, and mountain biking. Several physiological variables appear to be related to cycling performance levels and individual rider specialization, including: absolute and relative maximal oxygen consumption (VO_{2max}), lactate threshold (LT), power at VO_{2max} (W_{max}), anaerobic power, body mass index (BMI), and percent body fat (%Bf). In addition, bone mineral density (BMD), has been identified as an important anthropometric measure, due to concerns with low BMD in high-level road cyclists (1).

VO_{2max}, or maximal oxygen uptake, is commonly used as a marker of cardiorespiratory function (2, 3). Several studies have assessed VO_{2max} values in adult cyclists and indicate that VO_{2max} is an important indicator of training status and cycling performance level. For example, Padilla et al reported mean VO_{2max} values in male professional road cyclists of 78.8 $\pm$ 3.7 ml/kg/min (4). In addition, four-time Tour De France champion Chris Froome recorded a VO_{2max} of 84 ml/kg/min, which was estimated to be > 90 ml/kg/min during a subsequent competition, due to a 4 kg reduction in body weight (5). These values are almost double those reported in age- and sex-matched healthy control subjects (6). In addition, the aforementioned values in elite cyclists are substantially higher than those observed in recreationally-competitive cyclists. For example, Peiffer et al. reported VO_{2max} values of 60.7 ± 5.1 ml/kg/min in 35 - 44-year-old age-group cyclists (5), with decreasing values in older cyclists (45.9 ± 4.6 ml/kg/min in those 55-73 y). Heavy aerobic training is clearly shown to increase VO_{2max} values (7) and training status is undoubtedly responsible for some of the reported VO_{2max} differences between these groups. However, it is generally concluded that genetic predisposition explains approximately half of the inter-individual variability in VO_{2max}, and is an important factor in achieving VO_{2max} values > 60ml/kg/min (7, 8). While several studies on elite, professional, and competitive adult cyclists have emerged in literature, research on youth/adolescent cyclists is scarce.

Although high VO_{2max} values are considered a prerequisite for elite endurance performance, differentiation between athletes with relatively homogenous VO_{2max} values may be more related to VO_2 and pace/power at LT, as LT is typically associated with the ability to sustain workloads over time (9, 10). Previous literature has demonstrated that elite endurance athletes typically reach LT at intensities ≥ 70% VO_{2max} (3, 11). Furthermore, Coyle et al studied 14 competitive male cyclists in their early 20's with similar VO_{2max} values (± 100 mL). When cyclists with LT values of 81.5 ± 1.8% VO_{2max} were compared to those with LT values of 65.8 ± 1.7%, the cyclists with higher LT levels had significantly longer time to fatigue at 88% of VO_{2max} (60.8 ± 3.1min vs 29.1 ± 5min, respectively). Research has also demonstrated that LT is highly responsive to training. Poole and Gaesser recruited sedentary males with average LT values of 48.8 ± 3.6 % VO_{2max}. Subjects completed moderate-intensity exercise three days each week, for eight weeks. At the end of the study, average LT had increased to 58.3 ± 2.7 % VO_{2max} despite the fact that VO_{2max} was increased significantly following training (i.e. after training, LT occurred at a higher percentage of the improved VO_{2max} level).

LT values of teen-aged athletes are not well-documented, and could be meaningfully different from adult athletes, as previous research has demonstrated differences in substrate utilization between children and adults. While the exact mechanisms remain to be identified, children tend to prioritize fat oxidation over glucose utilization (12), and rely less heavily on anaerobic metabolism versus those who have completed maturation. For example, Timmons et al reported that boys (aged 9.8 ± 0.1 y) utilized 70% more fat and 23% less carbohydrate than men (aged 22.1 ± 0.5 y), when exercising at 70% VO_{2peak}. This same study also demonstrated that when carbohydrate beverages were consumed during moderate-intensity exercise (70% VO_{2peak}), boys exhibited 37% higher exogenous carbohydrate oxidation rates versus men, suggesting that carbohydrate availability may be a limiting factor in fuel utilization for younger athletes (13). Based on these age-related differences in carbohydrate utilization, it seems reasonable to expect that lactate responses in youth cyclists may differ from adults. While reported changes in LT have been identified as important for endurance performance and success in high level adult cyclists (14), LT values in high-level youth cyclists have yet to be reported.

Power output at VO_{2max} (W_{max}) has also been identified as an important factor for cycling performance, particularly when assessed relative to body weight (11). For example, Padilla et al observed W_{max} values of 432 ± 43 W in professional road cyclists

(4), which was modestly (9%) higher than values reported in middle-aged masters cyclists (393 ± 58 W) (17). When these values were examined relative to body mass, the differences between professional (6.3 ± 0.3 W/kg) and age-group cyclists (5.4 ± 0.5 W/kg) were of much greater magnitude (14%), due to the lower body weights of the professional cyclists. Notably, four-time Tour De France champion Chris Froome recorded a W_{max} of 575 W, and his W_{max} relative to body mass (7.5W/kg) is believed to be the highest ever recorded; a factor that has been attributed to his exceptional climbing abilities (5).

Short duration anaerobic power tests are also important indices of performance in cyclists because of the demands associated with sprinting, uphill climbing and passing (18, 19). Tanaka et al., examined anaerobic power output (from 30 second Wingate tests) from cyclists from the United States Cycling Federation to record 30 second Wingate values. In the different performance categories of cyclists in this study (USCF categories 2, 3, and 4), the highest mean power output was seen in category 2 cyclists (994 ± 38 W) (19). This study also demonstrated both peak (13.86 ± 0.23, 13.55 ± 0.25, 12.80 ± 0.68 W) and mean watts (11.22 ± 0.18, 11.06 ± 0.15, 10.40 ± 0.30 W/kg) in levels 2, 3, and 4 respectively, increased with each increase in rider classification (19).

Many of the aforementioned variables appear to influence rider specializations. For example, sprinters and time trial specialists may require higher absolute power output, due to the high power demands required to overcome wind resistance at high speeds, irrespective of body mass (20, 21). By contrast, climbing specialists require high power: weight values due to increased energy costs associated with moving a higher mass uphill against gravity (and minimal impact of wind resistance at slower climbing speeds)

(20). As such, Sallet et al reported that climbing specialists had higher relative VO_{2max} values (per kg) than flat terrain riders, however, flat terrain riders and sprinters had higher absolute W_{max} values (22). Similarly, Lee and Martin demonstrated that road cyclists have higher absolute W_{max} values than mountain cyclists, however mountain cyclists have higher W_{max} values when relativized to body weight (23).

Anthropometric measurements have also been assessed in professional cyclists, such as BMI, Bf%, and BMD. Previous research has demonstrated that elite cyclists generally tend to be shorter and lighter than cyclists in lower performance categories (23). In addition, there are measurable differences in the physiological profiles of riders with different specializations. Lee et al. observed that mountain bikers were leaner, weighed less, and had higher power to weight traits than other road cyclists (23). Impellizzeri et al examined similar variables in female cyclists, and also reported that mountain bikers were lighter (and had less surface area) than road cyclists.

