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TRAINING CHARACTERISTICS AND POWER PROFILES OF USA CYCLING ROAD CYCLISTS

Robert Sroka
University of Tennessee, Knoxville, rsroka@vols.utk.edu

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I am submitting herewith a thesis written by Robert Sroka entitled "TRAINING CHARACTERISTICS AND POWER PROFILES OF USA CYCLING ROAD CYCLISTS." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Kinesiology.

David R. Bassett Jr., Major Professor

We have read this thesis and recommend its acceptance:

Jessica L. Kutz Fleming, Dawn P. Coe

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

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TRAINING CHARACTERISTICS AND POWER PROFILES OF USA CYCLING ROAD CYCLISTS

A Thesis Presented for the
Master of Science
Degree
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Robert Sroka
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ABSTRACT

New advancements in bicycle instrumentation and social media applications have made it possible to obtain quantitative data on training and racing. **PURPOSE:** To analyze training data (training volume, frequency, distance, speed, and race days) and power profiles of road racers in USA Cycling, in order to compare genders and categories (professional, 1, 2, 3, 4, 5). **METHODS:** Part 1: Using USAC race results, racers with an active Strava® account were selected. Using data uploaded from on-bike GPS head units, 543 USAC racers' (279 men, 264 women), 2019 data were documented. Part 2: Subjects with power meter data displayed on Strava® were contacted for demographic information and peak power data (5-s, 1-min, 5-min, 20-min, and 1-h). 92 amateur racers (67 men, 25 women) completed this part of the study. Annual training metrics, power data, and survey results were compared across the categories and genders using ANOVAs. **RESULTS:** Part 1: In 2019, professional women (N=20) rode 634.7±135.2 hours, 16,581±3,562 km, and completed 304.4±28.5 ride days, 33.2±7.8 races; professional men (N=29) rode 864.7±160.0 hours, 26,103±5,210 km, and completed 310.6±39.3 ride days, 49.9±17.1 races. There were significant gender differences among professionals, for all variables except for ride days ($p<0.05$). Among amateurs, training volume, distance, races, and ride days all declined as category increased, but there were no gender differences within categories 2, 3, 4, and 5 for these variables. Part 2: The power profiles showed an exponential decline in power output (W/kg) with increasing measurement periods (5-s to 1-h). Category 1 women had significantly higher power outputs compared to other amateur women in 5-s, 5-min, and 20-min power ($p<0.05$). The differences between category 3-5 women were non-significant. Category 1 men had significantly higher values than other amateur men in 5-min, 20-min, and 1-h power ($p<0.05$), and category 2 men were significantly higher than category 5 men

in 20-min power ($p<0.05$). **CONCLUSION:** Some differences exist for annual training data and power profiles between USAC categories and genders. Knowledge of the training characteristics and power profiles of USAC men and women athletes could be useful to road racers and coaches in designing training programs.

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CHAPTER I: INTRODUCTION

Introduction

Road racing in the United States grew in popularity during the 1970s, with the introduction of the sport's governing body, the United States Cycling Federation, which later became USA Cycling (USAC). While professional road racing still remains far more recognized in Europe, participation in the United States at the amateur level has soared. 69,684 unique racing licenses were acquired in 2010, an increase of 63% from the 42,724 licenses acquired in 2002 (1). Of those USAC license holders, each racer is designated as belonging to a category between I and V, with category 5 comprised of beginners. Racers can earn upgrade points through placings at USAC-sanctioned events to move up in category.

Competitive road cycling consists of three primary disciplines: road races, time trials, and criteriums. There are differences in the length and format of each of these events, and distinct energetic demands are necessary to be successful in each. Riders with different physiological characteristics and training habits may be more suited to one event than to others. Many physiological factors determine a racer's success in the aforementioned disciplines: maximal oxygen uptake (VO_{2max}), lactate threshold (LT), and muscle fiber type are relevant to all road racing scenarios. VO_{2max} values have been well documented in road cyclists; this is particularly true at the elite level (2-5), but less so at the sub-elite level (6). Power outputs below LT can be sustained for a considerable length of time and outputs above LT are not sustainable for extended periods of time (7) and is thus critical to performance. It should be noted that the trained muscles of endurance athletes often possesses a much higher percentage of Type I muscle fibers (8) and this seems to hold true amongst cyclists, as well (9).

Although these precise physiological metrics are best measured in the laboratory, recent developments in technology have essentially allowed for cyclists to have a rolling laboratory on their bikes- even on outdoor rides. Head units use a global positioning system (GPS) to display a live map of a rider's location for navigation, and can also display and record distance, speed, elevation, heart rate (HR), and mechanical power output (if linked to a power meter). Due to the popularity of head units and power meters, and the use of social media apps such as Strava®, riders can upload GPS files to track progress along road segments or compete (asynchronously) against their peers on the same road segment. The use of Strava has increased significantly over the past five years. In many instances, Strava records are publicly available; this includes data on distance, duration, heart rate, and power. While the accuracy of laboratory measurements is preferred by exercise physiologists, the information provided from a head unit coupled with a power meter can be nearly as informative for the aspiring road cyclist. Scientific studies have been published on the training habits and power outputs of professionals ((2-5, 10, 11)), but far less information is available at the amateur level (6), and especially regarding the differences between categories.

Training plans have been outlined in literature to guide road cyclists in using these head units and power meters effectively. A book by Friel, *The Cyclist's Training Bible* (12), has masses of background information, case studies, and also contains a table of "suggested annual training durations." The anticipated training volumes (in hours) can be used to develop a yearly/weekly training plan for professionals and categories I-V within USAC. The book recommends that professionals train (between cycling and other forms of training including the suggested strength training from the book) 800-1200 hours annually, category I and II's 700-1000 hours, category III's 500-700 hours, category IV's 350-500 hours, and category V's 200-350 hours annually (12). These values were originally 'rough estimates' according to Friel's earlier editions of the book and most likely based on his own personal coaching experience.

However, although these numbers are frequently cited, little empirical research exists to support them. This is especially true in regard to gender differences. While Friel's training recommendations include time spent on the bike, resistance training, and cross-training, the current study will be gathering data exclusively on cycle training.

Coggan and Allen's *Training and Racing with a Power Meter* (13), published in 2006, was one of the first books to show individuals how to analyze power data and use it effectively in training. Inside, a chart developed by Coggan displays power outputs relative to weight (W/kg) for each category across the timeframes 5-sec, 1-min, 5-min, and functional threshold (95% of one's 20-minute power). Coggan built this chart using interpolation to estimate the range of values for eight categories (international pro, domestic pro, categories I-V, non-racer) based on the highest known values ever recorded (by pros) and those recorded by the average, untrained population. These timeframes (5-sec, 1-min, 5-min, and functional threshold (95% of one's 20-minute power)) were chosen to yield power outputs that reflect neuromuscular power, anaerobic capacity, VO_{2max}, and LT. Even without access to a laboratory, cyclists can ride their own bike equipped with a power meter to obtain this information. Compiling an individual's data from these four timeframes has been dubbed 'power profiling' and can be used to predict what type of rider the cyclist is (i.e., sprinter, climber, all-arounder). Race performance is the best indicator of how an individual compares to other road racing cyclists or their respected category, but these benchmarks (W/kg) can provide training parameters or goals for athletes. Coggan's original power profile table was developed by anchoring the high and low ends of the continuum against professional riders and untrained cyclists, respectively, and then verifying it against amateur riders (13). However, there may be a need to compare their power profiles to those of other USAC road racers.

Thus, the purpose of this study is to further explore training habits and power profiles of current USAC road racers. Today, online platforms such as Strava® have publicly available data that allow a closer look at the training habits and performance capabilities of professionals and amateurs alike. This could provide insight into differences between genders and categories, and perhaps serve as a practical guide for what racers are currently doing in training and racing.

Statement of problem

Little information has been published regarding training volume among different categories of USAC road racers. Although there are resources on the training volumes of professional cyclists, amateur racers should not attempt to replicate the pros, since this could lead to burnout or injury. While on-bike power meters are popular in amateur cycling, to date, few empirical studies have been conducted on the differences between USAC road racers, as a function of category and gender.

Statement of purpose

The primary purpose of this study is to analyze training data (annual training volume, frequency, distance, speed, and race days) collected by USAC road racers. The relationships between category as well as gender will also be analyzed to determine where differences occur. The secondary purpose is to compare on-bike peak power data (W/kg) between road racers in different categories (USAC categories 1-5) and determine whether peak power benchmarks for different durations (i.e., 5-s, 1-min, 5-min, 20-min, 1-hour) exist between categories.

Significance of these studies

Publicly available data exists regarding the current habits of USAC road cyclists; however, the collection and analysis of this data has not yet been documented in the scientific literature. The results of this study will yield valuable information regarding what current racers are completing and perhaps serve as a practical guide for coaches and athletes alike.

CHAPTER II: REVIEW OF LITERATURE

Abstract

New advancements in bicycle instrumentation and social media applications have made it possible to obtain quantitative data on training and racing. **PURPOSE:** To analyze training data (training volume, frequency, distance, speed, and race days) and power profiles of road racers in USA Cycling, in order to compare genders and categories (professional, 1, 2, 3, 4, 5). **METHODS:** Part 1: Using USAC race results, racers with an active Strava® account were selected. Using data uploaded from on-bike GPS head units, 543 USAC racers' (279 men, 264 women), 2019 data were documented. Part 2: Subjects with power meter data displayed on Strava® were contacted for demographic information and peak power data (5-s, 1-min, 5-min, 20-min, and 1-h). 92 amateur racers (67 men, 25 women) completed this part of the study. Annual training metrics, power data, and survey results were compared across the categories and genders using ANOVAs. **RESULTS:** Part 1: In 2019, professional women (N=20) rode 634.7±135.2 hours, 16,581±3,562 km, and completed 304.4±28.5 ride days, 33.2±7.8 races; professional men (N=29) rode 864.7±160.0 hours, 26,103±5,210 km, and completed 310.6±39.3 ride days, 49.9±17.1 races. There were significant gender differences among professionals, for all variables except for ride days ($p<0.05$). Among amateurs, training volume, distance, races, and ride days all declined as category increased, but there were no gender differences within categories 2, 3, 4, and 5 for these variables. Part 2: The power profiles showed an exponential decline in power output (W/kg) with increasing measurement periods (5-s to 1-h). Category 1 women had significantly higher power outputs compared to other amateur women in 5-s, 5-min, and 20-min power ($p<0.05$). The differences between category 3-5 women were non-significant. Category 1 men had significantly higher values than other amateur men in 5-min, 20-min, and 1-h power ($p<0.05$), and category 2 men were significantly higher than category 5 men

in 20-min power ($p<0.05$). **CONCLUSION:** Some differences exist for annual training data and power profiles between USAC categories and genders. Knowledge of the training characteristics and power profiles of USAC men and women athletes could be useful to road racers and coaches in designing training programs.

Introduction

Competitive road cycling is composed of three primary disciplines: road races, time trials, and criteriums. While there are differences in the length and format of these events, distinct energetic demands are necessary to be successful in each- this allows riders with different physiological makeups and training habits to be more suited to one event than to others.

The road race is a mass-start event that is typically between 30 and 80 miles for amateurs, with professional races often much longer (14); this is the most commonly seen form of racing in Europe (15). Due to the reduced energy requirements of riding in the slipstream of another cyclist, drafting often plays an important role in the outcome of a road race (16). The terrain also impacts the outcome and flow of the race, as well as the riders who would be favored to win it. In a flat or slightly hilly road race without much elevation change, teammates or other riders can attempt to break away from the pack. A small group of riders will work together by utilizing drafting to overcome the main impediment in this terrain-- air resistance (17). Teams generally have one or two sprinters who will try to win if the peloton comes to the finish in a mass group; this is reserved for riders with a high anaerobic capacity (18).

Steep road races that have more elevation change are suited to riders with a high relative maximal oxygen uptake (VO_{2max} in $ml \cdot kg^{-1} \cdot min^{-1}$) and the ability sustain 80-90% of their VO_{2max} for upwards of an hour (19). In such mountainous terrain, the primary obstacle shifts from battling air resistance to overcoming gravity (20). Time trials are normally an individual race with no drafting allowed (except for the team time trial, where 6-8 riders from a team start together). Riders (or teams) start 30- or 60-seconds apart in these races. These races generally last an hour or less, and both comfort and optimal muscular efficiency are often sacrificed to achieve an aerodynamic advantage (21). It has been well documented that aerodynamics are greatly influenced by body position and equipment choices (22). Time trial events tend to favor riders with a high proportion of slow-twitch muscle fibers, who know how to pace themselves to meet the demands of the race; riders who deviate from a sustainable pace during a time trial tend to accumulate lactic acid quickly and deplete their glycogen levels faster (23).

Criteriums are mass start events (~ 40-90 mins in length) that consist of many laps of a closed circuit and are often held in a downtown area or on city streets to attract spectators; these events have become quite popular under USA Cycling (USAC) sanctions perhaps due to the spectator friendliness and sponsorship opportunities (15). This type of racing closely mimics the scratch race or points race in track racing with many accelerations out of corners, and it often favors the anaerobically gifted rider (24).

Mechanical factors associated with cycling have been well studied, especially air resistance, drafting, rolling resistance. As a rider increases their velocity by a factor of two, they have twice as many air molecules to contend with and the air molecules hit the rider twice as fast, requiring a massive amount of power to overcome them. At 40 kph, overcoming air resistance accounts for more than 80% of all the combined forces a cyclist has to overcome (25). Rider drag can be quantified through drag coefficient equations, which can be measured in a wind tunnel, or calculated using mathematical models as Kyle and Bassett have done (21). To overcome air resistance, road racing cyclists are often seen drafting and using each other to "block the wind." Kyle (25) states that a close drafting cyclist effectively places the trailing cyclist in an artificial tailwind from the front rider decreasing the air drag of the trailing riders upwards of 40%, or in terms of power- a reduction of ~30% compared to the front rider. As the gradient increases and speeds are lowered, air resistance has less of an impact, and rolling resistance becomes a greater factor in performance (26). Rolling resistance is affected by the weight on the tires, tread pattern, tire pressure, tire material, the tire's contact patch, and the road's surface (27).

Equipment selection in road cycling includes the bike, as well as the helmet and clothing a cyclist wears in an event. With the majority of a bike's weight in the frameset and wheels, these are often the most sought after upgrades and with notable reason- Jeukendrup and Martin (28) developed a mathematical model to compare a standard bicycle frame against an aerodynamic bicycle frame to demonstrate there are substantial benefits to more modern aerodynamic frames. Kyle (27) has used wind tunnel testing to similarly show that aerodynamic wheels are vastly faster than traditional wheels; Blocken and Malazia (29) have more recently used computational fluid dynamic modeling to further support this. This has led to many manufacturers producing aerodynamically shaped road racing frames and wheelsets with a deeper profile (often made of carbon fiber) in recent years.

Certain physiological characteristics like VO_{2max}, lactate threshold (LT), and muscle fiber type have been studied extensively in cyclists, particularly at the elite level. VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) values for champion cyclists are among the highest ever recorded (2, 3, 5, 10, 30). While much controversy exists regarding the methods to determine the power output associated with LT (31, 32), it can be seen that in almost all studies of professional cyclists, their LT power represents an extremely high percentage of their VO_{2max} power- in many cases near 90% (33). Subsequent studies have also delved into the notion of different somatotypes and physiological characteristics existing between specialty riders (10).

Training for competitive road cyclists has been built upon the concepts of specificity, overload, progression, and recovery (91), similar to other endurance sports. Training regimens are frequently broken into different cycles: macro-, meso-, and micro-. Macrocycles generally consist of a road cyclist's year-long plan and contain the athlete's long-term goals, while mesocycles are generally between 2-6 weeks in length and work on a specific area relative to the racer's specific needs. Microcycles break down training even further to between 3-7 days (34). Effective interval programs for improving VO_{2max}, particularly for those who are well-trained and have plateaued in fitness, may include repeated bouts of strenuous exercise that elicit 95-100% of VO_{2max} (35). While many interval programs can elicit this, there is controversy regarding the precise intensity and duration of interval bouts that is most effective.

The measurement of training load has been greatly influenced by technological advancements, particularly head units and power meters. Head units display a live map of the rider's location through global position system (GPS) to help them navigate. They can also display and record other metrics like distance, speed, HR, power, and elevation gain. Power output has long been available on cycle ergometers in laboratories. However, on-bike power meters allow cyclists to ride their own bicycle *and* to have a snapshot of their work rate at any moment in time. The accessibility of head units and power meters has also made it possible to conduct research on the training habits of road racing cyclists. While the accuracy of electrically braked cycle ergometers in the laboratory may be superior, the information provided from a head unit coupled with an on-bike power meter can provide sufficient accuracy for the aspiring road cyclist.