A final anthropometric variable that has received attention in professional cyclists is BMD. Previous studies have reported that road cyclists have low BMD compared to other weight bearing athletes (1, 24, 25), and potentially also in comparison to non-athletes (26, 27). However, Warner et al. demonstrated that cycling specializations influence BMD differently (28). When compared to road cyclists and controls, mountain bikers displayed significantly higher BMD values in the femur and lumbar spine (28). While road cyclists remain on their bicycle almost constantly, mountain bikers engage in weight bearing activity by carrying their bicycles to avoid trail obstacles, which may explain the difference in BMD between groups. Thus, cycling specialization appears to be associated with BMD, which may have important implications for bone health with aging. However, we are aware of no studies that have examined BMD in youth cyclists.

As discussed above, a variety of physiological/anthropometric variables have been associated with the identification and development of competitive cyclists. However, the majority of research has been completed in adults, with research in youth/adolescent cyclists being scarce. A study by Rampinini et al., measured various determinants of performance (VO_{2max}, W_{max}, BMI, and BF%) in 147 junior Italian cyclists, categorized by specialization (29). VO_{2max} values in all rider specialization groups were > 60 ml/kg/min and W_{max} values were > 360 W. Riders were consistently light in weight, and lean; the highest BMI values were observed in sprinters (22.2 ± 1.0 kg/m^2), and highest BF% values in flat terrain specialists (8.2 ± 2.3%). Similarly, in a recent study, Fornasiero et al tested nationally competitive Italian youth cyclists aged 13-16 y, and compared values between each age group (i.e. 1 y increments) (30). Average VO_{2max} (72.7 ± 4.4 ml/kg/min) and W_{max} (395 ± 41 W) values were comparable to those reported by Rampinini (29). Peak VO_2 and power values relative to body mass did not differ substantially between age groups. However, average body mass increased incrementally across each age group, and was 11% higher in the oldest group (16.3 ± 0.2 y) than the youngest group (13.6 ± 0.2 y), presumably due to normal growth/maturation. In concert with these changes in mass, absolute $VO2_{max}$ (L/min), W_{max}, and anaerobic power were 18-22% higher in the older group (30). These findings suggest that increases in body mass associated with growth and development may be associated with meaningful improvements in absolute power output in teen-aged cyclists.

Although these are important studies with a larger sample sizes, there is a need for considerably more research in this area. For example, these studies did not include lactate threshold, VO_{2max} at LT, or BMD as outcome variables. Given that this is a crucial period for bone development and adaptability, educated decisions made at these ages may lay the foundation for young cyclists to optimize performance and could better equip these cyclists while they pursue a professional career. In addition, although all subjects were highly competitive junior cyclists, the study did not differentiate performance levels within subjects.

Recently, the JMU Human Performance Laboratory (HPL) partnered with the Miller School of Albemarle's (MSA) Endurance Team, to provide performance-based testing and educational services to athletes in their cycling program. The MSA Endurance Team is an internationally recognized high school cycling program and a USA Cycling 'Center of Excellence' (www.msacycling.org). The team boasts a strong record of developing junior cyclists, and despite the relatively short history of this program (less than a decade), their riders have garnered multiple national championships, college scholarships, World Championship team selections, and professional cycling contracts. The partnership with the MSA Endurance Team provides the HPL with a unique level of access to a group of elite cyclists in a consistent training environment. Therefore, the purpose of the present study is to characterize the aerobic, anaerobic, and anthropometric characteristics of elite teen-aged cyclists and to compare these values to prior data in high-level junior Italian cyclists and professional adult cyclists.

Purpose and Hypotheses

The purpose of the present study is to characterize the aerobic, anaerobic, and anthropometric characteristics of elite U.S.-based teen-aged cyclists, and to compare these values to prior data in high-level junior Italian cyclists and professional adult cyclists. A secondary purpose of the present study is to ascertain the BMD of elite teen-aged cyclists, in comparison to age/sex-based normative data.

It is hypothesized that our sample of elite U.S.-based teen-aged cyclists will possess similar aerobic, anaerobic, and anthropometric characteristics to high-level junior Italian cyclists and have somewhat lower values than professional adult cyclists. In addition, it is hypothesized that this sample of elite youth cyclists will have normal BMD (>50% percentile), due to the mountain biking and running that are part of their training regimen.

Significance

Interest in the science behind competitive cycling has continued to grow. If physiological factors can be consistently identified in diverse populations of cyclists, training can become more targeted and talent identification more specific. While there is an adequate body of research focusing on adult cyclists, there is minimal data available in adolescent cyclists. Therefore, data from this study can provide information to aid in the identification and development of young competitive cyclists and provide a background for future experimental projects examining how various training/nutrition interventions may influence these variables.

Chapter II

Methodology

Subject Recruitment

Eight male cyclists from the Miller School of Albemarle (MSA) Endurance Team completed a series of physiological tests during the 2017-18 school year, following parent/guardian consent and athlete assent. Testing was conducted to provide the MSA athletes/coaches with data to utilize in developing training programs, and for ascertaining future changes in these variables with training/development. Permission to utilize data for this research study was obtained via e-mail, and separate consent/assent forms from parents/athletes were obtained from all participants for this purpose. Study protocols were approved by the Institutional Review Board at James Madison University.

Overview

All exercise testing was completed in a single session. Testing was completed in the following order: anthropometric measurements (height, weight, DEXA), graded exercise test (lactate threshold and VO_2max), Wingate power test, and muscle function testing. To ensure consistency in test results, subjects were instructed not to complete heavy exercise for 48 h prior to testing, and to follow normal dietary habits. Subjects completed dietary and exercise logs for 24- and 48-h, respectively, to encourage adherence to these instructions (see Appendix A and Appendix B).

Anthropometric Measurements

Height was measured without shoes using a stadiometer. Weight was recorded using a digital floor scale (Pelouze, model 4040). Weight was obtained in cycling shorts only. Following height and weight measurements, subjects completed an assessment of bone mineral density and body composition, using Dual Energy X-Ray Absorptiometry (DEXA; Lunar, General Electric, Baltimore, MD). Subjects wore compression clothing free of metal for this test. Subjects were initially positioned on the DEXA platform for a whole-body scan and instructed to lay still in the supine position for six minutes while the scan completed. After completion, bilateral hip scans were completed in the supine position. Both feet were attached to a foot positioner which rotated the feet inwards by 25 degrees with Velcro straps. The DEXA laser was centered three inches below the greater trochanter and 1 inch medial to the shaft of the femur on the hip being measured. This process was repeated for both hips. Lastly, a lumbar spine scan was completed with subjects lying in the supine position. The DEXA laser was centered one to two inches below the iliac crest in the midline of the body. BMD values were recorded for total body, spine (L1-L4), right femur (total), and right femoral neck, and percentile rankings for age/sex were calculated, using a website-based application (https://bmdcs.nichd.nih.gov/zscore.htm).

Graded Exercise Test

Following the DEXA measurements, subjects completed a graded exercise test to assess lactate threshold and VO_{2max}. Subjects began cycling on an electronically braked cycle ergometer (Velotron, Racermate Inc., Seattle, WA) at a workload intended to represent a sustainable intensity for a 2-3 hr ride (based on input from the athlete's coaches prior to the onset of the test). This workload was selected to ensure that the starting intensity was below lactate threshold, but high enough to minimize excessive test duration. Subjects completed 3 min of cycling at the initial workload, followed by a 1 min rest period to permit finger-stick blood draws to assess blood lactate levels. Blood lactate was assessed from whole blood using a YSI analyzer (YSI Inc. Yellow Springs, OH). Metabolic measures [VO_2, ventilation, respiratory exchange ratio (RER)] were assessed continuously during exercise using a Vmax Vyntus metabolic cart (Yorba Linda, CA). Heart rate was measured using a Polar heart rate monitor (Lake Success, NY, USA), and ratings of perceived exertion (6 – 20 Borg scale) were recorded during the final 15 sec of the stage. After 1 min recovery, workload was increased by 25 watts, and this discontinuous cycling protocol was repeated until blood lactate levels exceeded 4 mmol/L. Subjects received 2 min of recovery after the stage that elicited a lactate level > 4 mmol/L. Subsequently, subjects completed a continuous cycling protocol until volitional fatigue. This phase of testing began at the final workload completed in the discontinuous test, with workload increased each minute until the subject failed to maintain a cadence > 50 rpm for 5 sec. All aforementioned variables, other than blood lactate, were obtained during each 1 min stage. Lactate threshold (LT) was recorded as the highest workload that elicited a blood lactate concentration < 4.0 mmol/L (OBLA). VO_{2max} was recorded as the highest 30 sec average VO_2 value recorded during the graded exercise test.

Wingate Power Test

Following the graded exercise test, subjects received 10 min of recovery, and then performed a 3 min warm up at 150 W prior to completing Wingate power test on a Velotron cycle ergometer, using Wingate software (Racermate, Inc, Seattle, WA) on an interconnected computer. The power test consisted of a pre-programmed, standardized protocol, which included: a) 20 sec at 125 W, b) a 10 sec ‘countdown’ period, in which subjects were instructed to progressively increase their cadence to maximal levels at the end of the countdown, and c) a 30 sec period of maximal effort against a resistance equal to 10% of the subject’s body weight. During this 30 sec period, subjects were encouraged to provide a maximal effort, and were provided with visual and verbal feedback regarding the time remaining in this period. Power output was measured continuously during this test, and the following outcome measurements were calculated by the cycle ergometer software: peak power (W), anaerobic capacity (peak power/kg), average power (W), anaerobic power (average power/kg), and total work (W).

Muscle Function Test

Following the Wingate test, subjects underwent a muscle function test performed on a Biodex Advantage (Shirley, NY). Subjects were strapped into the machine in seated position and given instructions to extend and flex their lower leg against a padded arm. Subjects completed eight sets of contractions where isokinetic peak torque was measured at a fixed speed of 240 degrees/second, followed by the next four sets at 120 degrees/second.

Rider Characterization

Using feedback from the athletes' coaches, riders were categorized based on their riding specialization: uphill/climbing, time trial, sprinter, or mountain bike. In addition, riders were characterized by their performance level as: regional-, national-, or international- level competitive athlete. Specifically, MSA coaches were asked to classify s*pecialization* as the area of each athlete's greatest strength as a cyclist, and rate *competitive level* based upon the riders "current level of performance (not potential level in the future), compared to other riders of the same age/sex".

Statistics

For each of the dependent measures, descriptive data (mean and standard deviation) were calculated. These values were compared qualitatively with existing data in the literature. Due to the small sample of subjects in this study, data obtained regarding rider specialization/performance level were also used to qualitatively interpret our findings, in comparison to other studies.

Chapter III

Manuscript

Physiological and Anthropometric Profiles of Elite Teen-Aged Cyclists

Abstract

Lenzi D. N., N. D. Luden, C. J. Womack, and M. J. Saunders. Physiological and anthropometric profiles of elite teen-age cyclists. **Purpose:** Previous research has demonstrated that maximal oxygen consumption (VO_{2max}), lactate threshold (LT), aerobic/anaerobic power output, and several anthropometric characteristics are related to elite cycling performance in adults. These values also improve during maturation in children. However, there is little research examining how these values differ between elite teen-age cyclists and their adult counterparts. Previous literature has also reported low bone mineral density (BMD) in adult cyclists when compared to recreationally active controls. This study sought to characterize the aerobic, anaerobic, and anthropometric profiles of elite U.S.-based teen-age cyclists and compare these values to high-level junior Italian cyclists and professional cyclists in the literature. This study also sought to characterize BMD in elite teen-age cyclists and compare them to age-specific normative data. **Methods:** Eight competitive male cyclists (age 16.8 ± 1.4 y; height 175 ± 5.8 cm, weight 61.5 ± 5.0) completed a DEXA scan (Body fat %, BMD), graded exercise test (VO_{2max}, LT, W_{max}), anaerobic power test, and muscle function test (isokinetic peak torque) in consecutive order. Descriptive data (means and standard deviations) were reported for all dependent measures and were qualitatively compared to existing data from the literature. **Results:** Elite U.S.-based teen-age cyclists possess comparable relative/absolute VO_{2max} and W_{max} values to high-level junior Italian cyclists, with inter-study differences likely explained by differing rider specializations and competitive-levels, and potentially methodological differences between studies. Our sample of teen-aged cyclists were smaller, lighter, and presented lower peak aerobic capacity (4.6 ± 0.7 vs. 5.4 ± 0.5 L) and power outputs (375 ± 67 vs. 432 ± 43 W) in comparison to professional cyclists. The teen-age cyclists had site-specific BMD values above the 50^{th} percentile for age/sex, which may be attributable to MTB/running cross-training completed by these athletes. **Conclusion:** Our results are consistent with prior data in elite youth cyclists, and suggest that with further maturation and development, some of these riders have the potential to achieve physiological profiles equal to those required to reach the professional level. **Keywords:** CYCLING, PERFORMANCE, ELITE, TEEN-AGE, BONE MINERAL DENSITY.

Introduction

Prior studies of competitive cyclists have identified a variety of physiological and anthropometric variables related to performance, including maximal oxygen consumption (VO_{2max}), lactate threshold (LT), peak aerobic and anaerobic power, body weight and body fat percentage (Bf%)(4, 9, 11, 1). The majority of these studies have been completed on adults and typically exclude children, despite impressively high values reported in two studies of high-level junior Italian cyclists (30, 29). Padilla and colleagues reported mean VO_{2max} values in male professional road cyclists of 78.8 ± 3.7 ml/kg/min, which almost doubles the values seen in healthy, age matched controls (31, 6). In addition, lactate threshold levels often differentiate the performance abilities between individuals with similar VO_{2max} values (9, 10). For example, cyclists who reached LT at 81.5 ± 1.8% of VO_{2max} completed significantly longer time to fatigue at 88% of VO_{2max} than those who reached LT at 65.8 ±1.7% (9). Research has also demonstrated that both VO_{2max} and LT are highly trainable attributes (7, 32). While LT values are poorly documented in teen-aged athletes, there is reason to believe their values may be different from adults due to lower concentrations in glycolytic enzymes, predominate fat utilization, and lower power outputs (12, 13).