Types of events in road cycling & rider characteristics

Competitive road cycling is a strenuous activity that required many hours of training, tactical knowledge, and combativeness in competition. However, it is not just one type of event; there are sub-disciplines that act almost as an entirely separate sports within road cycling. Both professional and amateur racing consist primarily of three events: road races, time trials, and criteriums. Due to the distinct energetic demands and characteristics of each event, riders with vastly different physiological makeups can be more suited towards one event than to others.

Road race. The road race is the event seen most commonly in European bicycle racing (15) This mass-start event is often between 30 and 80 miles for amateurs, while professionals can have single day races be in excess of 180 miles (14). Road races can consist of laps of the same loop, a course that goes away from town but ends with finishing circuits, or (as often seen in a stage-race) it can be a point-to-point route.

Long, flat road races (or those on rolling terrain) present a variety options for teams from a strategic standpoint; the team can attempt to place an aerobically gifted rider(s) in a breakaway that goes ahead of the peloton (i.e.- the main pack of riders), or the team can try to keep the race together and lead-out a sprinter. Road races can often encompass a race within a race, as riders try to get into the breakaway. This pivotal moment can be the most physically demanding part of the race (36). Teammates or other riders in the breakaway can then work together by utilizing drafting to overcome the prominent force in this terrain: air resistance (17). Due to the reduced energy requirements of riding in the slipstream of another cyclist, drafting plays an immense role in the outcome of the race (16). Meanwhile, teams that do not have a rider in the breakaway will attempt to chase the breakaway down, so that they can get their sprinter into the right position in the peloton for the final kilometers of the race; the sprinter attempts to draft his/her teammates (to minimize energy expenditure) until the very end, and then outsprint the competition in the final meters. Races that are many hours in length often end up being decided by centimeters. These flat and fast finishes make up about one-third of the stages at a Grand Tour (Giro d'Italia, Tour de France, Vuelta a España) event, and many other race days throughout the year in both amateur and professional ranks (14). Although events ending in a mass bunch sprint are very common, teams often have one designated sprinter due the unique physiology required (18). Sprinters must possess exceptional maximal power output after hours of racing, with the final 10-15 seconds exceeding 1,000 watts at the professional level (37). Moreover, sprinters must also be able to produce extremely high *repeatable* anaerobic efforts to be in the proper position to sprint (18). These repeated anaerobic efforts in the lead-up to the final sprint can be lessened with the help of teammates and effective cornering skills. This minimizes the accelerations over the final ten minutes of the race and preserves the muscle's energy stores for one final acceleration in the dash for the finish line (38). In other words, a bunch sprint is not just about peak power, previous literature has compared power output in the final 5 minutes of a flat road race to the intensity of a team pursuit, with many high cadence, high power, and high-speed efforts (18). Due to the long duration of most road cycling events, Burke and Costill (39) have noted that an extremely high proportion of fast twitch muscle fibers may not be required for success in cycling sprints, as seen in other Olympic level "sprint" events. However, compared to their road racing peers, sprinters are likely to have a higher percentage of fast twitch (Type II) muscle fibers (40).

Hilly road races favor a different type of rider than flat road races, since the primary obstacle shifts from fighting air resistance to overcoming gravity (20). Where the hills occur in the race, the gradients, and the total elevation change can all influence the outcome. However, certain riders who excel in this terrain typically have certain physiological characteristics: an extremely low body fat percentage coupled with a high maximal aerobic power output (41). Elite climbers not only have a high relative VO_{2max} (2-5, 41, 42), these riders can also sustain 80-90% of their VO_{2max} power for upwards of an hour (19). This sustainable 1-hour power output has been shown to be highly correlated with blood lactate concentrations of 4mM (7). When there are long, sustained gradients in road races or uphill finishes, the maximal-power-output-to-body-weight ratio (W/kg) is widely regarded as the single most important determinant in performance (13). Elite climbers excel in particular on racecourses that finish on a steep, sustained climb as their skillset is magnified.

Time trial. The individual time trial is the only event in road racing where racers do not start *en masse* (all together), and it is often referred to as "the race of truth". There is no drafting allowed; the rider is only relying on their own fitness without others to break the wind. In one sense, a time trial is the simplest form of racing, but technological advances have made it quite intricate. Most time trials cover flat to rolling terrain, and air resistance is the primary factor opposing the rider in these events (43). With no drafting allowed, and time trial races generally lasting an hour or less, comfort and optimal muscular efficiency (44) are often sacrificed to gain an aerodynamic advantage. It has been well documented that aerodynamics is greatly influenced by body position (22). A horizontal upper body coupled with forearms resting on pads and handlebar extensions straight in front of the rider are used to decrease aerodynamic drag (43). This body position was pioneered by Boone Lennon (inventor of the aerobars) and popularized by Greg LeMond in the 1989 Tour de France. Scottish Rider Graham Obree used even more extreme bicycle set-ups and body positioning, but these have since been disallowed by the governing body of cycling (Union Cycliste Internationale) (21). Time trial events tend to favor aerobically gifted riders who know how to pace themselves to meet the demands of the race; riders who deviate from a sustainable pace during a time trial and ride a variable pace will accumulate lactic acid more rapidly, deplete their glycogen faster, and become vulnerable to fatigue (23). It has also been proven through wind tunnel testing that racers who are larger in stature do have considerably more frontal surface area than smaller riders, but their increased aerodynamic drag is more than offset by their larger aerobic power (20). Consequently, taller cyclists with the greatest absolute aerobic power (VO_{2max} in L/min) have an advantage over smaller cyclists in flat time trials.

Criteriums. Criteriums are mass start events (~40-90 mins in length) that consist of many laps of a closed circuit and are often held in the downtown of a city to attract spectators (15). This type of racing closely mimics the scratch race or points race in track racing, or the cycling leg of draft-legal triathlon in terms of power output (24). Criterium racing demands repeated pace changes and accelerations for multiple corners per lap. The power output of a criterium race can also resemble the power surges of trying to get into a breakaway, with many 5-30s high intensity efforts (45) repeated throughout the entire event. Furthermore, criteriums also regularly offer mid-race prizes (primes) as incentivizes, which increase the need for short, intense efforts. Success in criteriums requires effective cornering skills that reduce the intensity of accelerations and limit anaerobic efforts, yet many criteriums come down to the final sprint, from either a breakaway group or the entire peloton (18). It has been shown that varying the power output prompts greater glycogen depletion, especially in type II muscle fibers (46). If a rider can maintain a more constant power output, this allows him to spare muscle glycogen and have greater levels of adenosine triphosphate (ATP) and phospho-creatine (PCr) stores in muscle which are needed to fuel a finishing sprint (47). Consequently, riders with exceptional anaerobic ability who ride in a way that conserves the body’s energy stores tend to be successful criterium racers. Depending on the nature of the course, a flat course with significant opportunities will suit a sprinter while a criterium course with significant elevation change will suit a climber (20).

Stage-races. The most prestigious events in the sport of cycling are stage-races, combining events of the previously mentioned disciplines. A common format in stage racing is taking the finish time of an individual rider on each stage, and adding them all together to determine an overall, cumulative time (15). These events range from 2-21 days in length and are often decided by time differences of mountain-top finishes (from 5 to 20 km in length) and time trial events (~30-60km in length) (48). This makes the dynamics of the stage-race compelling, as the physiology of a superior climber and a superior time trial rider are often different. Besides the aforementioned differences in rider size, Lucia et al. (49) has found that ‘climbing specialists’ often have a greater ability to recruit muscle fibers than their ‘time-trialing specialist’ counterparts. This would explain their ability to change speed in the mountains, when grade fluctuations require up to 100% VO_{2max} power for maintaining speed. Time trial specialists, on the other hand, often have a more efficient pedaling pattern and lower fiber recruitment at a comparable power output (49).

Categories in road cycling

Professional. Currently, men’s professional road cycling is comprised of three levels: World Tour, Pro Continental, and Continental teams. Women’s professional road cycling is comprised of World Tour and Continental level teams. Nearly every professional race requires racers to compete as a part of a team regardless of the team’s level. Each of these pro levels has their own minimum salary for riders and teams at all professional levels may compete at the same events throughout the season. These pro teams often are associated with a training and/or development team with the same or similar sponsors, that help develop riders for a higher level.

Amateur. Amateur cycling categories vary from country to country. However, in the United States the governing body of the sport, USA Cycling (which evolved out of the USCF) ranks riders into Categories 1 to 5, for both men and women. A novice begins at a category 5 and may upgrade through categories by winning points at mass start events. Both mandatory and voluntary upgrades exist in amateur USA Cycling. Riders who are clearly outperforming other riders in their category can be forced to upgrade after having earned a maximum number of points in the last 36 months of their respected category, while others seeking an upgrade can meet a minimum number of points and voluntarily upgrade (1).

Physiological factors influencing performance

Maximal oxygen uptake. Maximal oxygen uptake (VO_{2max}) is widely regarded as an accurate gauge of cardio-respiratory fitness (50) and the best measurable limit of the ability of the cardiovascular system to deliver oxygen to the muscles, where it is consumed in the mitochondria (51). Increases in VO_{2max} can result from increased cardiac output (i.e. stroke volume) or an increased a-v O_2 difference (i.e. muscle blood flow or capillary density and size of mitochondria). VO_{2max} can be expressed in absolute terms ($L \cdot min^{-1}$) or relative to a person's body mass ($ml \cdot kg^{-1} \cdot min^{-1}$); the latter is more commonly used in road cycling since body mass plays such a critical role in performance. VO_{2max} values have been well documented in road cyclists (men), particularly for professionals (2-5) but less so for amateurs (6). Although many studies obtained the values using a graded exercise test (GXT), it is worth noting that varied levels of initial power output and the increments in power between the stages across protocols have been used (52). A set of criteria for the attainment of VO_{2max} (53) has been established and used in many studies, but the most reliable method for verifying attainment of VO_{2max} is to allow the individual to recover after a VO_{2max} test, then have them pedal as long as they can at a supra-maximal work rate and see if a higher value for VO_{2max} value achieved (54, 55). If not, then it is certain that VO_{2max} was attained. Prediction equations for estimating VO_{2max} have been created and used in some settings but they are less accurate than having a subject perform a maximal GXT, and measuring oxygen uptake by respiratory gas exchange (56). Regardless, it has been accepted that VO_{2max} is an important factor in endurance road cycling performance as it sets both an upper limit for steady state VO_2 and thus an individual's ability to produce energy via aerobic pathways during athletic competition (57). The % of VO_{2max} at lactate threshold (LT) is the highest power output during an incremental test before an exponential increase in blood lactate concentration begins to occur (58). With that being said, a high VO_{2max} is a prerequisite for cycling at the elite level (59).

Lactate threshold. Previous research suggests that LT might be an even more important determinant in road cycling performance than VO_{2max}. Accumulation of lactate acid is indicative of the physiological stress within exercising muscle, and it also indicates the degree to which anaerobic metabolism is called upon. Power outputs below LT can be sustained for a considerable length of time (several hours) since the rate of lactate appearance equals the rate of lactate disappearance, and lactate is not accumulating in the blood. Power outputs above LT are not sustainable for extended periods of time (rate of appearance > rate of disappearance). Just as LT in runners is highly correlated with running performance in races ranging from 3,200 meters to marathons (60), in cycling LT is highly correlated from the 4,000-meter pursuit to 3-week stage races (57). LT is particularly applicable in cycling because, it determines the power output that can be sustained during a long-distance event (13). Cyclists with the same VO_2 (submaximal or maximal) values can be travelling at different velocities due to interindividual economical differences between riders, however, when coupled with power output *and* LT, a closer predictor to race performance is determined (42). Furthermore, although VO_{2max} can be increased through intense training, it has been noted that LT appears to be far more "trainable", and it can continue to change over many years of intense training. This is why some athletes do not reach their peak performance until they are in their 30s; their LTs continue to increase even though their VO_{2max}

has stopped going up (61). Untrained individuals can have an LT around 50-60% of their VO_{2max}, while highly trained individual's LT may not occur until 75-90% of VO_{2max} (62).

Muscle fiber type. Muscle fiber profile of a cyclist may also influence performance in competitive road cycling. Burke et al. (39) were among the first to describe how athletes frequently have a different fiber type makeup compared to the average population. In the study, elite endurance runners were found to have 60-70% Type I (slow, aerobic, fatigue-resistant) fibers, while track & field sprinters had ~80% Type II (fast, anaerobic) fibers; untrained individual displayed a 50/50 ratio of Type I to Type II fibers. It has also generally been accepted that endurance training can alter muscle fiber physiology, with Type IIx fibers (very fast, very low resistance to fatigue) being converted toward Type IIa fibers (moderately fast, fairly high resistance to fatigue). There is also an increase in the cross-sectional area of Type I (slow twitch) fibers that are recruited during endurance-type activity. This can depend on the intensity and duration of training. With resistance training, selective hypertrophy of Type II fibers occurs. However, with most cycling training programs emphasizing aerobic riding, it can be assumed Type I fibers will undergo more hypertrophy. This theory holds because of the size principle of motor unit recruitment- small, slow-twitch motor units are the easiest to recruit, while larger, fast-twitch motor units are the last to be recruited and this only occurs when there is a need to generate high power outputs (63). The trained musculature of endurance athletes often possesses a much higher percentage of Type I muscle fibers (8), and this seems to hold true amongst cyclists as well (9). Some studies have shown that cycling efficiency is greater in those individuals with a greater percentage of Type I muscle fibers in the vastus lateralis (64), potentially due to the greater efficiency of Type I muscle fibers compared to Type II muscle fibers, but other studies have contradicted this (65). In bicycle road racing, sprinting ability may be less dependent on having a high percentage of fast-twitch fibers than other sports (e.g.- track and field). In part, this is because road racers can shift their gears to allow slower or faster speeds of muscle contraction, and more or less force generation, at the same cycling velocity.

Mechanical efficiency. Due to the convenience of cycle-ergometry, gross efficiency (GE) has been studied extensively in cycling; GE is determined by dividing the mechanical work rate (i.e., power output in watts) by metabolic energy expenditure (kcal/minute). Metabolic energy expenditure is usually determined by indirect calorimetry (i.e.- respiratory gas exchange methods used to assess VO_2 and V_{CO2}) (66). GE in bicycling exercise is usually in the range of 20-25% (42).

Pedaling cadence. Pedaling cadence (rpm) has been studied extensively in regard to GE. It has been well established that road cycling with a high cadence (>90rpm) reduces the force required per pedal stroke (67) and Hagan et al. (68) have shown that the RER is significantly lower in cyclists riding at 90 rpm than 60 rpm. However, it appears cycling at a high cadence does demand a greater energy expenditure (69) and many early studies with short protocols (1-6 minute bouts) consistently favored a very low cadence (40-50 rpm) (70, 71). It was not until Coast et. al (72) began implementing lengthier bouts of cycling with more experienced riders, and studied range of power outputs, that physiologists gained a deeper understanding of the relationship between cadence and GE. At higher power outputs for longer periods of time (much more comparable to in-race efforts), a much higher cadence (80rpm) seemed “optimal” from both a GE and perceived exertion standpoint. However, the authors found that cycling at low power outputs still favored a lower cadence, which was in agreement with previous research. These results tended to support the notion that cadence may impact fiber type recruitment with a greater number of Type I muscle fibers recruited as cadence increases (73). Type I fibers work more efficiently, thus result in a higher GE in the rider. Regardless, it appears that elite cyclists gravitate towards higher cadences (73).

Crank length and saddle height. Other factors that can influence GE are crank length and saddle height. Bike fit is critical not only from an injury prevention standpoint, but also for maximizing power output. Surprisingly, research shows that even very significant changes in crank length (up to 50mm) elicit relatively small changes in GE (74, 75) while small changes (<20mm) in saddle height prompt larger changes in GE (75, 76). However, the adverse long-term effects of using extreme crank lengths or riding with an improper bike fit (ex. seat height > 50 mm different from 'correct' position) from have not been well documented.

Mechanical factors influencing performance

Factors such as air resistance, rolling resistance, and gravity are all unavoidable impeding forces acting upon a road cyclist. The sum of these factors could be described as the power requirement that a rider must generate through aerobic and anaerobic contributions. These mechanical factors have been studied extensively in wind tunnels and outdoors, particularly since the introduction of the SRM power meter (that directly measures power output on a cyclist's own bike). To increase a rider's power supply is not that simple, and to decrease the energy required of a rider might be an easier way to tip the scales in favor of the rider.