Power output at VO_{2max} has also been identified as an important factor for cycling performance, given it is associated with climbing abilities, especially when expressed relative to body weight (11). Padilla et al observed W_{max} values of 432 ± 43 W in professional road cyclists (4) which was 9% higher than values reported in middle-aged masters cyclists (393 ± 58 W) (17). In comparison, elite junior values have been reported to be 422 ± 36 (29) and 395 ± 41 W (30). In addition, short duration anaerobic tests are also indicative of performance because of the demands associated with sprinting, uphill climbing, and passing (18, 19).

Elite cyclists generally tend to be shorter and lighter than cyclists in lower performance categories (23). Body size, and it's associated effects on relative aerobic and anaerobic power output (i.e. power per kg body weight) have also been shown to be associated with rider specialization (23, 33). For example, sprinters and time trial specialists require higher absolute power output to overcome wind resistance at high speeds, and therefore tend to be among the heavier cyclists (20, 21). By contrast, climbing specialists require high power: weight values due to increased energy costs associated with moving a higher mass uphill against gravity, and tend to be lighter than other road cyclists (20).

In addition to height and weight, bone mineral density (BMD), has been identified as an important anthropometric measure in cyclists. Previous studies have reported that road cyclists have low BMD compared to other weight bearing athletes (1, 24, 25), and even non-athletes (26, 27). However, Warner et al. demonstrated that cycling specializations (i.e. MTB versus road cycling) influence BMD differently (28), due to differing weight-bearing demands. Thus, the potential for low BMD in cyclists could have important implications for bone health with aging. However, we are aware of no studies that have examined BMD in youth cyclists.

Previous research assessing physiological and anthropometric variables in high-level teen-aged cyclists appears to be limited to two studies of Italian junior cyclists (30, 29). These studies generally corroborate studies in adults, suggesting that elite young cyclists tend to be small and lean, with high aerobic capacities and power output at max (particularly relative to body weight). However, study of other groups of elite youth cyclists is required to fully characterize this population, and prior studies have not measured lactate threshold responses or bone mineral density, which can be critical to performance and long-term bone health respectively. Therefore, the purpose of this study was to characterize the aerobic, anaerobic, and anthropometric profiles of elite teen-age cyclists and to compare these values to existing data in the literature. It was hypothesized that values will be similar to high-level junior Italian cyclists and be slightly lower than professional level cyclists.

Methodology

Subject Recruitment

Eight male cyclists from the Miller School of Albemarle (MSA) Endurance Team completed a series of physiological tests during the 2017-18 school year, following parent/guardian consent and athlete assent. Testing was conducted to provide the MSA athletes/coaches with data to utilize in developing training programs, and for ascertaining future changes in these variables with training/development. Permission to utilize data for this research study was obtained via e-mail, and separate consent/assent forms from parents/athletes were obtained from all participants for this purpose. Study protocols were approved by the Institutional Review Board at James Madison University.

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Following the DEXA measurements, subjects completed a graded exercise test to assess lactate threshold and VO_{2max}. Subjects began cycling on an electronically braked cycle ergometer (Velotron, Racermate Inc., Seattle, WA) at a workload intended to represent a sustainable intensity for a 2-3 h ride (based on input from the athlete's coaches prior to the onset of the test). This workload was selected to ensure that the starting intensity was below lactate threshold, but high enough to minimize excessive test duration. Subjects completed 3 min of cycling at the initial workload, followed by a 1 min rest period to permit finger-stick blood draws to assess blood lactate levels. Blood lactate was assessed from whole blood using a YSI analyzer (YSI Inc. Yellow Springs, OH). Metabolic measures [VO_2, ventilation, respiratory exchange ratio (RER)] were assessed continuously during exercise using a Vmax Vyntus metabolic cart (Yorba Linda, CA). Heart rate was measured using a Polar heart rate monitor (Lake Success, NY, USA), and ratings of perceived exertion (6 – 20 Borg scale) were recorded during the final 15 sec of the stage. After 1 min of recovery, workload was increased by 25 watts, and this discontinuous cycling protocol was repeated until blood lactate levels exceeded 4 mmol/L. Subjects received 2 min of recovery after the stage that elicited a lactate level > 4 mmol/L. Subsequently, subjects completed a continuous cycling protocol where workload was increased by 25 W every minute until volitional fatigue. This phase of testing began at the final workload completed in the discontinuous test, with workload increased each minute until the subject failed to maintain a cadence > 50 rpm for 5 sec. All aforementioned variables, other than blood lactate, were obtained during each 1 min stage. Lactate threshold (LT) was recorded as the highest workload that elicited a blood lactate concentration < 4.0 mmol/L (OBLA). VO_{2max} was recorded as the highest 30 sec average VO_2 value recorded during the graded exercise test.

Wingate Power Test

Following the graded exercise test, subjects received 10 min of recovery, and then performed a 3-min warm-up at 150 W prior to completing Wingate power test on a Velotron cycle ergometer, using Wingate software (Racermate, Inc, Seattle, WA) on an interconnected computer. The power test consisted of a pre-programmed, standardized protocol, which included: a) 20 s at 125 W, b) a 10 s 'countdown' period, in which subjects were instructed to progressively increase their cadence to maximal levels at the end of the countdown, and c) a 30 s period of maximal effort against a resistance equal to 10% of the subject's body weight. During this 30 s period, subjects were encouraged to provide a maximal effort, and were provided with visual and verbal feedback regarding the time remaining in this period. Power output was measured continuously during this test, and the following outcome measurements were calculated by the cycle ergometer software: peak power (W), anaerobic capacity (peak power/kg), average power (W), anaerobic power (average power/kg), and total work (W).

Muscle Function Test

Following the Wingate test, subjects underwent a muscle function test performed on a Biodex Advantage (Shirley, NY). Subjects were strapped into the apparatus in a seated position and given instructions to extend and flex their lower leg against a padded arm. Subjects completed eight sets of contractions where isokinetic peak torque was measured at a fixed speed of 240 deg/s, followed by the next four sets at 120 deg/s. Each set was followed by 30 s of rest.

Rider Characterization

Using feedback from the athletes' coaches, riders were categorized based on their riding specialization: uphill/climbing, time trial, sprinter, or mountain bike. In addition, riders were characterized by their performance level as: regional-, national-, or international- level competitive athlete. Specifically, MSA coaches were asked to classify s*pecialization* as the area of each athlete's greatest strength as a cyclist, and rate *competitive level* based upon the riders "current level of performance (not potential level in the future), compared to other riders of the same age/sex".