Air resistance. While differences in training and genetics can explain the physiological differences between riders, there are many other factors such as rider position and equipment choice that can impact cycling performance by decreasing the power requirement. Even untrained cyclists may have the ability to ride at 20 kph (12.4 mph) on level ground. To go twice that speed might require four or five times as much power- due to the greater forces impeding the cyclist. In fact, air resistance for more than 80% of the combined forces that a cyclist has to overcome at 40 kph (25). As a cyclist increases their velocity by a factor of two, there are twice as many air molecules to contend with and the air molecules hit the rider twice as fast, requiring a massive amount of power to overcome them. Air resistance increases as the square of velocity; thus, an immense amount of the power is necessary to overcome the drag on the rider and bike (43). Rider drag can be dictated by a drag equation (C_dA) that encapsulates all relevant drag information about the rider. While much of initial research on drag has been done in wind tunnels, researchers such as Kyle and Bassett (21) have constructed mathematical models based upon C_dA to determine the power requirements of events such as the Hour Record. Although the particular equation used was pertinent to track cycling and factored in the embankments of a velodrome, the advances in understanding air resistance compared to speed still held. The 'C_d' represents the aerodynamic drag coefficient and the 'A' illustrates that drag is proportional to size; 'A' is synonymous with frontal area (FA) for cyclists. Combining the bike and rider can establish FA; this is proportional to the power required to overcome air resistance (20). FA can be captured through a photo in front of the rider in their racing position, typically ⅔ of FA is from the rider, the other ⅓ is from the bike itself. This process is difficult to measure and hard to recreate, so Kyle and Bassett (21) were able to develop a formula ($A_f = 0.0293H^{0.725}\,M^{0.425} + 0.0604$) factoring in rider height (meters) and weight (kg) (body surface area (SA)) to approximate FA. By combining this with empirical measurements from a power meter, they were also able to compute the drag coefficient. This development helped further quantify why smaller cyclists are at a disadvantage when cycling on flat terrain- the increased energy requirements of the bigger cyclist's frontal drag is more than offset by the larger absolute power output (due to the higher absolute VO_{2max}).

Drafting. Cyclists are often seen working together to overcome air resistance through the process of drafting. Drafting is critical in all mass start road races and provides a unique aspect of cycling where riders from different teams may work in unison. This cohesion can be seen with opposing riders working together in the breakaway, or in opposing riders working together to catch the breakaway. Kyle (25) states that closely drafting cyclists are subjected to decreased air resistance of up to 40% when in the peloton, and up to 30% when drafting a single rider. This reduction in drag could be extrapolated out to a decrease VO_2 in by 14% or a decrease in heart rate by 7.5% (77). McCole et. al (78) also concluded that the metabolic (VO2) benefit of drafting becomes greater as the velocity increased. Drafting helps to explain why tactics in road cycling are incredibly crucial, and why mass start races are not always won by the rider with the greatest maximal aerobic power. The effects of drafting are amplified the closer a rider trails the rider/s in front who is “blocking” the wind. However, it is critical to acknowledge that riders also can obtain slipstream effects even up to five bike lengths behind a leading rider (25). The no-drafting rule is strictly enforced in individual time trials; as riders catch a slower rider, they need to maintain a distance of at least five bike lengths before using the other side of the road to pass the slower rider. Enforcing this rule helps to minimize the benefits of drafting. In addition, the rider in front can also receive upstream benefits from a trailing rider; this can lead to as much as a 3% reduction in drag (79). While drafting is perhaps simplest to understand with a direct headwind, it can also be very effective if the wind is coming from the side. In a cross-wind, a rider can obtain the greatest drafting effect when riding on the leeward side, slightly behind and to the side of another rider (27). In this instance, echelons will form. This is where riders line up in a diagonal manner across the road seeking maximum draft in a crosswind.

Rolling resistance. While air resistance increases as the square of velocity, rolling resistance appears to remain constant despite changes in velocity (25). It should be noted that frictional resistance in the drivetrain (bottom bracket, chain, and cassette) and wheel bearings also exist but are occasionally lumped in with rolling resistance. It is hard to improve upon resistance in the drivetrain and wheel bearings, due to the limited range of equipment from a couple of manufacturers who dominate the market. For that reason, rolling resistance of tires appears to be more frequently studied in regard to cycling performance. A bicycle tire (and wheel) deforming on the road surface is the primary cause of rolling resistance. The frictional resistance against the tires is affected by the amount of weight on the tires, tread pattern, tire pressure, tire material, and the road surface (27). Wider tires (>25mm) at lower tire pressures are being seen more and more commonly in road races in the last five years; in fact, no team started with a tire less than 25mm in width in the 2017 Tour de France (80). Continental has published in house tests and claims that "a 20mm tire with 160psi, a 23mm tire at 123psi, a 25mm tire at 94psi and a 28mm tire at 80psi all have equal rolling resistance" due to the way a tire deflects under load (81). The theory is that narrow tires may 'flatten' further than a wider tire, so although the contact patch to the road is the same area, the wider tire holds a rounder profile. Although wider tires have less rolling resistance at the same inflation pressure, they also have more aerodynamic drag than narrow tires (82). However, with the wider rims now being produced, the aerodynamic penalty of using wider tires is reduced, and this explains their growing popularity. Rolling resistance is incredibly difficult to measure outside due to the road surface not always being constant and the presence of other confounding variables. For example, having a rider hold the same body position, at the same velocity, and the wind being perfectly constant, would be required to measure rolling resistance (83).

Altitude. Altitude has been extensively studied because of the challenges and opportunities it holds for cycling performance. As elevation increases, the partial pressure of oxygen decreases and subsequently air density decreases. This drop in wind resistance alone should result in faster cycling speeds; however, the drop in partial pressure of oxygen at high altitude limits VO_{2max} and aerobic energy production. The oxygen cost of riding a stationary cycle ergometer at 100 watts is essentially 1.5 L/min of oxygen at both sea level and high altitude, but the relative effort is much higher at altitude due to the effects of altitude on VO_{2max}. VO_{2max} drops by 5-9% for each 1,000-meter increase in altitude (16, 84-86). These observations create an interesting dynamic when cycling at higher elevations. Although the effects of air resistance (or aerodynamic drag) are smaller at high altitude than at sea level, the relative exercise intensity increases and may counteract any wind resistance benefits.

A common example studied in literature is the 1968 Summer Olympics in Mexico City situated at 2,300 meters (7,300 feet). While many anaerobic sprint running and cycling events in these games were faster than their sea level races in prior Olympics, endurance events like the men's marathon slowed by more than 8 minutes (6.2%) compared to the prior Olympics in Tokyo (held at sea level). It also appeared that to be competitive for a medal at the distance events in the 1968 Olympics, athletes who were high-altitude natives or had recently completed altitude training had a distinct advantage (87). The 1968 Olympics helped bring altitude training and competition to the forefront of exercise science. In fact, they prompted Eddy Merckx to successfully attempt the cycling world hour record in 1972 in Mexico City. Although the effects of altitude on cycling performance have since been studied through further hour record attempts on velodromes, it is still up for debate as to what altitude is optimal for record-setting. It is dependent on a number of factors such as the amount of time a rider spends at higher elevations and the extent of their physiological acclimatization. In 2015, Sir Bradley Wiggins broke the unified hour record (aerodynamic equipment- but with UCI restrictions) in London at 9 m (29 feet) elevation above sea level (a.s.l.). In 2019, Victor Campenaerts surpassed this mark in Aguascalientes at 1,890 meters (6,200 feet) elevation. While Kyle and Bassett (21) have estimated an altitude of 2,500 meters (8,200 feet) to be optimal for record-setting (and even higher altitudes optimal for shorter events), few velodromes exist that are that high in elevation. There is also an advantage to indoor velodromes, which eliminate headwinds that could slow the rider. Smooth, shiny track surfaces will decrease rolling resistance by reducing "scrubbing" of the tires on the track that occurs whenever front and rear wheels are not perfectly aligned.

Although it is difficult to predict exactly how altitude influences mass start road racing, it can be seen that the level of absolute intensity does decrease as altitude increases (88). Many races take place at moderately high altitudes 1,500 - 2,500 meters (4,920 feet - 8,200 feet) which may favor the more acclimatized riders. Consequently, to compensate for not being born or living at altitude, elite riders often spend sojourns at higher altitudes or sleep in hypobaric chambers. Some athletes use an "altitude tent" which simulates high altitude with a lower % of inspired oxygen. All of these can provide some of the benefits often associated with altitude training: increases in hemoglobin concentration in the blood, blood buffering capacity, and in alteration in substrate utilization- a decreased reliance on fat as a substrate and increase glucose uptake perhaps can improve economy (63). However due to the time needed for sufficient adaptations to occur these options are not always practical. Much research has been done on the type of altitude training: live high, train low (LHTL), live high, train high (LHTH), and live low, train high (LLTH). It is difficult, however, to come to a conclusion as to which is most effective with regards to performance at altitude and sea level. Moderate to high-altitude training camps have proven beneficial for events occurring at an altitude greater than 1,500 meters (4,920 feet) (89) but the literature is divided on the benefits of altitude training for subsequent sea-level performance (90-92). While many factors can be investigated, it appears the reason not all altitude camps are successful at improving sea-level performance of athletes can be of the following reasons: time to acclimatize may be insufficient or the altitude may be too low to stimulate an increase in red blood cell mass, quality of training is compromised (altitude limits training intensity), or the enhanced stress associated with training altitude can lead to overtraining (88). Due to the aforementioned reasons, the LHTL paradigm has received the most positive results regarding performance at sea-level (93). According to the LHTL paradigm, training below 1,500 meters (4,920 feet) but living above 2,500 meters (8,200 feet) should allow an athlete to still acquire the physiological advantages of living at altitude (increases in hemoglobin concentration, adaptations in skeletal muscle, buffering capacity, or an alteration in substrate utilization where glucose uptake becomes more prominent) without compromising training intensity. However, the LHTL principle poses limitations for those who cannot attend a high-altitude training camp, or who do not have access to a hypobaric chamber. It should be noted there is controversy regarding the effectiveness in using a hypobaric chamber to simulate the LHTL principle in other endurance sports (94, 95).

Equipment selection

Equipment selection is another important factor that influences cycling performance. Beyond the rolling resistance of bicycle tires, frictional losses in the drivetrain and bearings, and rider position on the bike; the bicycle frame, wheels, clothing, and helmet can influence performance. An upgrade in any of these areas can reduce air resistance by reducing the drag coefficient, or increase performance by decreasing the overall weight of a rider plus bike. Due to

UCI and USAC regulations, equipment choices (and rider position) are somewhat limited. Since racers who compete in events promoted by these governing bodies make up a sizable portion of the market for cycling equipment, most of the equipment is designed for them, and made to be race legal.

Frame. The frame of the bicycle is limited by the UCI to a traditional 'double-diamond' shape (96). Frames traditionally came with tubes that were completely round and steel, however, the UCI has allowed the tubes to be streamlined, and the most common bike materials now are either carbon fiber or alloy and have some shape to attempt to reduce drag. The use of carbon fiber material has also allowed bike frames to become much lighter. Some early aerodynamic frames lacked lateral rigidity, but this is no longer as much of a concern. With today's frames, the gain in aerodynamic performance outweighs any drawbacks of diminished rigidity. Aerodynamic frames become standard issue for road racers not just in individual events like the time trial, but also in mass-start events. Jeukendrup and Martin (28) developed a mathematical model to compare a standard bicycle frame against an aerodynamic bicycle frame. They examined three levels of rider and predicted that in a 40 km time trial, using an aerodynamic frame saves between one-minute and 17 seconds and one-minute and 44 seconds depending on the rider's fitness. While body position plays a larger role in individual time trial performance, the frame of the bicycle can reduce drag significantly in mass start and individual events.

Wheels. Wheels are perhaps the most sought-after upgrade due to the likelihood an individual can get both an aerodynamic advantage and a weight advantage from stock equipment without rebuilding the entire bicycle. However, to procure an aerodynamic *and* lightweight wheelset will cost the rider financially. Rotating weight is considered far more crucial in performance due to inertia. Since wheels rotate far more than other parts of the bike, this makes weight savings at the wheel's rim advantageous (82). Many racing wheels exist that are made of carbon fiber composite for racing. The spoke count, rim depth and surface can all influence wheel weight, stiffness, and aerodynamics. Spokes and rim depth can influence stiffness or aerodynamics, and the surface of the rim and spokes can either be dimpled to provide a 'golf-ball' effect, completely smooth and shiny, or a combination of the two to achieve maximal aerodynamic benefit (29). While manufacturers use these proprietary technologies for marketing purposes, nearly every wheel in the modern era follows the pattern of both wheels being 622mm (27") in diameter due to UCI restrictions (96). Professional teams often have a wheel sponsor that provides them with a variety of rim-profiles and spoke counts to best suit the terrain, with riders often selecting the lightest wheels if grades found in the race reach a steep grade (~10%) where speed drops and work against gravity is the major obstacle. If the course is flat to rolling, a deeper rim, although heavier, is often selected due to its superior aerodynamics. In fact, it is common to see a completely solid rear wheel (a solid front is not legal) in an individual time trial event, even though the poor stability in crosswinds initially discouraged riders from using them (27). Similar to bicycle frames, wheels have been studied extensively in wind tunnel testing, computational fluid dynamics (CFD), and real-world conditions. However, without a uniform testing methodology, direct comparisons of wheels are difficult (97). In general, it can be concluded that an aerodynamic front wheel is of more benefit than an aerodynamic rear wheel (28) since the rear wheel is partially shielded by the frame and rider. Also, bladed spokes are faster rather than round spokes (78), and the optimal rim depth depends on the wind speed and rider size (98). It should also be noted that due to the rapid development and popularity of disc brakes on road bikes, manufacturers have been attempting to aerodynamically optimize frames and wheels to work better with this type of braking system.

Helmets and clothing. Both helmets and clothing are critical for reducing wind resistance as well, but neither has as much variability in weight as frames or wheels. Hence, less emphasis is placed upon them. Although helmets and clothing have become more optimized with individual time trials originally in mind, riders can now be seen wearing skinsuits and aerodynamic helmets in mass start events. Helmets have become significantly more aerodynamic than the "hair-nets" road cyclists used to wear in the early to mid-1900s. Rounded edges, smooth lines, and very little ventilation are often seen in helmets for individual time trial events as these often can improve time by up to one second per mile over even a shaved head without a helmet (49). Helmets in the 1990s and early 2000s for individual time trials almost all had a long-tail "tear drop" that would lower drag when in the optimal position, however, recent wind tunnel tests have shown that if the rider breaks from the optimal position, the tail actually results in increased drag (99). This has led many helmet manufacturers to reduce the length of the helmet- still keeping the rounded edges and smooth lines to make the helmet more circular but overall making the helmet noticeably shorter. This trend has carried over to helmets made for mass-start races, albeit with much more ventilation.

Clothing has also made enormous gains in recent years in terms of road cycling performance relative to wind resistance- the drag of an ill-fitting jersey is easily discernible to the naked eye, since wrinkles in the jersey fabric create increased drag. It has been demonstrated on cycling mannequins in the wind-tunnel and with road cyclists in the real world that well-fitting, plain polyester-based lycra is nearly as fast aerodynamically as spandex and about one-minute faster across a 40km time trial than the wool cycling jersey (49). While a one-piece skinsuit often rests flusher against the skin and thus is more aerodynamic, it was not optimized to keep a rider cool, until wicking technology was developed. Combining a light-weight spandex and elastomer combination allows road cyclists to be the most aerodynamic possible while still allowing body heat to escape.

Training concepts & technological advancements

Endurance training studies. It has been well established that different individuals respond differently to endurance training. Some untrained individuals see as much as a 50% improvement in maximal oxygen uptake (VO_{2max}) from a training program (either endurance or interval-based) while others, categorized as non-responders, see little or no gain in VO_{2max} (100). Study designs for competitive cyclists often involve: a pre-test, a randomized control trial (RCT), and a post-test (101). The pre- and post-tests on typically use an identical protocol (ie. cycle ergometer VO_{2max} test with the same ramp rates).

Traditional training studies generally follow an agenda of these principles, whether clearly stated or not: functional over-reaching (FOR), non-functional over-reaching (NFOR), and exceedingly rarely overtraining syndrome (OTS) designs. FOR study designs are workouts that take a very short time to recover from within it- usually days; NFOR study designs are a much higher training load or volume and often take weeks to recover from, while OTS study designs are the most rigorous and may take months to completely recover from (102). These broad concepts of training can be applied to both resistance and endurance training and are not just limited to cycling programs. A typical training study design is typically 4-12 weeks in duration (101) and may follow one of the four methods that a cyclist may use in more naturalistic settings. These include block periodization, linear/traditional periodization, non-linear/undulating periodization, or reverse periodization. Variations in terminology can lead to inconsistencies between studies (103). Regardless, all of these study designs rely heavily on high intensity interval training (HIIT). However, each periodization model uses HIIT at different times throughout the plan. HIIT involves repeated bouts of high intensity exercise (power ranging from 90-170% of VO_{2max} for 30-240 s) interspersed with recovery periods (ranging from 60-360 s). Such interval training is one of the most effective ways to improve metabolic function and cardio-respiratory fitness in an individual (104).

Cycles of training. Phases and timing of training are heavily debated among both coaches and athletes. Both athlete and coach need to make adjustments according to the race program the racer participates in during the season. In general, there are different cycles during a typical training season: macrocycles, mesocycles, and microcycles. Macrocycles generally consist of a road cyclist's year-long plan and contain a road cyclist's long-term goals, while mesocycles are generally between 2-6 weeks in length and work on a specific area relative to the racer's specific needs (34). A typical and perhaps the most common mesocycle found in road cycling literature might be 3-weeks of demanding and specific training, followed by 1-week of planned recovery, during which both the volume and intensity purposely decrease to allow time to adapt to the prior three weeks (12). Microcycles break down training even further to 3-7 days. These days, all together, comprise a 'block' of workouts to help progressively overload the training volume (105). Many training programs contain everything from the macrocycle on down to the microcycle, with the coach and athlete starting with broad goals and then breaking them down into more specific performance goals. One way to structure a training program is for these specific performance goals to be tested after each mesocycle. For example, a coach may designate a 4-week block of threshold training in preparation for an upcoming race with an extended climb at the finish of the race. Throughout this 4-week mesocycle, a rider may complete 2-3 workouts per week designed to improve their functional threshold power (ie. 2x20 minute efforts just below functional threshold power). After a short rest period, the coach would then see if the athlete improved their threshold power, as determined by either a graded exercise test or a 20-minute power test.

Measuring training load. Assessment of physical activity (PA) can be done using physical activity questionnaires (PAQs). These PAQs ask about the amount of time that certain activities are performed at a certain number of metabolic equivalents (MET) and often used to compute a weekly training volume (in MET·minutes). While useful for the lay individual, PAQs are very subjective, and some do not even report exercise intensity. This provides little value for those engaged in competitive sport (106). Measuring training load can also be done objectively, through the use of heart rate monitors, GPS units, wearable devices, and power meters. These methods are all used in road cycling.

Heart rate. Heart rate (HR) is extremely accurate when the monitor is a chest-strap device that wirelessly transmits to a receiver unit. When compared to an electrocardiograph (ECG) (107) HR monitors provide extremely valid and reliable estimates of heart rate (108). HR monitors provide a measure of the physiological load on the body imposed by different external work rates (i.e. power requirements). Furthermore, HR values are impacted by changes in stress, hydration, temperature, and/or altitude nearly instantaneous feedback. With regard to road cycling, a heart rate monitor can easily show how much harder the body is working to overcome gravity and ascend a hill than to descend it. HR training books such as *Precision Heart Rate Training* by Burke (109) suggest categorizing heart rate values into zones to help monitor intensity. A simple index of total training stress could be obtained using a points per minute in zone (TRIMPS: one-minute in zone 1 is one point, one-minute in zone 2 is two points, to help estimate a total workload for a given ride or week. Furthermore, if the heart rate training zones are determined during a laboratory test (which is necessary since maximal heart cannot be estimated accurately) and coupled with blood lactate testing, this can provide a very sound basis for training zones. However, rapid fluctuations in intensity seen in road cycling are very difficult to account for just by using heart rate. There is a time lag between when a cyclist increases his/her power and when the HR increases. In addition, many factors can influence HR, including changes in ambient temperature (110), hydration, altitude, stress, and/or position on the bicycle itself (111). Relying solely on heart rate in training makes it difficult to measure road cycling progress.

Resting heart rate. Resting heart rate (RHR) is not a direct measure of training load, but it can also be a useful metric. The most common method of using RHR to assess training stress is to take both a supine and standing value in the morning and compare the two values to monitor overtraining (112). Using this method, the athlete should take supine and standing HR daily- the greater the difference between these two values, the more likely it is that the individual is overtrained. Other studies and methods have been even simpler and require an individual to obtain a seated resting heart rate and compare it from day to day (113). Even though tracking RHR is a simple and perhaps effective (114) the concept of measuring resting heart rate to prevent overtraining is not well documented. In theory, if the resting heart rate is elevated, the athlete should rest, if resting heart rate is normal, the athlete can continue with the training program. Having a comparable resting heart rate to baseline is supposed to indicate that an individual is ready to continue the training program as prescribed, while an increase from baseline (particularly for the standing position) is considered an indicator of overtraining (115)96).

RHR has limitations as an indicator of over-training. It does not indicate readiness for competition or when an athlete should back off from doing intense workouts. Many studies do not have specific parameters as to what qualifies as too much of a HR difference from baseline (116). Furthermore, the build-up of training stress and purposeful overtraining (associated with FOR and NFOR) may or may not even present physiological signs and symptoms initially (102). To the best of our knowledge, no training studies have developed algorithms to alter the workouts based on the RHR value measured on that day- all studies are either “rest” or “train” based on the RHR indication; there is no light-to-moderate or endurance training days if the RHR is slightly elevated. If guided exclusively by RHR, this may limit the total number of training days for athletes.

Wearable devices. Wearable devices have also evolved drastically over the last fifteen years. Wearable devices can include similar features to pedometers, sleep-trackers, pulse-oximetry, HR monitors, or GPS units to name a few possible functions. Worn during workouts and throughout the day, devices like the WHOOP® strap or OURA™ ring record heart rate variability (HRV). This can help develop a ‘daily strain’ score (117) which has gained tremendous popularity among athletes and road cyclists alike. An athlete or coach can potentially use this to determine exercise intensity or duration for the day based upon the stress-recovery continuum the platforms record on based on HRV. HRV is a non-invasive metric that records the differences in R waves across time relative to the mean heart rate of an individual; then a score is reported that is derived from the root square mean of successive differences (118). HRV measured by these devices has also been deemed accurate compared to HRV determined by an ECG (119). HRV can fluctuate throughout the day and is purported to be indicative of readiness to perform vigorous exercise because of its link to the autonomic nervous system (120). It could also conceivably show that an individual is more recovered and ‘ready to perform’ in the evening than a morning workout. With these particular devices worn all-day, the proprietary algorithm used to generate 'daily strain' values most likely also takes into account HR and sleep. While HRV is highly interindividual and research is not entirely committed to the notion of it, there is research showing that with an increase in HRV, an individual can be more capable to perform moderate to vigorous PA (117, 121). Likewise, an individual dealing with recurring stress- physical or otherwise, can use HRV as a signal the autonomic nervous system is disrupted. This is perhaps how the HRV devices are most marketed as a training tool- to prevent overtraining to optimize physical performance- rather than as a recording device. High vagal activity is directly related with an increase in physical performance (122). Adding the variable of HRV allows an athlete to see if their vagal activity was high and further can indicate to what extent the previous day(s) training stress is weighing on their body (116, 117, 123). If the individual's HRV was very low compared to previous recordings, it could prevent an athlete from attempting a HIIT workout, failing to complete the prescribed workout, and falling further into NFOR. Instead, the athlete or coach determining the workouts could prescribe an easier, more-manageable workout for the athlete. There are few studies that provide evidence for the efficacy of using HRV to guide an athlete's training (124). With the WHOOP® strap or OURA™ ring providing HRV, an athlete can receive a suggestion to train moderately on the day, as opposed to either training or not training on the day (118). The HRV devices can suggest an intermediate workload or a "proceed with caution" element that is not often seen with RHR.

<u>Head units.</u> Prior to Global positioning system (GPS) devices becoming popularized in early 2000s, much simpler, cycling-specific computers were still commonly seen on most road cyclists' bicycles. These devices, called cyclometers, calculated distance based upon wheel circumference and revolutions, measured with a simple magnet on the spokes and magnetic reed switch on the fork, could display trip length, average speed, maximum speed, and time.

Cyclometers allowed road cyclists to capture and record total training volume, while HR monitors measured training intensity. Coupled together, road cyclists were able to better capture fluctuations in training load; however, with road cycling being so heavily dependent on conditions (i.e., wind speed/direction, road surface, equipment, drafting, etc.) there was still large room for error.

Today, commercial GPS head-units are extremely popular amongst racing road cyclists. Garmin® (Olathe, KS) and Wahoo (Atlanta, GA) dominate the market even internationally and have the ability to capture many data points beyond the original cyclometers. These devices are commonly found on the handlebars of a racer's bike. Head units not only display a live map of the rider's location to help them navigate but can also display other metrics like HR, power, and elevation gain. A power meter uses strain gauges to measure torque applied by the cyclist, and when combined with angular velocity can calculate power in watts (13). Power can be displayed (just like HR) from a wired or wireless connection to the head unit. GPS (head unit) devices like this have also increased the popularity of social media apps, such as Strava®, which allows users to upload GPS files to track progress along road segments or compete (asynchronously) against their peers on the same road segment.

Power meters. On-bike power meters are now widely available and are perhaps the most effective way to track a road cyclist's training load. When combined with accompanying software, power meters can provide information on both training volume and intensity. Power meters can be located in the bicycle's crankset, pedal, or rear hub. With more options becoming available each year, the price is starting to come down from thousands to hundreds of dollars. Power output measurements have long been available on cycle ergometers; however, the on-bike power meter allows a cyclist to ride their own bicycle *and* to have a snapshot of their power at any moment in time. Commercially available power meters can display a rider's power output (in watts) and they also allow for data to be recorded through either ANT+, Bluetooth, or the company's own head-unit. These data recording allows for athletes and coaches to examine the completed training session and associated physiological responses in much greater detail. While power meters report the amount of work done in kilojoules (kJ) and energy expenditure is typically measured in kilocalories (at least in the United States), it must be noted that power meters are measuring external work (kJ)- not total energy needed to perform that work. By knowing the level of external work, this can be used to estimate the amount of metabolic energy used to accomplish that work. By definition, gross efficiency is the ratio of external work to the energy expended in order to do that work. The gross efficiency of most road cyclists usually falls between 20-25%, depending on a number of factors (125). (e.g., 300kJ of mechanical work / 4.184 = 71.4kcals; 71.4kcals * 4 (efficiency is 25%) = 285kcals) For each 1.0 kJ of mechanical work performed, a cyclist expends 4.18 kJ (i.e. 1.0 kcal) of energy. Thus, a cyclist can use the number of kJ of mechanical work displayed on their head unit to estimate the metabolic energy they used during their ride, and this in turn can be helpful in estimating how many kcal they should consume each day.

The SRM (Jüllich, Germany) crank-based power meter was the first commercially available power meter in the late 1980s, however it was both extremely expensive and heavy which discouraged even the most data-driven athlete. PowerTap™ (Madison, WI) released a hub-based power meter in the late 1990s which was also heavy and limited rear wheel options for riders, but the device was far less expensive and began to open up the market for amateurs and professionals who became sponsored. SRM and PowerTap™ (now with pedal-based power) are still two of the top power meter companies, but brands like Quarq (Chicago, IL), Stages

(Saddleback Ltd., UK), Rotor (Salt Lake City, Utah), Pioneer (Tokyo, Japan) and Power2Max (Waldufen, Germany) have entered the market at much more affordable rates, further driving down the cost of owning a power meter. Although mobile power meters existed much earlier, few knew how to interpret the data that was being recorded, particularly due to the highly variable nature of outdoor riding. Hunter Allen and Andrew Coggan (13) published one of the first comprehensive guides for interpreting power meter data titled *Training and Racing with a Power Meter* in 2006. This book has established a foundation that many software companies (ie. TrainingPeaks™) have based training stress around, often with a heavy reliance on Coggan's concept of Normalized Power® (NP). Coggan's PhD in exercise physiology and personal riding background helped him recognize that the mean power output of an outdoor bike ride does not adequately describe the relative effort. A bike ride on undulating terrain, or one where speed alternates between fast and slow, is perceived as much more strenuous than a bike ride on flat terrain with constant speed. Coggan reasoned that the physiological responses (e.g. lactate production, glycogen utilization, hormone levels) are curvilinear in regards to exercise intensity, and this means that segments performed at or above lactate threshold are far more demanding on the body. Coggan also documented that these physiological processes are not instantaneous with the power output, and have 30-second half-lives (e.g. ventilation, plasma epinephrine concentration, HR). Taking these factors into account, Coggan formulated a metric called normalized power (NP) to help provide a more accurate measure of the true physiological stress of a given training session, compared to mean power. Furthermore, companies like TrainingPeaks now use NP to measure training stress and determine the Intensity Factor® (IF) of a ride, coupled with duration can provide a Training Stress Score® (TSS).

Physiological characteristics and training habits of cyclists. Studies on the physiology of cyclists exist; however, they are usually only done on cyclists at the very elite level (*Table 1, Appendix A*). A men's professional cyclist VO_{2max} generally falls between 5.0-5.5 L/min or 70-80 $ml \cdot kg^{-1} \cdot min^{-1}$(19) with exceptional riders like the previously mentioned well above these markers, particular during the race season in peak condition. Similarly, Burke (82) reported that the 1984 U.S. men's national team had a VO_{2max} of 74.0 ± 8.3 $ml \cdot kg^{-1} \cdot min^{-1}$ (mean ± SD) and the amateur category I men studied with a VO_{2max} of 70.6 ± 9.5 $ml \cdot kg^{-1} \cdot min^{-1}$. Burke noted the relatively small metabolic differences between these two groups; this has prompted further studies (126) that have looked at the physiological differences between professional road cyclists (who have ridden at least one of the three Grand Tours) and elite cyclists who were the same age as their professional counterparts. Interestingly, the differences between the two of these groups were seen at submaximal intensities and not necessarily VO_{2max}. The professional riders' LT occurred at a higher relative intensity, suggesting a very high reliance on fat metabolism. While much controversy exists regarding the methods used to determine the power output corresponding to LT (31, 32), it can be seen that in almost all studies including professional cyclists, the professional riders' LT power is at an extremely high percentage of their VO_{2max} power- in many cases it is near 90% (2, 10). This 90% value is noticeably different than that seen in amateurs and based on not just these studies but past evidence. LT is the best physiological indicator of road cycling performance, even more so than VO_{2max} (52). Fewer studies have both examined and reported physiological characteristics like VO_{2max} of amateur cyclists below category I, and even less so with regard to categorical differences amongst women cyclists (6). While it is expected that there is a decline in VO_{2max} amongst categories in USAC, Tanaka et al. (6) reported the VO_{2max} of amateur categories II, III, and IV cyclists in the United States Cycling

Federation: men category II riders in the group presenting a mean VO_{2max} of 69.39 ± 1.28 $ml \cdot kg^{-1} \cdot min^{-1}$, men category III riders 64.98 ± 1.71 $ml \cdot kg^{-1} \cdot min^{-1}$, men category IV riders 63.63 ± 1.94 $ml \cdot kg^{-1} \cdot min^{-1}$, and women riders category II-IV at 52.48 ± 2.82 $ml \cdot kg^{-1} \cdot min^{-1}$ (*Table 2, Appendix A*). Although Tanaka had a relatively small sample size of women (N=6), interestingly, a meta-analysis conducted consisting of twenty studies totaling 232 competitive women cyclists, VO_{2max} was reported as a mean of a nearly identical 52.5 ± 5.5 $ml \cdot kg^{-1} \cdot min^{-1}$ (127). It should also be noted that most masters' road racers, regardless of gender, experience a decline in VO_{2max}- despite continuance of training (128).