Statistics

For each of the dependent measures, descriptive data (mean and standard deviation) were calculated. These values were compared qualitatively with existing data in the literature. Due to the small sample of subjects in this study, data obtained regarding rider specialization/performance level were also used to qualitatively interpret our findings, in comparison to other studies.

Results

Eight males from the Miller School of Albemarle Endurance Team completed all testing (including one recent graduate from the program). Three of these cyclists were competitive at an international level in their age-class, 4 were nationally-competitive, and 2 were regional-level athletes at the time of testing. In addition, the cyclist specializations were described as: 3 climbers, 0 time-trialists, 1 sprinter, 1 mountain biker, and 3 all-rounders (relatively equal strengths). The anthropometric, aerobic and anaerobic characteristics of these cyclists are displayed in tables 1-6, below.

Table 1. Age and Anthropometric Characteristics

	Age (y)	**Height (cm)**	**Weight (kg)**	**Percent Fat (%)**
Elite Teen-Age Cyclists	16.8 (15-19)	175.8 ± 5.8	61.5 ± 5.0	13.6 ± 2.6

Table 2. Aerobic and power output at VO_{2max}

	VO_{2max} (L/min)	**VO_{2max} (mL/kg/min)**	**W_{max} (W)**	**W_{max} (W/kg)**
Elite Teen-Age Cyclists	4.6 ± 0.7	74.9 ± 6.6	375 ± 67	6.1 ± 0.7

Table 3. Site-specific Bone Mineral Density

	Total BMD	Spine (L1-L4) BMD	Right Femoral Neck BMD	Right Femur (Total) BMD
Elite Teen-Age Cyclists	1.142 ± 0.088 (53.8)	1.015 ± 0.076 (59.6)	1.051 ± 0.074 (75.8)	1.042 ± 0.086 (51.4)

Values are shown in g/cm^2. Percentile ranks are provided in parentheses

Table 4. Physiological Responses at Lactate Threshold (OBLA)

	Power (W)	**VO_2 (L/min)**	**VO_2 (ml/kg)**	**% VO_{2max}**	**LA (mmol/L)**	**HR (bpm)**	**RER**	**RPE**
Elite Teen-Age Cyclists	250 ± 64	3.8 ± 0.9	60.7 ± 9.7	80.6 ± 6.9	3.3 ± 0.7	171 ± 17	0.96 ± 0.04	13.6 ± 0.9

Table 5. Anaerobic Power Output from 30 s Wingate Test

	Peak Watts (W)	30s Average (W)	Anaerobic Power (Peak W/kg)	Anaerobic Capacity (Avg W/kg)	Total Work (kJ)
Elite Teen-Age Cyclists	932 ± 88	651 ± 57	15.1 ± 0.8	10.6 ± 1.0	20,029 ± 950

Table 6. Isokinetic Peak Torque of Quadriceps

	Peak Torque 120 Degrees (ft/lbs)	Peak Torque 240 Degrees (ft/lbs)
Elite Teen-Age Cyclists	106.53 ± 13.02	86.65 ± 7.91

Table 7. Age and Anthropometric Comparison Data between Studies

	Age (y)	Height (cm)	Weight (kg)	BF (%)
Elite Teen-Age (U.S.)	16.8 ± 1.4	175.8 ± 5.8	61.5 ± 5.0	13.6 ± 2.6
High-Level Junior Italian Road*	17.1 ± 0.6	178.1 ± 6.1	68.5 ± 7.2	6.7 ± 1.6
High-Level Junior Italian Cross Country#	16.3 ± 0.2	172.9 ± 6.6	59.5 ± 5.4	NR
Professional Cyclists^	26 ± 3	180 ± 6	68.2 ± 6.6	NR

* = Menaspà et al. (29); # = Fornasiero et al. (30); ^ = Padilla et al. (4).

Table 8. Aerobic and Anaerobic Comparison Data between Studies

	VO_{2max} (L/min)	VO_{2max} (ml/kg/min)	W_{max} (W)	Peak Power (W)	Peak Power (W/kg)
Elite Teen-Age (U.S.)	4.6 ± 0.7	74.9 ± 6.6	375 ± 67	932 ± 88	15.1 ± 0.8
High-Level Junior Italian Road*	4.6 ± 0.4	67.3 ± 4.9	422 ± 36	1074 ± 161	15.8 ± 1.4
High-Level Junior Italian Cross Country#	4.3 ± 0.4	72.7 ± 4.4	395 ± 41	987 ± 130	16.6 ± 1.4
Professional Cyclists^	5.4 ± 0.5	78.8 ± 3.7	432 ± 43	1140 – 1115	15.0 – 15.7

* = Menaspà et al. (29); # = Fornasiero et al. (30); ^ = Padilla et al. (4).

Discussion

The primary purpose of this study was to characterize the aerobic, anaerobic, and anthropometric profiles of a group of U.S.-based, elite teen-aged cyclists, and to compare these values to prior data in high-level junior Italian cyclists and professional adult cyclists. In general, the cyclists in the present investigation possessed similar physiological profiles to previously studied groups of high-level male junior cyclists from Italy (29, 30). Peak values for aerobic capacity and W_{max} in each of these groups of youth cyclists tended to be somewhat lower than values reported in professional male cyclists, particularly when expressed as absolute values. Specific differences and similarities between these groups are discussed below, as well as unique aspects of the present investigation.

Anthropometric and aerobic profiles of our cyclists were compared to previously reported values from high-level Italian junior road (29) and cross-country (MTB) cyclists (30) respectively. Our sample of cyclists were similar in mean age (16.8 ± 1.4 vs. 17.1 ± 0.6 vs. 16.3 ± 0.2 y), and height (175.8 ± 5.8 vs. 178.1 ± 6.1, vs. 172.9 ± 6.6 cm) to these groups, but tended to be lighter than the road cyclists (61.5 ± 5.0 vs. 68.5 ± 7.2 kg) and slightly heavier than the MTB cyclists (59.5 ± 5.4 kg) (29, 30). These findings are consistent with prior data obtained in adult cyclists, in which body size/mass appears to be associated with rider specialization (22, 23). Specifically, MTB/climbing specialists tend to have lower body mass (and higher aerobic power characteristics relative to body mass) than other road cyclists, and the low number of sprint/time-trial specialists in our sample likely explains why our group's values are lower than the Italian road cyclists (30) and more similar to the MTB specialists. Body fatness was not assessed in the Italian MTB cyclists, but our sample had higher % fat values than the road cyclists tested by Menaspa et al (13.6 ± 2.6

vs. 6.7 ± 1.6%) (29). The sizable differences in body fat percentages may be due to differences in testing methodology (34). The Italian road cyclists were measured using the skinfold technique, while our sample was measured using DEXA. Stewart and Hannan reported that mean % fat values obtained by DEXA were 3% higher than values obtained from skinfold measures, estimated using the same Jackson and Pollock equation used by Menaspa and associates (35). Therefore, direct comparison between body fatness levels in studies warrants caution, and it may be worthwhile to assess skinfold thickness in these subjects in any future studies (in addition to DEXA) to provide values for comparison.