As physiological characteristics like VO_{2max} and LT have been obtained, data has also been collected and analyzed at the very elite level to reflect the physical demands of races- in particular Grand Tours (Giro d'Italia, Tour de France, Vuelta a España) and discussed extensively (45, 48, 129). Even more emphasis has been placed on riders excelling at different types of races. Subsequent studies have also delved more into the notion of different somatotypes and physiological characteristics existing between specialty riders; this is especially true at the professional level (10). These studies have been translated down to the amateur level- grouping riders into "flat terrain," "hill climbers," or "all-around riders" determined by a cycling team's coach (130). While the main differences are anthropometric measurements like body mass index (BMI, in kg/m^2, body fat percentage (BF%), body mass (muscular, bone, and fat mass) and height were significantly different between "flat terrain" riders and "hill climbers" with the latter having lower values in all of metrics in this particular study (130). The only physiological difference between those groups was for relative VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$) with the "hill climbers" having a higher VO_{2max} than the "flat terrain riders" (130).

Information has been published about the specific training habits of professionals, but less information exists at the amateur level. Total training volume has been estimated at between 25,000 km and 35,000 km for the average (man) pro cyclist (52); it is estimated to be between 70-80% of this for the (woman) professional cyclist, who typically competes in shorter events (11). Van Erp, et al. (11) also reported on mean training volumes and time spent in various intensity zones, in men and women professional cyclists. Their study concluded that women professional cyclists spend less time on the bike, but train at a higher relative intensity than men professionals. However, they did not report on the power outputs that can be sustained over varying time periods. This is commonly known as the "power profile" of a racing cyclist, which is constructed using the on-bike power meter that is used throughout the year.

Coggan has published a theoretical model of power profiles relative to cycling category (13) but few studies have empirically studied professional bike racers to document peak power outputs that can be sustained over varying periods of time (21, 131, 132). These data could prove useful since they are highly correlated with different physiological characteristics such as neuromuscular power, anaerobic capacity, VO_{2max}, and LT. While studies exist regarding power output at VO_{2max} (2, 10), peak power during a sprint (18, 38), and power at LT (33) in professional cyclists, few studies have been conducted on amateurs. Thus, "power profiles" of amateur cyclists could help refine our knowledge of differences in neuromuscular power, anaerobic capacity, VO_{2max}, and LT, without the need for expensive laboratory equipment.

Related to training volume and relative intensity are the effectiveness of different training regimes, a topic that has been studied at many levels of cycling, especially in relation to VO_{2max}. It should be noted that improvements in VO_{2max} are attributable to an increase in oxygen delivery by the heart, lungs, and red blood cells (central adaptations) and improved oxygen uptake in the muscles (peripheral adaptations) (63). Literature often designates two different types of training, continuous-training and interval-training, with many subcategories falling under the latter. While both interval training and continuous training can improve VO_{2max} in untrained persons, interval training, particularly HIIT (repeated power output ranging from 90-170% of VO_{2max} power for <45-240 s, interspersed with recovery periods) has been proven to be more effective at increasing VO_{2max} (133-135). Interestingly, in many studies, high-intensity interval training also proved to be more effective for weight loss and improving body composition, despite requiring significantly less caloric expenditure during the actual rides (135). However, simply saying that interval training is more effective than continuous training in many aspects of road cycling is an oversimplification; it is impossible to train at the intensity used in many of the short-term training studies for prolonged time periods. Attempting to do so could lead to burn out or injury.

While it is well established that interval-training is more effective at increasing VO_{2max} than continuous training, the relative intensity of the intervals, length of recovery from the intervals, and frequency of the intervals is far more complex and difficult to determine what is most effective for road cyclists. Effective intervals in regards to improving VO_{2max}, particularly for those who are considered well-trained and have plateaued in fitness, include repeated bouts that elicit 95-100% of VO_{2max} (35). While many intervals can elicit this, literature has some controversy regarding what length and intensity is the most effective. There have been significant increases in VO_{2max} with intervals as short as “Tabata intervals” (134) very short bouts of extremely high intensity at 170% VO_{2max} power for 20-seconds of work with only 10-seconds of recovery repeated seven or more times over. However, longer high-intensity intervals such as 8 minutes at 90% VO_{2max} power for four repetitions, followed by 4 minutes of recovery, have proved effective at increasing VO_{2max} (136). Intervals longer than 8 minutes (although still more intense than continuous training) would generally fall below the HIIT range of power outputs (<90% VO_{2max} power output) and may not result in as much improvement in VO_{2max}. However, this type of training program will induce other training adaptations such as: an increased reliance on fat oxidation, promotion of fast-twitch muscle fibers to have slow-twitch muscle fiber characteristics, and increases in cardiac output (137).

Looking at training intensity distribution can also help at what training habits riders are currently completing; however, the importance of volume is often overlooked when just analyzing intensity distribution, just as studying exclusively volume or mean intensity does not paint the entire picture of a training program. Many sources use different training models based on anywhere from three to seven zones of intensity which complicates the literature and perhaps misleads unfamiliar researchers and cyclists alike. Two of the most popular training programs currently are based upon completing sessions regarding “sweet spot” training (SST) (13) and “polarized” training (138) which differ significantly in training intensity distribution. In an SST-based program, cyclists train with long interval bouts (often 15-45 mins) exclusively at 88-94% of LT power many times per week. SST would, in theory, elicit many physiological benefits such as an increase in plasma volume, an increase in LT, an increase in muscle glycogen storage, and hypertrophy of ST-muscle fibers. The idea is to train just below the LT to avoid fatigue and burnout. On the other hand, with polarized training the vast majority (~85%) of training is conducted well below their LT power (perhaps as low 60%), as little training as possible falls into the “gray area” of 75-100% of LT power, and the remaining 10-15% of training is at a high intensity, certainly above the LT and often at around 100% VO_{2max} (138). Professional athletes in a variety of sports often follow a model that resembles polarized training (139, 140). In part, this may be due to the fact that many have the time required to ride many hours (20+) weekly, and lots of purely aerobic training may be the only thing physically possible for such durations.

While there is controversy in the literature regarding the effectiveness of varying interval lengths and intensity, many studies have deemed that block periodization is more effective than traditional or linear periodization (141, 142). Traditional periodization is when the athlete simultaneously develops his/her training abilities (sprint, threshold, endurance) throughout a season, whereas block periodization consists of very concentrated periods directing towards developing the athlete's specific abilities sequentially over a period of time, generally between 1-4 weeks (143). Within a single 'block,' a common strategy is to progressively load the amount of targeted intensity, e.g., a coach may designate a 4-week block towards threshold training in preparation for an upcoming race with an extended climb at the finish of the race. The "training blocks" in blocked periodization are then separated by a period of recovery to allow for necessary physiological adaptations, and the blocks 'build' upon each other, getting more physically demanding as time goes on. Many plans start back after an off-season with a training program that has one or two endurance-based, low-intensity blocks of continuous-training in an attempt to build up the aerobic capacity, improve reliance on fat metabolism, and increase plasma volume. The program then moves on to an interval-based training block.

Resistance training has also been shown to improve performance in cyclists, particularly in regard to peak power output and economy, in both men (144-146) and women (147). These studies have used 'maximal strength training' for lower body exercises that includes high loads and few repetitions to stress neural adaptations rather than muscle hypertrophy. Short bouts of maximal strength training appear optimal for cyclists since the resistance training ensures activation of the neuromuscular system. However, none of the studies above resulted in weight gain (148), which is often seen with other weight lifting programs. Core stability training has been less studied in regard to improving performance but it may help with cycling mechanics (149). Core stability training may also be useful from an injury prevention perspective (150).

CHAPTER III: MANUSCRIPT

Abstract

New advancements in bicycle instrumentation and social media applications have made it possible to obtain quantitative data on training and racing. **PURPOSE:** To analyze training data (training volume, frequency, distance, speed, and race days) and power profiles of road racers in USA Cycling, in order to compare genders and categories (professional, 1, 2, 3, 4, 5). **METHODS:** Part 1: Using USAC race results, racers with an active Strava® account were selected. Using data uploaded from on-bike GPS head units, 543 USAC racers' (279 men, 264 women), 2019 data were documented. Part 2: Subjects with power meter data displayed on Strava® were contacted for demographic information and peak power data (5-s, 1-min, 5-min, 20-min, and 1-h). 92 amateur racers (67 men, 25 women) completed this part of the study. Annual training metrics, power data, and survey results were compared across the categories and genders using ANOVAs. **RESULTS:** Part 1: In 2019, professional women (N=20) rode 634.7±135.2 hours, 16,581±3,562 km, and completed 304.4±28.5 ride days, 33.2±7.8 races; professional men (N=29) rode 864.7±160.0 hours, 26,103±5,210 km, and completed 310.6±39.3 ride days, 49.9±17.1 races. There were significant gender differences among professionals, for all variables except for ride days ($p<0.05$). Among amateurs, training volume, distance, races, and ride days all declined as category increased, but there were no gender differences within categories 2, 3, 4, and 5 for these variables. Part 2: The power profiles showed an exponential decline in power output (W/kg) with increasing measurement periods (5-s to 1-h). Category 1 women had significantly higher power outputs compared to other amateur women in 5-s, 5-min, and 20-min power ($p<0.05$). The differences between category 3-5 women were non-significant. Category 1 men had significantly higher values than other amateur men in 5-min, 20-min, and 1-h power ($p<0.05$), and category 2 men were significantly higher than category 5 men

in 20-min power ($p<0.05$). **CONCLUSION:** Some differences exist for annual training data and power profiles between USAC categories and genders. Knowledge of the training characteristics and power profiles of USAC men and women athletes could be useful to road racers and coaches in designing training programs.

Introduction

Road racing in the United States grew in popularity during the 1970s, with the introduction of the governing body United States Cycling Federation (USCF), which later developed into USA Cycling (USAC). While professional road racing still remains far more recognized in Europe, participation in amateur bike racing in the United States has increased in popularity. There were 69,684 unique racing licensees acquired in 2010, an increase of 63% from the 42,724 licenses in 2002 (1). Of those USAC license holders, each racer is designated as belonging to a category between 1 and 5, with category 5 comprised of beginners. Racers can earn upgrade points through placings at USAC-sanctioned events to move up in category.

Road cycling consists of three primary disciplines: road races, time trials, and criteriums. There are differences in the length and format of each of these events, and distinct energetic demands are needed to be successful in each. This allows riders with different physiological characteristics and training habits to be more suited to one event than to others. Several physiological factors determine a racer's success in the aforementioned disciplines: maximal oxygen uptake (VO_{2max}), lactate threshold (LT), and muscle fiber type are relevant to bicycle road racing. VO_{2max} values have been well documented in road cyclists; this is especially true at the professional level (2-5), but less so at the amateur level (6). VO_{2max} is important in cycling because it sets the upper limit for aerobic energy production via oxidative pathways. Power outputs below LT can be sustained for several hours, but outputs above LT are not sustainable for extended periods of time (7) and thus LT is critical to performance. It should be noted that the trained muscles of endurance athletes often possesses a much higher percentage of Type I muscle fibers (8), and this seems to hold true amongst cyclists, as well (9).

Although these precise physiological metrics require a laboratory-like setting to measure, recent developments in technology have essentially allowed for cyclists to have a rolling laboratory on their bikes, even on outdoor rides. Head units use a global positioning system (GPS) to display a live map of a rider's location for navigation, and can also display and record distance, speed, elevation, heart rate (HR), and power output (if linked to a power meter). In addition, the use of social media apps, such as Strava®, now allow riders to upload GPS files to track progress along road segments and compete (asynchronously) against their peers on the same road segment. In many instances, these data (i.e., distance, duration, heart rate, and power) are publicly available. While the accuracy of laboratory measurements is preferred by exercise physiologists, the information provided from a head unit coupled with a power meter can be almost as informative for the aspiring road cyclist. Scientific studies have been published on the training habits and power outputs of professionals (2-5, 10, 11), but far less information is available at the amateur level (6).

Training plans have been outlined in literature to guide road cyclists in using these head units and power meters effectively. A book by Friel, *The Cyclist's Training Bible* (12), provides background information, case studies, and a table of "suggested annual training durations." The anticipated training volumes (in hours) can be used to develop a training plan for professionals as well as for amateurs in categories I-V within USAC. It is recommended that professionals train between 800-1200 hours annually, category I and II's 700-1000 hours, category III's 500-700 hours, category IV's 350-500 hours, and category V's 200-350 hours annually (12). These values were originally 'rough estimates' according to Friel's earlier editions of the book and most likely based off his own personal coaching experience. The type of training that Friel recommends includes cycling, resistance training, and other forms of cross training. However, although these numbers are frequently cited, little empirical research exists to support them. This is especially true in regard to gender differences. While Friel's training recommendations include time spent on the bike, resistance training, and cross-training, the current study will be gathering data exclusively on cycle training.

Coggan and Allen's *Training and Racing with a Power Meter* (13), published in 2006, was one of the first books to show individuals how to analyze power data and use it effectively in training. Inside, a chart developed by Coggan displays power outputs relative to weight (W/kg) for each category across the timeframes 5-sec, 1-min, 5-min, and functional threshold (95% of one's 20-minute power). Coggan built this chart using interpolation to estimate the range of values for eight categories (international pro, domestic pro, categories I-V, non-racer) based on the highest known values ever recorded (by pros) and those recorded by the average, untrained population. These timeframes (5-sec, 1-min, 5-min, and functional threshold (95% of one's 20-minute power)) were chosen to yield power outputs that reflect neuromuscular power, anaerobic capacity, VO_{2max}, and LT. Even without access to a laboratory, cyclists can ride their own bike equipped with a power meter to obtain this information. Compiling an individual's data from these four timeframes has been dubbed 'power profiling' and can be used to predict what type of rider the cyclist is (ie. sprinter, time-trialist, climber, all-arounder). Race performance is the best indicator of how an individual compares to other road racing cyclists or their respected category, but these benchmarks (W/kg) can provide training parameters or goals for athletes. Coggan's original power profile table was developed by anchoring the high and low ends of the continuum against professional riders and untrained cyclists, respectively, and then verifying it against amateur riders (13). However, there may be a need to compare their power profiles to those of other USAC road racers.

The purpose of this study is to further analyze the training habits and power profiles of current USAC road racers. Today, online platforms such as Strava® can serve as a publicly available database that allows a closer look at the training habits and performance capabilities of professionals and amateurs alike. This could provide insight into differences between genders and categories, and perhaps serve as a practical guide for what racers are currently doing in training and racing.

Methodology: Part 1- Training/racing characteristics of USAC road racers

1. Participants

The first part of the study was conducted anonymously. The inclusion criteria included having an active USA Cycling (USAC) race license, racing in the US in 2019, having a public Strava® profile, and performing regular uploads from January 1, 2019 – December 31, 2019. Results from USAC races across all regions were selected, and then cyclists who participated in these races were searched for on Strava®. If a cyclist did not have a public Strava® profile with weekly data from January 2019 – December 2019, they were excluded from the study. In total, publicly available data on 543 subjects were examined. For each of the USAC Categories 2, 3, 4, and 5, we studied 50 men and 50 women. For Category I men, 50 racers were studied. However, due to the limited number of category I women and professional racers meeting the inclusion criteria, only 44 category I women, 29 professional men, and 20 professional women were studied. The study methods and procedures were approved by The University of Tennessee, Knoxville Institutional Review Board.

2. Procedures

For the first part of the study, subjects were chosen using a stratified sampling technique. For each region of the country (Northeast, Southeast, Midwest, Southwest, and West) an equal number of USAC races were selected to represent the study. Three placings in each race were selected to be searched using a random number generator, to help ensure an accurate representation of categories (both high and low placings with and amongst categories (e.g. 3rd, 11th, and 27th place in each category of each event). If there was no 27th place due to a low number of race participants, or if the rider did not meet the criteria for inclusion in the study, then another number was randomly generated until three riders per category per event were obtained. The corresponding rider's publicly available data were obtained on www.Strava.com, which is a social media app for endurance sports that can record cycling activities when paired with global positioning systems (GPS). In order for a subject to qualify for this study they had to have an active USAC license and an active Strava® account. If an individual had an active USA Cycling race license but did not have a Strava® account, data could not be collected for that individual and the individual was excluded from the study. If the individual met the inclusion criteria of having a public Strava® profile to which they uploaded weekly for the two-year period of January 1, 2019 to December 31, 2019, then data were recorded based upon their respective cycling category in USAC. By using the cyclist's Strava® profile and USA cycling page, their annual cycling distance, annual cycling hours, days of racing per year, total races per year, and days of riding per year were recorded. All of this information was publicly available.