Our athletes had higher relative VO_{2max} values (74.9 ± 6.6 vs. 67.3 ± 4.9 vs. 72.7 ± 4.4 ml/kg/min), similar absolute VO_{2max} values (4.6 ± 0.7 vs. 4.6 ± 0.4 vs. 4.3 ± 0.4 L), and lower W_{max} values (375 ± 67 vs. 422 ± 36 vs. 395 ± 41 W) when compared to the aforementioned Italian junior road and MTB cyclists, respectively (29). As indicated above, these differences may be partially due to differences in the proportion of MTB/climbing specialists in each group, as these athletes tend to be lighter with higher relative VO_{2max} values (but lower absolute values) than other road cyclists. The variability between studies may also be due to subtle differences in the caliber of cyclists in each study, which cannot be objectively compared between studies. One unexpected finding from the data above is that our sample had lower W_{max} values than the other groups, despite similar/higher absolute VO_{2max} values at that workload. This anomaly could possibly be attributed to a few different factors. For example, the ergometer protocol used in the present study utilized relatively long stages, in order to obtain reliable sub-maximal lactate responses. As a result, the protocol may have elicited more muscular fatigue, preventing our subjects from completing a final stage (i.e. 25 W) in which VO_2 values had achieved a plateau. Furthermore, we recorded the highest completed workload as W_{max}, rather than factoring in any time completed at a subsequent stage (29, 30). Both of these factors would underrepresent the W_{max} values of our subjects compared to the other groups. In addition, the lower W_{max} values could possibly be explained by the maturational level of our cyclists. As discussed in greater detail below, immature athletes tend to have underdeveloped anaerobic/glycolytic capacities, which could have contributed to an inability to attain higher peak workloads. However, this possibility cannot be directly confirmed, as Tanner stages of development were not reported in any of these studies. Lastly, we cannot discount the possibility of equipment-related inconsistencies in VO_2 and/or workloads between laboratories, in which our reported VO_2 values could be spuriously high (or W_{max} values spuriously low).

The anaerobic power output of our athletes can also be compared to junior road and MTB cyclists in the literature. Similar to the aforementioned W_{max} (aerobic power) values, our sample exhibited somewhat lower absolute peak anaerobic power (932 ± 88 W) than the Italian road (1074 ± 161 W) and MTB cyclists (987 ± 130 W). The proportional differences in power output between our athletes and the Italian road cyclists was reduced when relativized to body mass (15.1 ± 0.8 vs. 15.8 ± 1.4 W/kg), but the Italian MTB specialists possessed the highest values per unit weight (16.6 ± 1.4 W/kg) (29). As described above, these outcomes are at least partially related to differences in rider specialization, as sprinters and time trial specialists may require higher absolute power output, due to the high power demands required to overcome wind resistance at high speeds, irrespective of body mass (20, 21). By contrast, climbing specialists require high power: weight values due to increased energy costs associated with moving a higher mass uphill against gravity (and minimal impact of wind resistance at slower climbing speeds)

(20). It is also possible our data was negatively impacted by fatigue, as all of the tests were completed in succession, or a lack of familiarization with the Wingate protocol, which most of our subjects had not completed previously.

A unique aspect of the present study was the assessment of isokinetic peak torque values, which provide an evaluation of muscle strength/function. It is logical to assume that increases in isokinetic strength may be associated with changes in peak anaerobic power and/or aerobic power (W_{max}). However, we are not aware of any studies reporting these data in young and/or adult cyclists. An analysis of these data in the existing sample suggests that isometric peak torque (IPT) values at 120°/s may be moderately associated with W_{max} (r = .451), peak anaerobic power (r = .384), and average (30 s) anaerobic power (r = .596) [IPT at 240°/s exhibited similar trends, despite consistently lower correlations of .399, .162 and .425, respectively]. However, these values were taken during a somewhat fatigued state and our sample size was inadequate to provide generalizable (or statistically significant) results. However, these preliminary data suggest that it may be useful to assess isokinetic peak torque in future studies, to determine how changes in muscle strength in cyclists (due to maturation, strength training, etc.) may influence aerobic and anaerobic power.

When comparing the profiles of our cyclists to those of top adult professionals reported in the literature, professional cyclists are older (16.8 ± 1.4 vs. 26 ± 3 y), slightly taller (175.8 ± 5.8 vs. 179.8 ± 5.8 cm) and heavier (61.5 ± 5.0 vs. 68.2 ± 6.6 kg) than our sample (4). Our young cyclists also had lower absolute (4.6 ± 0.7 vs. 5.4 ± 0.5 L) and relative (74.9 ± 6.6 vs. 78.8 ± 3.7 ml/kg/min) VO_{2max} values, as well as lower power output at VO_{2max} (375 ± 67 vs. 432 ± 43 W) (4). The observed differences in performance-related measures could logically reflect the higher competitive caliber of the professional cyclists, but could also partially reflect normal age-related differences in maturational status. For example, Fornasiero studied junior cyclists aged 13-16 y, separated into 1-y increments. Absolute VO_{2max} and W_{max} values tended to increase incrementally with age, in concert with increasing body mass, while relative VO_{2max} was not systematically different between groups (30). In addition, Naughton et al noted that individuals going through puberty generate less power per kilogram of body weight compared to adults, suggesting that maturational changes in males may lead to increases in W_{max} and VO_{2max} over time (36). Therefore, it is logical to assume that at least some of the cyclists in our sample will observe continued increases in size/mass due to normal maturational development, which would likely contribute to further increases in absolute (and to a lesser extent, relative) W_{max} and VO_{2max}, and a number of these cyclists may have the potential to achieve physiological profiles similar to those of professional cyclists.

While not fully understood, the disparity in power production between young/adult athletes may be due to differences in glycolytic capacity (37). Previous research has used P-magnetic resonance spectroscopy (P-MRS) to indirectly measure glycolytic activity in children during high intensity exercise. It was reported that that children (9.3 ± 1.0 y) exhibited attenuated changes in pH , as well as 73% lower Pi/PCr ratios at the end of heavy exercise in comparison to adults (33.7 ± 6.9 y) (38). Collectively, these data suggest that children possess underdeveloped anaerobic capacities versus adults, which could contribute to impaired work outputs during high intensity exercise.

Our sample of young male cyclists exhibited similar relative physiological responses at lactate threshold to those of professional cyclists in the literature. Compared to our sample, professional cyclists recorded a LT2 breakpoint (OBLA) at a slightly higher percentage of VO_{2max} (81 ± 6 vs. 86%) while eliciting a higher heart rate response LT2 (172 ± 17 vs. 178 bpm). The professional cyclists exhibited considerably higher at LT2 (250 ± 64 vs. 386 W) which, as previously discussed, is at least partially attributed to their higher body mass (4.6 W/kg vs. 5.7 W/kg). It has also been suggested that power disparities exist between adults and individuals that are still maturing (36). While the mechanisms behind these maturation-related differences remain unclear, they could be related to lower glycolytic enzyme concentrations. Previous research has demonstrated children to have lower RER values at any submaximal intensity, possibly due to differences in glycolytic enzyme concentrations and thus, a higher affinity for fat oxidation (12, 36). However, because our sample presented adult-like patterns of substrate utilization and some were in their late teenage years, it is difficult to determine the extent maturation played on performance, and, that these measures may have been more related to differences in total mass.