3. Statistical analysis

Statistical analyses were performed with IBM SPSS statistics software version 27.0 (IBM, Armonk, NY). Data were analyzed using 2-way ANOVAs (USAC category x gender) for two main effects and the interaction effect of annual duration (2019 rider average hours), annual distance (2019 rider average km), average speed (2019 average speed), and annual races (2019 rider average race days). If the interaction was significant, the data were first split by category and tested for gender differences within each category. Then the data were split by gender and tested for differences between the categories. If there was no interaction effect between gender and categories, the data were analyzed for gender with pairwise comparisons for categories. Post-hoc analyses were run on the data using independent sample t-tests within each cycling category, or using a 1-way ANOVAs within each gender. To adjust for multiple comparisons, Tukey post-hoc procedures were used. Briefly, the computed p values were multiplied by the number of comparisons (e.g. 6 in the case of cycling category), and this value was then compared to the alpha level. The alpha level remained at 0.05 for all comparisons.

Methodology: Part 2- Power profiles of USAC road racers

1. Participants

For the second part of the study, a subset of the original 543 participants were studied. All those who uploaded and displayed their power-meter data were contacted. In all, 346 potential participants were contacted (214 men, 132 women) and asked to fill out a survey (Appendix E) and submit their power meter data to the researchers. In total, 92 USAC racers (67 men, 25 women) completed the survey and provided peak power data, which was recorded anonymously. The study methods and procedures were approved by The University of Tennessee, Knoxville Institutional Review Board.

2. Procedures

While the power data for each cyclist is visible on a ride-by-ride basis, it would be nearly impossible to pull the peak power data for every ride on a cyclist, since they complete hundreds of rides per year. When logged into one's own personal account, however, one can create a 'power curve' that displays the peak power outputs across a selected time period (e.g., one year). Cyclists with power-meter data (these data are visible on Strava) were contacted via the Strava® "app" to see if they were willing to provide their personal peak power files for 2019. If a cyclist provided informed consent, they were then asked to fill out a survey detailing their indoor riding, level of education, job status, height, weight, and USAC category. In addition, the cyclist was also asked to provide information by attaching screenshots on their maximum sustained power output for 5-seconds, 1-minute, 5-minutes, 20-minutes, and 1-hour time periods from 2019.

3. Statistical analysis

Statistical analyses were performed with IBM SPSS statistics software version 27.0 (IBM, Armonk, NY). Repeated-measures 3-way ANOVA's were conducted regarding power data obtained from 92 participants. Gender x USAC Category x Condition (W/kg across different time intervals) were compared. All power data was analyzed in relative terms, power to weight (W/kg) across five different time frames: 5-second, 1-minute, 5-minute, 20-minute (and 95% of 20-minutes) and 1-hour. Men and women were analyzed separately because of the significant interaction between gender ($p < 0.001$), and the lack of category 2 women in the study (0). Pairwise comparisons were run to test for differences between categories, for each gender.
To explore significant interactions, we ran multi-comparison within category with Tukey adjustments. 2-way repeated-measures ANOVA's (Tukey's Post-hoc) were run for men. To explore significant interactions, multiple comparisons were run within each category. For the tables describing the characteristics of participants in part two (Table 3 for females, Table 4 for males), Chi-Square tests were completed to look at indoor riding (expressed as a % of total volume) between men, women, and both. Indoor riding was analyzed using a nonparametric 1-

way ANOVA's (Kruskal-Wallis). Zwift Use was analyzed using a Chi-Square Test. Men and women were analyzed separately, and then a similar analysis was run on all individuals combined. Age and BMI were analyzed using a 1-way ANOVA with Tukey post-hoc to test for significant differences between categories, and separate analyses were run for men and women.

Results: Part 1- Training/racing characteristics of USAC road racers

In total, 543 USAC racers had their data anonymously collected for the 2019 cycling season. Descriptive characteristics of the cyclists' training and racing habits are presented in Table 1 (women) and Table 2 (men).

<u>Women.</u> Women covered significantly more distance (km) and had a higher volume (hours) of training and racing than each of the amateur categories in 2019 (both $p < 0.001$). Categories 1 and 2 were very similar in terms of distance ($p = 0.992$) and volume ($p = 0.998$), but each category below that was significantly different from one another. The less elite categories cycled less distance and amassed fewer hours of training. In terms of average speed, both category 1 and 2 racers were comparable to their professional counterparts ($p = 0.952$, and $p = 1.000$, respectively). Women in the less elite categories (3, 4, and 5) were similar to one another, but significantly different from the higher categories (pro, 1, and 2). Category 1 and 2 females were not significantly different in terms of annual training days ($p = 0.775$), but every remaining category was significantly different from one another in training days. In general, the less elite the category, the fewer days were ridden in 2019 (all $p = 0.001$). Category 1 females (M = 31.59 ± 14.50) participated in nearly an identical number of race days as professional riders (M = 32.45 ± 7.86), while every other category had significantly fewer race days than the preceding category.

Men. Professional men were significantly younger (M= 26.31 ± 3.81 years), and rode more distance (km) and volume (hours) than all amateur categories ($p < 0.001$, $p < 0.001$). There were no significant differences between the category 2 and 3 men in terms of distance (p = 0.256) or duration ($p = 0.241$) and likewise with category 3 and 4 ($p = 0.409$, $p = 0.373$), but all other category-to-category comparisons were significantly different. Professionals and category 1 men were not significantly different in average speed (M= 30.15 km/hour, 29.26), but these two groups were significantly faster than racers in categories 2, 3, 4, and 5. The latter four groups recorded nearly identical average speeds (M= 27.93, 27.65, 27.70, and 27.48kph, respectively). In terms of 2019 training days, there were no statistical difference between professional and category 1 men ($p = 0.439$), 1 and 2 ($p = 0.637$), nor between category 3 and 4 racers ($p = 0.584$), but every other comparison between categories was significantly different (p < 0.05). All male categories differed from one another ($p < 0.001$) in terms race days, except for category 3 and 4 males ($p = 0.083$).

Gender and category. Comparisons between gender were made within category. Figure 1 depicts 2019 training volume (hours), for each gender and category. While male professionals and male category 1 racers rode hours than their female counterparts ($p = 0.001$, $p = 0.003$, respectively), there were no differences for men and women in each of the remaining categories. A similar pattern is shown in Figure 2 with regards to cycling distance (km). The precise values are shown in Tables 1 and 2 for each gender and category. In each category, men had a higher average speed than women ($p < 0.001$), as shown in Figure 3. No significant differences were found in 2019 ride when comparing both gender and category ($p = 0.523$, $p = 0.310$, $p = 0.379$, p = 0.985, $p = 0.838$, $p = 0.545$) as shown in Figure 4. Professional men raced more often than professional women ($p < 0.001$); however, there were no gender differences in race days for amateurs in categories 1-5 ($p = 0.686$, $p = 0.788$, $p = 0.728$, $p = 0.162$, $p = 0.646$) (Figure 5).

Results: Part 2- Power profiles of USAC road racers

Descriptive characteristics of the women who completed the survey are displayed in Table 3. Descriptive characteristics of the men who completed the survey are presented in Table 4. No data on professional cyclists were collected in Part 2, because none of them returned the survey or provided power profiles. In this sample of competitive road racers, there were no statistically significant differences between USAC categories or gender, in regard to the *percentage* of indoor training, Zwift usage, or age. Body mass index (BMI) showed no significant differences in women; However, category 4 men had significantly higher values than men in categories 1, 2, and 3 ($p < 0.001$, $p < 0.001$, $p = 0.004$). Job status and level of education were also reported but were not analyzed for main effects or interactions.

<u>Women.</u> Table 5 presents the power profiles of the 25 amateur women in the sample. As expected, power output was inversely related to the measurement period. Category 1 women had greater 5-second power (W/kg) than all other women on which data were obtained (i.e.- categories 3, 4, and 5) ($p = 0.003$, $p = 0.001$, $p < 0.001$). The 1-minute power in category 1 was not statistically different than category 3 ($p = 0.323$) but statistically higher than category 4 and 5 racers ($p = 0.021$, $p = 0.002$). Both 5-min and 20-min power were significantly higher category 1 women, compared to category 3, 4, 5 racers, with no significant differences between the latter categories. With regard to 1-hour power, category 1 women were significantly different than category 4 women ($p = 0.011$) but no other statistical differences existed amongst women.

<u>Men.</u> Table 6 presents the power profiles of the 67 amateur men in the sample. There were no statistical differences in 5-second power among any of the categories. Category 1 men

showed statistically significant differences in power output (1-minute, 5-minute, 20-minute, 1-hour) from cyclists in all other (men's) categories, except for category 3 in 1-minute power (*p* = 0.397). In addition, category 2 racers had significantly different 20-minute power compared to category 5 (*p* = 0.020).

Discussion

Part 1: Training/racing characteristics of USAC road racers

This study revealed important findings in regard to annual training volumes and the number of events that road racers compete in per year. In general, road racers in more elite categories had greater training volume, rode farther, and trained and competed more frequently than less elite categories. However, the magnitude of the differences between categories only became apparent after analyzing the data, and this was perhaps the most important contribution of this study. Overall, there were significant differences between men and women in 2019 training volume (M= 503 hours; M = 450 hours trained and raced, respectively) and distance (M = 14,435 km; M = 11,700 km, respectively). However, category 2 men and category 2 women had comparable volume volumes and distance; the same is true for category 3 men and category 3 women, category 4 men and women, as well as category 5 men and women.

Although Van Erp et. al (11) compared the training characteristics of professional riders, very little information has been published regarding gender differences in amateur riders, especially in terms of training volume. We found that professional men accumulated more hours of training annually than professional women and rode faster, but there were few gender differences among the amateur ranks (specifically, categories 2-5). It could be theorized that the playing field is more level at the amateur level. The vast majority of our subset of amateur racers who provided demographic data were employed for wages in occupations other than cycling.

However, professional men cyclists rarely hold jobs outside of cycling, since they have better sponsorship opportunities. Professional women, on the other hand, are more likely to work part time or be in school, due to wage disparities. Cyclists' Alliance reported in 2020 that 25% of professional women were earning no salary at all in 2020 (152). In amateur racing, nearly everyone has a paid occupation outside of cycling, or they are attending school. This may explain the reasons many amateur categories are more comparable.

Friel's book, *The Cyclist's Training Bible* (12), has suggested training volumes for each USAC category, however this includes weight training and other forms of cross-training and our present study only looked at cycling training (as well as cycling racing) volume. There is no mention of gender differences in Friel's guide, but the numbers from our 543-rider sample have been placed against Friel's for sake of comparison (*Table 3, Appendix A*). In general, the suggested training volumes in Friel's book exceeded the training volumes observed in the present study which could be expected as Friel's chart included weight-training and other forms of cross-training. However, the magnitude of the differences particularly in category 2 racers is noteworthy, nonetheless.

The results from the present study may be useful to racers looking to upgrade their USAC category, since it will give them a realistic idea of the time commitment required. Although the present study did not assess training intensity, time-in-training-zones, or the various types of intervals that USAC racers are completing, it was nevertheless able to provide accurate, quantitative, and objective data on how many hours per year road racers are putting in during training and racing. Thus, while Table 3 can provide a rough guide of how much to train, the prescribed intensity is left up to the discretion of the rider (or rider and coach). In the future, obtaining more data on average power, normalized power, and time-in-training zones could help to better quantify the intensity requirements of the sport of cycling.

Average speed (kph) is depicted in Figure 3. Two distinct groups separated out from each other, within each gender. There were pronounced differences in average speed between [professional women, 1, 2] and [women 3, 4, 5] categories. Similarly, there was a large difference in average speed between [professional men, 1] and [menv2,3,4,5] categories. Part of the reason could be that cyclists in the more elite categories completed significantly more races that are done at a much faster pace. Another factor is that since elite riders are perhaps more likely to receive equipment sponsorships, they may be using lighter and/or more aerodynamic cycling equipment, allowing them to go faster.

The number of 2019 ride days (comprised of both training and racing days) are displayed in Figure 4. Men and women were comparable within each category (e.g., category 3 women from our sample rode an average of 236.6 days and category 3 men rode 236.4 days). In fact, the number of ride days was nearly identical within each category. It should also be noted that even professional riders took days off the bike. In this study, we cannot distinguish between mandatory days off (due to injury, illness, travel, etc.) or optional days off. However, it appeared in our sample that most professionals and elites purposely take 2-4 consecutive weeks off the bike in the off-season. The training volumes that professional riders accumulate throughout the year may make this necessary to avoid chronic fatigue. However, this was less prevalent in less elite categories. It was also interesting that even category 5 racers are getting more days on the bike than off it, further demonstrating the time commitment needed to race at even a beginner amateur level.

The first part of the study had several strengths. Firstly, it captured on-the-bike training metrics from highly reliable GPS head unit devices, and the results provide a general guideline on training characteristics (volume, distance, and speed) of road racers, separated out by category and gender. While head units have been utilized for quite some time in sport, few studies have looked at longitudinal data across the span of a years' time (11), especially in amateur categories or women. This study also had a unique design that enabled data from a large sample size to be obtained from a publicly available "app"; this provided an efficient and cost-effective method of harvesting data. In the subset of 92 racers who provided power data, this allowed us to establish power data without requiring visits to the laboratory.

As with any study relying on anonymous data collection and self-report, there were limitations. The sample could have been biased in several ways. First, riders were placed into each category in which they raced during the 2019 season; upgrading or downgrading categories could have occurred within a season. Thus, a rider could have changed categories during 2019 without the research team knowing this. We searched for riders of different placings at races on Strava and excluded riders who did not have a Strava account, and this could have biased the results. For example, the use of Strava could be more skewed to a younger population, which would mean that we were not getting a truly representative sample of all USAC racers. Since this study only searched for riders who were 18 years of age and older, and juniors make up a sizable portion of the riders in some categories, the ages in the sample may not accurately depict the categories. With regard to the sub-sample used in Part 2, those who were in this study all used Strava, and this might make them more inclined to also use the virtual-reality platform Zwift (an online platform for indoor training and racing). Using self-report usually results in some degree of bias, particularly when it comes to recalling exact measurements of body height and weight (153).

For this study it was assumed that individuals uploaded every ride to Strava. Riders were excluded from the study sample if they were not uploading weekly, however, there is a chance that not all rides for every rider were published. Due to the way the most popular GPS head units upload via Bluetooth and directly to Strava or through a 3rd party application, as soon as one hits ‘end ride’ rides are usually all published. An individual would have to manually go back and delete the ride for it not to be aggregated into their yearly total. Due to this Strava characteristic, we can safely assume that a high percentage of riders were uploading every ride. One challenge that did arise was multi-discipline or multi-sport athletes. Even if a rider is uploading every cycling activity to Strava, if they do a lot of training off-road (either mountain bike, cyclocross, or gravel) their yearly distance and average speed could significantly be impacted. While this study did everything possible to ensure that those studied were primarily active road racers in USAC, athletes who used other cycling disciplines were not excluded. Athletes who trained using other modes (e.g., running, lifting, swimming) did not have that volume recorded.

Part 2: Power profiles of USAC road racers

The survey data indicated that cyclists from this sample (N=92) tend to be highly educated (82 (89%) holding a college degree or more). They tended to use indoor cycle training and, in many cases, virtual-reality platforms (e.g., Zwift) with their indoor training. While there were no significant differences between category or gender, roughly 30% of the cyclists’ training was completed indoors, and 60-65% of the indoor training was done on Zwift. Unfortunately, the survey did not refer to a specific year in reference to indoor training and Zwift, these values could potentially be overestimates due to the recent surge in both indoor training and racing on Zwift during the ongoing coronavirus pandemic and not an accurate reflection of 2019 data.

The power data provided from our sample has been overlayed (to the closest mean value) on Coggan's Power Profile chart (adapted from *Training and Racing with a Power Meter; Table 4, Appendix A and Figures 8-15, Appendix B*). Many of the mean (W/kg) values of category 1 racers obtained from our sample fell into the anticipated range of power outputs, but lower categories were less aligned. Coggan's table perhaps underestimates how similar in power categories 3 and 4 are and the difference in category could be more related to category 3 racers having more knowledge, better bike handling skills, or simply racing more frequently than category 4 racers.

To further emphasize individuals did not necessarily have power outputs equal to their categorical peers across each timeframe, three example riders from each gender have been noted in Figures 6 and 7; riders' classification was determined by power relative to means in their category (both category 1). Both the men and women 'sprinter' had noticeably higher 5-second (and in these cases 1-minute) power relative to the means of their categorical peers; the women's sprinter chosen had a comparable FTP to her categorical peers while the men's sprinter selected was noticeably lower than the majority of category 1 men. Both men and women 'climber' selected were more proficient in the 20-minute relative power yet were less anaerobically gifted with noticeably lower 5-second power outputs. The 'all-arounder' was a rider selected in each gender who had higher values than the category mean across all four timeframes collected.

The current study has both strengths and limitations. The primary strength was the use of a method that allowed us to gather data on the training and racing characteristics of USAC road racers across the country, as well as their power profiles, without having to bring them into the laboratory. Competitive road cyclists are heavily invested in the use of technology to monitor their training, and many of them own head units with GPS and power meters that send wireless signals to the head units. In addition, the Strava app is a useful platform that aggregates these data and makes them available to researchers.

A limitation of the study was the low number of women in part 2. Fewer women were contacted (since less of them had public profiles on Strava and displayed power data) and the response rate for the survey was low. In addition, it must be acknowledged that the power data were not collected using a structured laboratory protocol, with consistent warmup. *Training and Racing with a Power Meter* suggests completing a 5-minute all-out effort prior to the 20-minute all-out (then take 95% of this 20-min) bout to more accurately depict functional threshold power, but there was no way to determine how warmed up (or fatigued) all riders were prior to any of these peak power outputs. Nevertheless, the riders' peak power outputs were recorded across the entire year, and this was consistent across riders. Another limitation could have been differences in the values obtained by power meter produced by different manufacturers. Most power meter brands on the market today are advertised as either ±1% or ±2% accurate, but their overall accuracy can be affected by the fact that many power meters only have strain gauges on one side (i.e., left crank arm) and a rider's leg strength imbalances can increase the magnitude of error.

Conclusion

Differences exist for annual training metrics between different USAC road race categories and gender. The data presented in this study could be used to guide riders and coaches when planning an annual training program or developing goals for power output (W/kg) under different conditions (5-s, 1-min, 5-min, 20-min, 1-hr). Future studies should replicate the methods used in this study on a larger scale and place more emphasis on obtaining power data from women.

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APPENDICES

APPENDIX A: TABLES

Table 1. Physiological characteristics of professional bike racing champions.

Rider	VO_{2max} (ml·kg^{-1}·min^{-1})	Power Output at 4mM Lactate (watts)	Peak Power Output (watts)	Annual Distance (km)	Body Fat (%)	Body Weight (kg)	Maximal HR (bpm)	Resting HR (bpm)	Study Authors
Thibaut Pinot	85	402	-	29,340	-	65	-	-	Pinot et. al (3)
Chris Froome	84	505	525	-	9.5	67	170	31	Bell et. al (2)
Miguel Indurain	88	505	572	24,000	-	76	191	28	Mujika et. al (10)
Lance Armstrong*	81.2	404	-	-	8.8	72	207	32	Coyle (5)

*Athlete admitted to taking growth hormone, testosterone, cortisone, and EPO, as well as blood doping (151)

Table 2. Aerobic and anaerobic characteristics of amateur cyclists with subject characteristics.

Recreated from Tanaka et. al (1993) (6)

Category	**Men II (n=7)**	**Men III (n=11)**	**Men IV (n=12)**	**Women II-IV (n=6)**
VO_{2max} ($ml \cdot kg^{-1} \cdot min^{-1}$)	69.39 ± 1.28	64.98 ± 1.71	63.63 ± 1.94**	52.48 ± 2.82*
5-second peak power (W/kg)	13.86 ±0.23	13.55 ± 0.25	12.80 ± 0.41	12.17 ± 0.68*
30-second mean power (W/kg)	11.22 ± 0.18	11.06 ± 0.15	10.40 ± 0.30**	9.56 ± 0.46*
% Fatigue	34.25 ± 0.76	33.46 ± 1.53	36.65 ± 1.73	37.80 ± 2.52

All values are expressed as mean ± SE. 5-second and 30-second power were determined from a Wingate cycle ergometer test.
*Significantly different ($p < .05$) from men (categories II, III, IV)
**Significantly different from category II men

Table 3. Annual training volume (hours). Comparison of values from *The Cyclist's Training Bible* (12) and empirical values (expressed as means ± SD) obtained in current study.

	Professionals	**Category 1**	**Category 2**	**Category 3**	**Category 4**	**Category 5**
Suggested Training Total Volume* (Friel)	800- 1200	700- 1000	700- 1000	500- 700	350- 500	200- 350
Current Study- Women Range (N=264)	500- 767	374- 635	360- 626	279- 557	245- 477	141- 441
Current Study- Men Range (N=279)	704- 1025	413- 803	319- 639	261- 562	231- 473	177- 426

*includes weight training and all cross-training, the present study only looked at cycling data

Table 4. Coggan's Power Profile Table with Part 2 participants overlayed. *(13)*

	Maximal power output (in Watts /kg of body weight)								
	Men				**Women**				
Test Duration	**5-second**	**1-minute**	**5-minute**	**Threshold power**	**5- second**	**1-minute**	**5-minute**	**Threshold power**	**Code from N=92 Sample (nearest value to means)**
World class	24.04	11.5	7.6	6.4	19.42	9.29	6.61	5.69	Category 1: Men N=23, Women N=8
(condensed for space)	…	…	…	…	…	…	…	…	Category 2: Men N=22
	20.23	9.89	6.15	5.15	16.4	8.02	5.31	4.54	Category 3: Men N=8, Women N=7
	19.96	9.78	6.05	5.07	16.19	7.93	5.22	4.46	Category 4: Men N=10, Women N =7
Excellent	19.69	9.66	5.95	4.98	15.97	7.84	5.13	4.38	Category 5: Men N=4, Women N=3
(e.g., cat. 1)	19.42	9.55	5.84	4.89	15.76	7.75	5.04	4.29	
	19.15	9.43	5.74	4.80	15.54	7.66	4.94	4.21	
	18.87	9.32	5.64	4.71	15.32	7.57	4.85	4.13	
	18.60	9.20	5.53	4.62	15.11	7.48	4.76	4.05	
	18.33	9.09	5.43	4.53	14.89	7.39	4.67	3.97	
Very good	18.06	8.97	5.33	4.44	14.68	7.30	4.57	3.88	
(e.g., cat. 2)	17.79	8.86	5.22	4.35	14.46	7.21	4.48	3.80	
	17.51	8.74	5.12	4.27	14.25	7.11	4.39	3.72	
	17.24	8.63	5.01	4.18	14.03	7.02	4.30	3.64	
	16.97	8.51	4.91	4.09	13.82	6.93	4.20	3.55	
	16.7	8.40	4.81	4.00	13.60	6.84	4.11	3.47	
	16.43	8.28	4.70	3.91	13.39	6.75	4.02	3.39	
Good	16.15	8.17	4.60	3.82	13.17	6.66	3.93	3.31	
(e.g., cat. 3)	15.88	8.05	4.50	3.73	12.95	6.57	3.83	3.23	
	15.61	7.94	4.39	3.64	12.74	6.48	3.74	3.14	
	15.34	7.82	4.29	3.55	12.52	6.39	3.65	3.06	
	15.07	7.71	4.19	3.47	12.31	6.30	3.56	2.98	
	14.79	7.59	4.08	3.38	12.09	6.21	3.46	2.90	
Moderate	14.52	7.48	3.98	3.29	11.88	6.12	3.37	2.82	
(e.g., cat. 4)	14.25	7.36	3.88	3.20	11.66	6.03	3.28	2.73	
	13.98	7.25	3.77	3.11	11.45	5.94	3.19	2.65	
	13.71	7.13	3.67	3.02	11.23	5.85	3.09	2.57	
	13.44	7.02	3.57	2.93	11.01	5.76	3.00	2.49	
	13.16	6.90	3.46	2.84	10.80	5.66	2.91	2.40	
Fair	12.89	6.79	3.36	2.75	10.58	5.57	2.82	2.32	
(e.g., cat. 5)	12.62	6.67	3.26	2.66	10.37	5.48	2.72	2.24	
	12.35	6.56	3.15	2.58	10.15	5.39	2.63	2.16	
	12.08	6.44	3.05	2.49	9.94	5.30	2.54	2.08	
	11.80	6.33	2.95	2.40	9.72	5.21	2.45	1.99	
	11.53	6.21	2.84	2.31	9.51	5.12	2.35	1.91	
Untrained	11.26	6.10	2.74	2.22	9.29	5.03	2.26	1.83	
(e.g., non-racer)	10.99	5.99	2.64	2.13	9.07	4.94	2.17	1.75	

Table 5. Comparison of USAC women between categories for Part 1.

	Professionals n=20	Category 1 n=44	Category 2 n=50	Category 3 n=50	Category 4 n=50	Category 5 n=50	Combined N=264
Age (years)	30.9 ± 7.2	34.7 ± 11.8	33.3 ± 9.9	32.2 ± 9.2	31.7 ± 8.1	33.5 ± 8.5	32.9 ± 9.4
2019 Duration (hours)[a]	634.7 ± 135.2	504.8 ± 130.5	493.1 ± 132.9	418.0 ± 138.8	361.2 ± 115.6	291.0 ± 149.6	428.3 ± 161.6
2019 Distance (kilometers)[a]	16,581 ± 3,562	13,510 ± 3,759	13,047 ± 4,133	10,617 ± 3,694	8,989 ± 3,310	7,457 ± 4,371	11,105 ± 4,685
2019 Speed (kph)[b]	26.1 ± 1.8	26.8 ± 2.5	26.3 ± 2.1	25.3 ± 2.5	24.8 ± 3.1	25.0 ± 3.1	25.6 ± 1.8
2019 Ride days[c]	304.4 ± 28.5	277.7 ± 37.8	262.4 ± 48.3	236.6 ± 54.1	216.7 ± 62.2	178.8 ± 76.3	238.7 ± 67.4
2019 Race days[d]	32.5 ± 7.9	31.6 ± 14.5	22.4 ± 11.0	14.3 ± 8.9	8.2 ± 0.6	3.0 ± 2.2	16.8 ± 14.0
2019 Races (total)[d]	33.2 ± 7.8	32.1 ± 14.4	22.8 ± 11.0	16.3 ± 9.8	9.3 ± 7.4	3.1 ± 2.3	17.62 ± 14.2

All values are expressed as means ± SD

[a] Indicates significant differences ($p < 0.05$) between professionals and categories 1, 2, 3, 4, 5; category 1 and categories 3, 4, 5; category 2 and categories 3, 4, and 5; category 3 and category 5

[b] Indicates significant differences between professionals and categories 3, 4, and 5; category 1 and categories 3, 4, 5; category 2 and categories 3, 4, and 5

[c] Indicates significant differences between professionals and categories 3, 4, and 5; category 1 and categories 3, 4, 5; category 3 and category 4; category 4 and category 5

[d] Indicates significant differences between professionals and categories 2, 3, 4, 5; category 1 and categories 2, 3, 4, 5; category 3 and categories 4, 5; category 4 and 5.

Table 6. Comparison of USAC men between categories for Part 1.

	Professionals n=29	Category 1 n=50	Category 2 n=50	Category 3 n=50	Category 4 n=50	Category 5 n=50	Combined N=279
Age (years)[a]	26.3 ± 3.8	31.3 ± 7.3	35.3 ± 12.1	34.7 ± 9.5	34.3 ± 10.1	33.8 ± 10.0	33.1 ± 9.8
2019 Duration (hours)[b]	864.7 ± 160.0	608. ± 195.3	479.2 ± 160.2	411.7 ± 150.5	351.8 ± 121.0	301.2 ± 124.3	475.5 ± 225.9
2019 Distance (kilometers)[b]	26,103 ± 5,210	17,885 ± 6,391	13,368 ± 4,603	11,380 ± 4,347	9,644 ± 3,127	8,232 ± 3,307	13,557 ± 7,011
2019 Speed (kph)[c]	30.2 ± 1.7	29.3 ± 2.5	27.9 ± 2.5	27.7 ± 2.9	27.7 ± 2.7	27.5 ± 2.6	28.2 ± 2.7
2019 Ride days[d]	310.6 ± 39.3	287.6 ± 55.9	271.2 ± 50.3	236.4 ± 50.2	219.0 ± 51.7	187.3 ± 64.3	247.6 ± 66.5
2019 Race days[e]	49.1 ± 17.2	30.4 ± 12.8	23.0 ± 10.4	14.9 ± 8.3	9.7 ± 4.2	2.8 ± 2.2	19.6 ± 16.7
2019 Races (total)[e]	49.9 ± 17.1	31.8 ± 13.2	23.8 ± 10.4	16.4 ± 8.9	10.9 ± 5.5	2.9 ± 2.4	20.6 ± 17.0

All values are expressed as means ± SD

[a] Indicates significant differences ($p < 0.05$) between professionals and categories I, II, III, IV, V

[b] Indicates significant differences between professionals and categories I, II, III, IV, V; category I and categories II, III, IV, V; category II and categories IV, V; category III and category V

[c] Indicates significant differences between professionals and categories II, III, IV, V; category I and categories II, III, IV, V

[d] Indicates significant differences between professionals and categories II, III, IV, and V; category I and categories III, IV, and IV; category II and categories IV, V; category III and category V; category IV and category V

[e] Indicates categories I, II, III, IV, V are all different from each one another.

Table 7. Descriptive characteristics of participants (women) for Part 2.

	Category 1 n=8	Category 3 n=7	Category 4 n=7	Category 5 n=3	Combined n=25
Age (years), mean ± SD	32.5 ± 9.1	33.4 ± 8.1	31.0 ± 7.1	39.3 ± 17.0	33.2 ± 9.1
BMI (kg/m^2), mean ± SD	21.5 ± 1.5	21.6 ± 1.9	21.4 ± 1.6	22.5 ± 1.7	21.6 ± 1.6
Education Level [n (%)]					
High School Diploma/GED	1 (12.5)	0 (0)	0 (0)	0 (0)	1 (4)
Some College, No degree	1 (12.5)	0 (0)	0 (0)	0 (0)	1 (4)
Associate degree	0 (0)	0 (0)	1 (14.3)	0 (0)	1 (4)
Bachelor's Degree	3 (37.5)	4 (57.1)	5 (71.4)	0 (0)	12 (48)
Master's Degree	2 (25)	2 (28.6)	0 (0)	0 (0)	4 (16)
Doctoral or Professional Degree	1 (12.5)	1 (14.3)	1 (14.3)	3 (100)	6 (24)
Estimated Indoor Training (% of total training), mean ± SD	25.0 ± 32.5	37.1 ± 16.0	28.6 ± 24.8	56.6 ± 11.6	33.2 ± 25.3
Zwift Usage [n(%)]					
Yes	5 (62.5)	4 (57.1)	3 (42.9)	3 (100)	15 (60)
No	3 (37.5)	3 (42.9)	4 (57.1)	0 (0)	10 (40)

Table 7. Continued.

Job Status [n (%)]					
Employed for wages	5 (62.5)	5 (71.4)	4 (57.1)	3 (100)	17 (68)
Self-employed	2 (25)	0 (0)	1 (14.3)	0 (0)	3 (12)
Out of work and looking for work	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Student	1 (12.5)	2 (28.6)	2 (28.6)	0 (0)	5 (20)
Military	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Retired	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Table 8. Descriptive characteristics of participants (men) for Part 2.

	Category 1 n=23	Category 2 n=22	Category 3 n=8	Category 4 n=10	Category 5 n=4	Combined n=67
Age (years), mean ± SD	32.5 ± 7.6	35.9 ± 11.9	37.3 ± 13.44	31.0 ± 6.4	39.3 ± 4.8	34.4 ± 9.8
BMI (kg/m^2), mean ± SD	22.2 ± 2.0	22.2 ± 1.7	22.7 ± 2.2	25.2 ± 1.2*	23.2 ± 1.5	22.8 ± 2.0
Education Level [n (%)]						
High School Diploma	0 (0)	0 (0)	1 (12.5)	0 (0)	1 (25)	2 (3)
Some College, No degree	1 (4.3)	3 (13.6)	0 (0)	1 (10)	1 (25)	6 (9)
Associate degree	0 (0)	1 (4.5)	0 (0)	1 (10)	0 (0)	2 (3)
Bachelor's Degree	16 (69.6)	13 (59.1)	5 (62.5)	5 (50)	1 (25)	40 (59.7)
Master's Degree	3 (13)	3 (13.6)	2 (25)	3 (30)	0 (0)	11 (16.4)
Doctoral or Professional Degree	3 (13)	2 (9.1)	0 (0)	0 (0)	1 (25)	6 (9)
Estimated Indoor Training (% of total training), mean ± SD	25.7 ± 17.8	24.1 ± 18.2	31.3 ± 17.3	41.0 ± 32.1	22.0 ± 12.6	27.9 ± 20.6
Zwift Usage [n (%)]						
Yes	19 (82.6)	12 (54.5)	5 (62.5)	6 (60)	2 (50)	44 (65.7)
No	4 (17.4)	10 (45.5)	3 (37.5)	4 (40)	2 (50)	23 (34.3)

Table 8. Continued.