The cyclists in this study presented mean BMD values that were above the 50^{th} percentile for all sites. In addition, our cyclists possessed nearly identical total body BMD to aged matched, recreationally active controls used by Olmedillas et al (1.142 ± 0.088 vs. 1.133 ± 0.127 g/cm^2). However, previous studies in adults have reported that road cyclists have low BMD compared to other weight bearing athletes (1, 24, 25), and potentially also in comparison to non-athletes (26, 27). Thus, concerns regarding the potentially negative effects of cycling on BMD were not upheld in our sample. This outcome may have been related to other forms of exercise our cyclists compete in outside of cycling. The cyclists in the present study regularly train on mountain bikes and participate in cross country running during their cycling off-season. It has been shown previously that adult runners have higher BMD than adult road cyclists, due to the positive effects of weight-bearing activity on bone mass (1, 24, 25). In addition, Warner et al. reported that adult mountain bikers displayed significantly higher BMD values in the femur and lumbar spine versus road cyclists and controls (28). While road cyclists remain on their bicycle almost constantly, mountain bikers engage in weight bearing activity by carrying their bicycles to avoid trail obstacles. Therefore, it seems reasonable to speculate that the combined effects of MTB and running training provided an ample weight-bearing stimulus in these subjects to support healthy BMD.

In conclusion, these elite teen-aged cyclists were similar to high-level junior Italian road and MTB cyclists, with subtle differences between these groups largely attributable to predictable differences in rider specialization and methodological issues. Our sample of cyclists had somewhat lower peak physiological levels than professional adult cyclists, particularly with respect to absolute aerobic/anaerobic power outputs. Future research should focus on larger sample sizes, inclusion of females, and performance relevant dependent measures.

Appendix A

24-HOUR DIET RECORD

*Name*_____________________ *Date*_______________

Time	Food and/or Drink	Method of Preparation	Quantity Consumed	Brand Name

Adapted From: Lee RD, Nieman DC. *Nutritional Assessment.* 2nd ed. United States of America: Mosby; 1996

24-HOUR DIET RECORD

*Name*____________________ *Date*_______________

Time	Food and/or Drink	Method of Preparation	Quantity Consumed	Brand Name

Adapted From: Lee RD, Nieman DC. *Nutritional Assessment.* 2nd ed. United States of America: Mosby; 1996

USE THE FOLLOWING TO HELP DETERMINE PORTION SIZES AND TYPES OF FOODS

	PLEASE SPECIFY
Beverages	Sugar or creamer? Regular or sugar-free? Alcohol content? Name of drink and ingredients (if mixed drink)
Breads	Butter or margarine added?
Cereal/Milk	Milk, sugar, or fruit added? The type of milk? (skim, 1%, 2%, whole) Cereal: dry or cooked measure?
Dairy	Is yogurt fruited or plain? % fat of milk or yogurt? Indicate brand name of cheese substitute and/or nondairy creamer.
Desserts	Whipped topping added? Frosting? Fat modified (i.e., reduced)? Sugar-free?
Eggs	Preparation method (scrambled, hard-boiled, etc)? Fat used in cooking?
Fast Food	What restaurant? If not a national fast food chain, describe food in detail Size order of fries? Super-size? ExtRa toppings on sandwich?
Fats/Oils	Regular or salt-free? Stick, tub, or liquid margarine? Reduced calorie or diet product?
Fish	Water or oil packed (fresh or canned)? Baked or fried (With batter or without)? Type of fat added? Raw or cooked weight?
Fruit	Sweetened or unsweetened? Fresh, canned, or frozen? With or without skin?
Meats	Visible fat removed? Light or dark meat? Raw or cooked?
Sugars and Sweets	Regular or reduced-calorie? Don't forget hard candy as well as chocolate.
Vegetables	Raw or cooked? Fresh, frozen, or canned? Low-sodium or regular? Added fat or sauce?

Helpful Hints with Portion Sizes

- 1 teaspoon (5 ml)
  - about the size of the top half / tip of your thumb
- 1oz (28g)
  - approximately inch cube of cheese
  - volume of four stacked dice
  - slice of cheese is about the size of a 3 1/2 inch computer disk
  - chunk of cheese is about as thick as 2 dominoes
  - 1 handful (palm) of nuts
- 2 ounces (57 g)
  - 1 small chicken leg or thigh
  - 1/2 cup of cottage cheese or tuna
- 3 ounces (85 g)
  - serving of meat is about the size of a deck of playing cards (3 exchanges)
  - the size of the palm of your hand
  - 1/2 of whole chicken breast
  - 1 medium pork chop
  - 1 small hamburger
  - unbreaded fish fillet
- 1/2 cup (118 ml)
  - fruit or vegetables can fit in the palm of your hand
  - about the volume of a tennis ball
- 1 cup (236 ml)
  - about the size of a woman's fist
  - breakfast cereal goes halfway up the side of a standard cereal bowl
  - broccoli is about the size of a light bulb
- 1 medium apple = A tennis ball

Appendix B

Physical Activity Records

Name________________________________

Date	Type of Exercise Performed	Duration of Exercise (minutes)	Intensity of Exercise (use scale below)

Intensity Scale

6	
7	Very, very light
8	
9	Very light
10	
11	Fairly light
12	
13	Somewhat hard
14	
15	Hard
16	
17	Very hard
18	
19	Very, very hard
20	

References

1. Rector RS, Rogers R, Ruebel M, Hinton PS. Participation in road cycling vs running is associated with lower bone mineral density in men. *Metabolism*. 2008;57(2):226–32.

2. Bassett D, Howley E. Limiting factors for maximum oxygen uptake and determinants of endurance performance. *Med Sci Sport.* 2000;(June 1999):70–84.

3. Costill DL, Thomason H, Roberts E. Fractional utilization of the aerobic capacity during distance running. *Med Sci Sports Exerc*. 1973;5(4):248–52. Available from: http://www.scopus.com/inward/record.url?eid=2-s2.0-0015759929&partnerID=40.

4. Padilla, Sabino; Mujika, Inigo; Cuesta, Guillermo; Goiriena JJ. Level Ground and uphill cycling ability in professional cycling. *Med Sci Sport Exerc*. 1999;31(6):878–85.

5. Bell PG, Furber MJW, Van Someren KA, Antón-Solanas A, Swart J. The Physiological Profile of a Multiple Tour de France Winning Cyclist. *Med Sci Sports Exerc*. 2017;49(1):115–23.

6. Whaley MH. *American College of Sports Medicine, Guidelines for Exercise Testing and Prescription*. Tenth Edit. Philadelphia: Lippincott williams & Wilkins; 2017.

7. Bouchard, Claude, Warwick Daw, Treva Rice, Louis Perusse, Jacques Gagnon, Michael A. Province, Arthur S. Leon, D,C, Rao, James S. Skinner JHW. Familial resemblance for VO2max in the sedentary states: the Heritage family study. *Med Sci Sport Exerc*. 1998;30(2):252–8.

8. Scott K. Powers ETH. *Exercise Physiology. Theory and Application to Fitness and Performance*. 2012. 285.

9. Coyle EF, Coggan AR, Hopper MK, Walters TJ. Determinants of endurance in well-trained cyclists. *J Appl Physiol*. 1988;64(6):2622–30.

10. Farrell PA, Wilmore JH, Coyle Edwardf, Billing JE, Exercise DLC, Tucson A. Plasma lactate accumulation and distance running performance.pdf. *Science 1979; (80)*.

11. Mujika I, Padilla S. Physiological and performance characteristics of male professional road cyclists. *Sports Med*. 2001;31(7):479–87.

12. Aucouturier J, Baker, J. S, Duche P. Fat and carbohydrate metabolism during submaximal exercise in children. *Sport Med* . 2008;38(3):213–38.

13. Timmons BW, Bar-Or O, Riddell MC. Oxidation rate of exogenous carbohydrate during exercise is higher in boys than in men. *J Appl Physiol*. 2003;94(1):278–84.

14. Joyner MJ, Coyle EF. Endurance exercise performance: The physiology of champions. *J Physiol*. 2008;586(1):35–44.

15. Hawley J a, Noakes TD. Applied Physiology and performance time in trained cyclists. *Eur J Appl Physiol*. 1992;79–83.

16. Noakes M, Keogh JB, Foster PR, Clifton PM. Effect of an energy-restricted , high-protein , low-fat diet relative to a conventional high-carbohydrate , low-fat diet on weight loss , body composition , nutritional status , and markers of cardiovascular health in obese women 1 – 3. 2005;1298–306.

17. Peiffer J, Abbiss C, Chapman D, Laursen P PD. Physiological Characteristics of Masters-Level Cyclists. *J Strength Cond Res*. 2008;22(5):1434–40.

18. Craig NP, Norton KI, Bourdon PC, et al. Aerobic and Anaerobic Indexes Contributing To Track Endurance Cycling Performance. *Eur J Appl Physiol Occup Physiol*. 1993;67(2):150–8.

19. Tanaka H, Bassett DR, Swensen TC, Sampedro RM. Aerobic and Anaerobic Power Characteristics of Competitive Cyclists in the United-States Cycling Federation. *Int J Sports Med*. 1993;14(6):334–8.

20. David S. The influence of body mass in endurance bicycling. *Med Sci Sports Exerc*. 1994;26(1):58–63.

21. E. F. Coyle, M. E. Feltner, S. A. Kautz, M. T. Hamilton, S. J. Montain, A. M. Baylor, L. D. Abraham GWP. Physiological and biomechanical factors associated with elite endurance cycling performance. *Med Sci Sport Exerc*. 1991;23(1):93–107.

22. Sallet P, Mathieu R, Fenech G, Baverel G. Physiological differences of elite and professional road cyclists related to competition level and rider specialization. *J Sports Med Phys Fitness*. 2006;46(3):361–5.

23. Lee H, Martin DT, Anson JM, Grundy D, Hahn AG. Physiological characteristics of successful mountain bikers and professional road cyclists. *J Sports Sci*. 2002;20(12):1001–8.

24. Stewart A, Hannan J. Total and regional bone density in male runners, cyclists, and controls. *Med Sci Sport Exerc*. 2000;32(8):1373–7.

25. Scofield KL, Hecht S. Bone Health in Endurance Athletes. *Curr Sports Med Rep*. 2012;11(6):328–34.

26. Campion J.F., Nevil A.M., Karlsson M.K., Lounana J., Shabani M., Fardellone P.

Bone Status in Professional Cyclists. *International Journal of Sports Medicine*. 2010; 31:511–5.

27. Nichols JF, Palmer JE, Levy SS. Low bone mineral density in highly trained male master cyclists. *Osteoporos Int*. 2003;14(8):644–9.

28. Warner SE, Shaw JM, Dalsky GP. Bone mineral density of competitive male mountain and road cyclists. *Bone*. 2002;30(1):281–6.

29. Menaspà P, Rampinini E, Bosio A, Carlomagno D, Riggio M, Sassi A. Physiological and anthropometric characteristics of junior cyclists of different specialties and performance levels. *Scand J Med Sci Sport*. 2012;22(3):392–8.

30. Fornasiero A, Savoldelli A, Modena R, Boccia G, Pellegrini B, Schena F. Physiological and anthropometric characteristics of top-level youth cross-country cyclists. *J Sports Sci*. 2018;36(8):901–6.

31. Jose J. Level Ground and uphill cycling ability in professional cycling. *Med Sci Sport Exerc*. 1999;(December 1998):1–12.

32. Poole DC, Gaesser G a. Response of ventilatory and lactate thresholds to continuous and interval training. *J Appl Physiol*. 1985;58(4):1115–21.

33. Impellizzeri FM, Ebert T, Sassi A, Menaspà P, Rampinini E, Martin DT. Level ground and uphill cycling ability in elite female mountain bikers and road cyclists. *Eur J Appl Physiol*. 2008;102(3):335–41.

34. Gutin B, Litaker M, Islam S, Manos T, Smith C, Trieber F. Body-composition measurement in 9–11-y-old children by dual-energy X-ray absorptiometry, skinfold-thickness measurements, and bioimpedance analysis. *Am J Clin Nutr*.

1996;63(March):287–92.

35. Stewart AD, James Hannan W. Prediction of fat and fat-free mass in male athletes using dual x-ray absorptiometry as the reference method. *J Sports Sci*. 2000;18(4):263–74.

36. Naughton G, Farpour-Lambert NJ, Carlson J, Bradney M, Van Praagh E. Physiological issues surrounding the performance of adolescent athletes. *Sports Med*. 2000;30(5):309–25.

37. Kaczor JJ, Ziolkowski W, Popinigis J, Tarnopolsky MA. Anaerobic and aerobic enzyme activities in human skeletal muscle from children and adults. *Pediatr Res*. 2005;57(3):331–5.

38. Zanconato S, Buchthal S, Barstow TJ CD. 31P-magnetic resonance spectroscopy of leg muscle metabolism during exercise in children and adults. *J Appl Physiol*. 1993;74:2214–8.

39. Jensen K, Secher NH. Influence of body mass on maximal oxygen uptake : effect of sample size. 2001;75:201–5.

40. Rowland T, Goff D, Martel L, Ferrone L. Influence of cardiac functional capacity on gender differences in maximal oxygen uptake in children. *Chest*. 2000;117(3):629–35.

41. L DB. Women and Exercise: Physiological Aspects. *Exerc Sport Sci Rev*. 1984;12(1):21–52.