Job Status [n (%)]						
Employed for wages	16 (69.6)	13 (59.1)	7 (87.5)	7 (70)	2 (50)	45 (67.2)
Self-employed	6 (26.1)	3 (13.6)	0 (0)	1 (10)	1 (25)	11 (16.4)
Retired	0 (0)	2 (9.1)	0 (0)	0 (0)	0 (0)	2 (3)
Student	1 (4.3)	3 (13.6)	1 (12.5)	1 (10)	0 (0)	6 (9)
Military	0 (0)	0 (0)	0 (0)	1 (10)	0 (0)	1 (1.5)
Out of work and looking for work	0 (0)	0 (0)	0 (0)	0 (0)	1 (25)	1 (1.5)
Out of work but not currently looking for work	0 (0)	1 (4.5)	0 (0)	0 (0)	0 (0)	1 (1.5)

*Indicates significant differences ($p < 0.05$) between categories 1, 2, 3

Table 9. Power characteristics of participants (women) for Part 2.

	Category 1 n=8	Category 3 n=7	Category 4 n=7	Category 5 n=3	Combined n=25
Peak 5-second	15.22 ± 2.13*	11.65 ± 1.59	11.22 ± 1.14	9.07 ± 1.71	12.36 ± 2.67
Peak 1-minute	7.23 ± 0.79**	6.45 ± 0.88	5.97 ± 0.62	5.07 ± 0.33	6.40 ± 0.99
Peak 5-minute	4.83 ± 0.32*	4.13 ± 0.59	3.85 ± 0.42	3.70 ± 0.15	4.22 ± 0.60
Coggan FTP-estimate (95% of peak 20-min)	4.04 ± 0.36*	3.20 ± 0.29	3.26 ± 0.18	3.07 ± 0.06	3.47 ± 0.48
Peak 1-hour	3.50 ± 0.38***	3.03 ± 0.34	2.89 ± 0.33	2.92 ± 0.16	3.13 ± 0.41
20-minute	4.26 ± 0.38*	3.37 ± 0.30	3.43 ± 0.18	3.23 ± 0.06	3.65 ± 0.50

All values are expressed as means ± SD in W/kg

*Significantly different ($p < 0.05$) from categories 3, 4, and 5

**Significantly different from categories 4 and 5

***Significantly different from category 4

Note: Coggan suggests a 5-minute all-out effort prior to obtaining 20-minute value for FTP-estimate.

Table 10. Power characteristics of participants (men) for Part 2.

	Category 1 n=23	Category 2 n=22	Category 3 n=8	Category 4 n=10	Category 5 n=4	Combined n=67
Peak 5-second	18.09 ± 2.25	16.62 ± 2.31	16.74 ± 2.86	16.48 ± 1.44	14.80 ± 3.63	17.01 ± 2.44
Peak 1-minute	9.48 ± 1.14*	8.33 ± 1.09	8.64 ± 1.41	8.15 ± 0.94	6.99 ± 1.46	8.65 ± 1.31
Peak 5-minute	6.10 ± 0.60**	5.39 ± 0.56	5.30 ± 0.56	5.19 ± 0.65	4.56 ± 0.28	5.54 ± 0.72
Coggan FTP-estimate (95% of peak 20-minute)	4.86 ± 0.42**	4.35 ± 0.49***	4.21 ± 0.38	3.99 ± 0.50	3.57 ± 0.42	4.41 ± 0.58
Peak 1-hour	4.49 ± 0.44**	3.96 ± 0.42	3.79 ± 0.30	3.56 ± 0.40	3.38 ± 0.31	4.03 ± 0.54
20-minute	5.11 ± 0.45**	4.58 ± 0.51***	4.43 ± 0.40	4.20 ± 0.53	3.76 ± 0.44	4.64 ± 0.61

All values are expressed as means ± SD in W/kg

*significantly different ($p < 0.05$) from categories 2, 4, and 5

**significantly different from categories 2, 3, 4, and 5

***significantly different from category 5

Note: Coggan suggests a 5-minute all-out effort prior to obtaining 20-minute value for FTP-estimate.

APPENDIX B: FIGURES

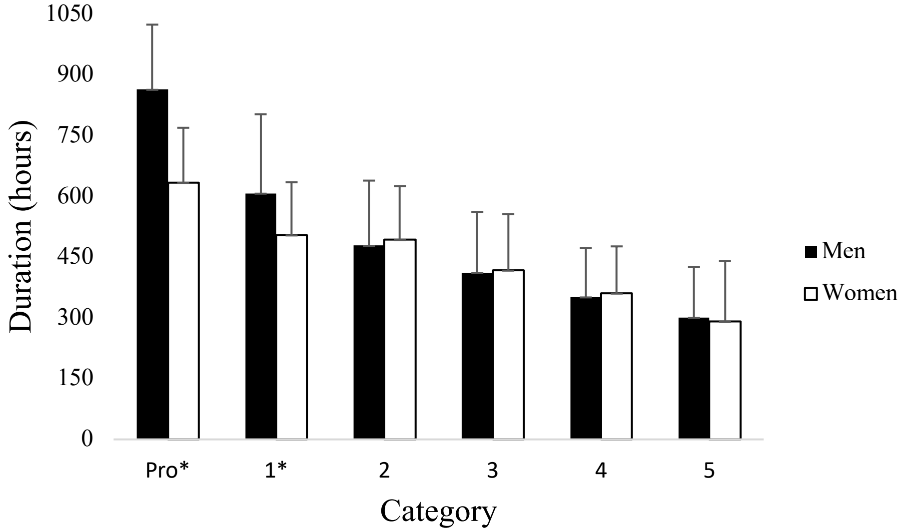


Figure 1. Volume of training and racing by USAC road cyclists in 2019.
*Indicates significant differences between men and women within the respected category ($p < 0.05$).

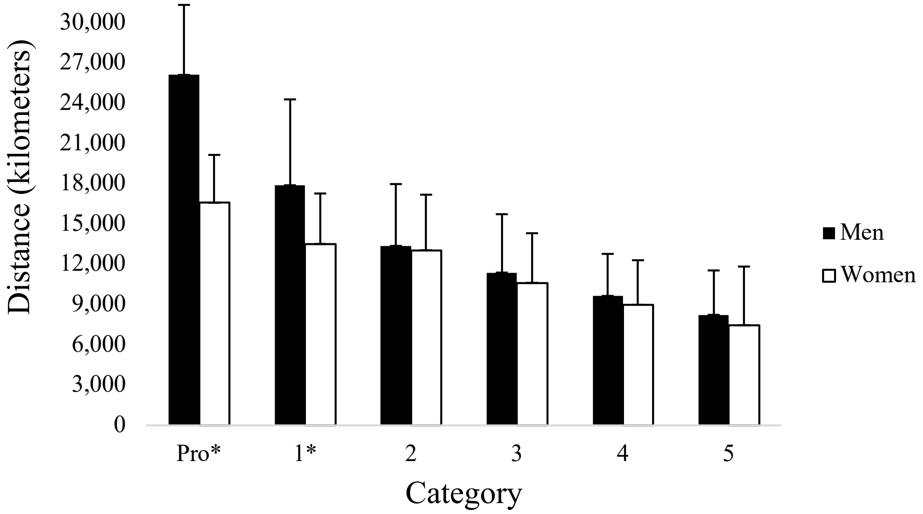


Figure 2. Distance of training and racing by USAC road cyclists in 2019.
*Indicates significant differences between men and women within the respected category ($p < 0.05$).

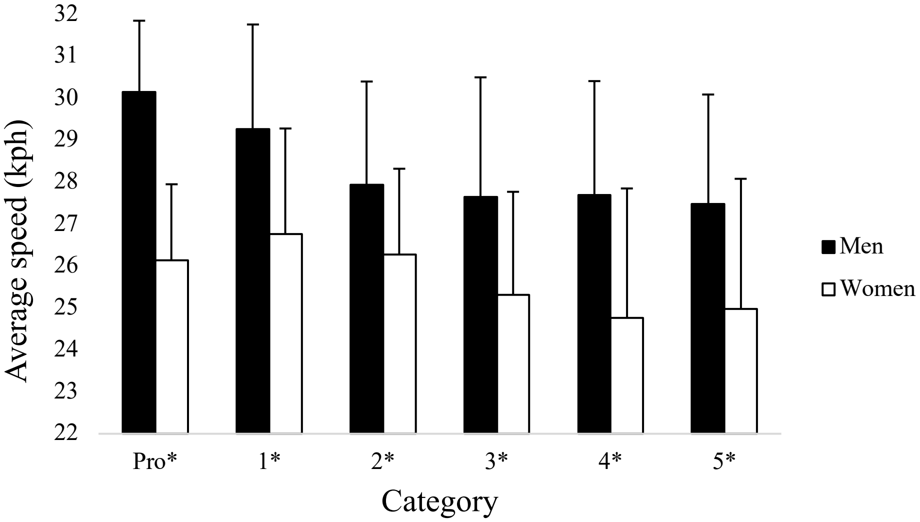


Figure 3. Average speed (kilometers per hour) traveled by USAC road cyclists in 2019 in both racing and training.
*Indicates significant differences between men and women within the respected category ($p < 0.05$).

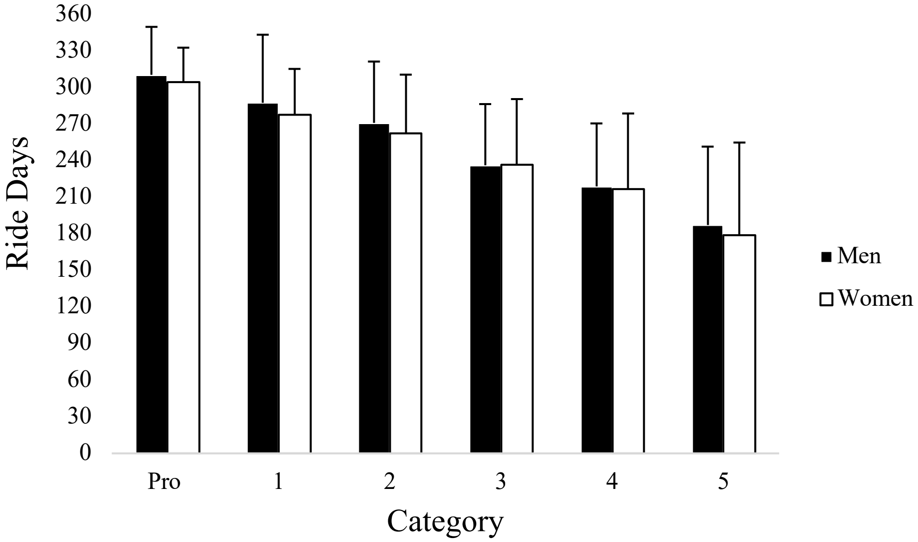


Figure 4. Number of days ridden (including race days) by USAC road cyclists in 2019.

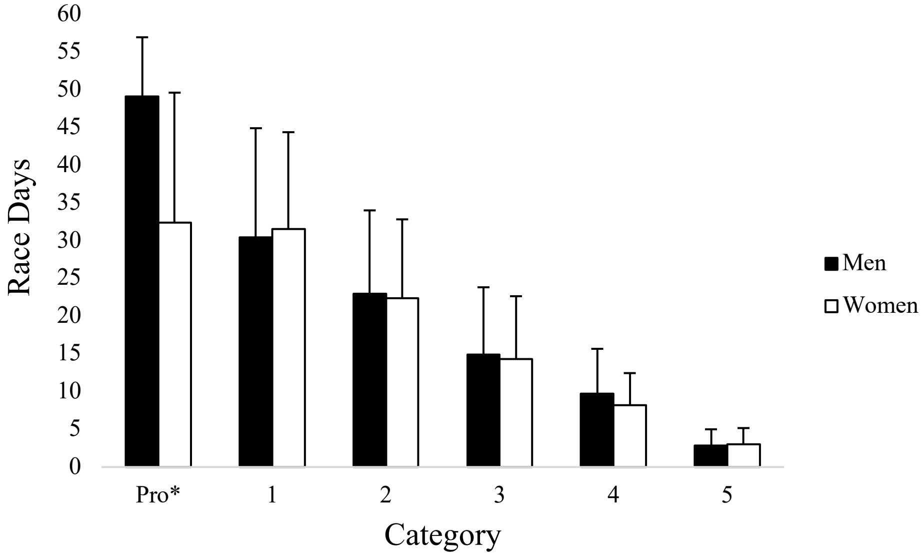
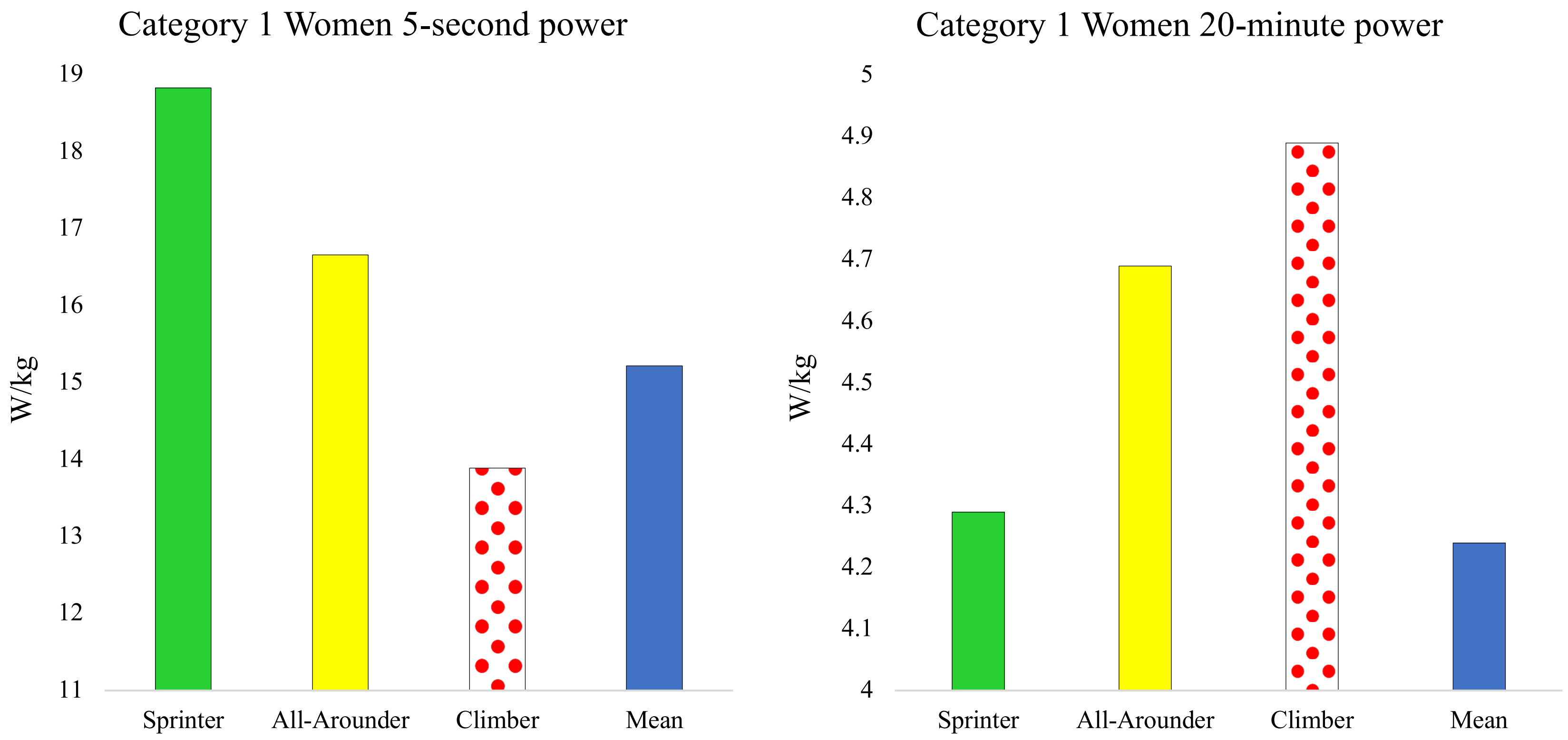


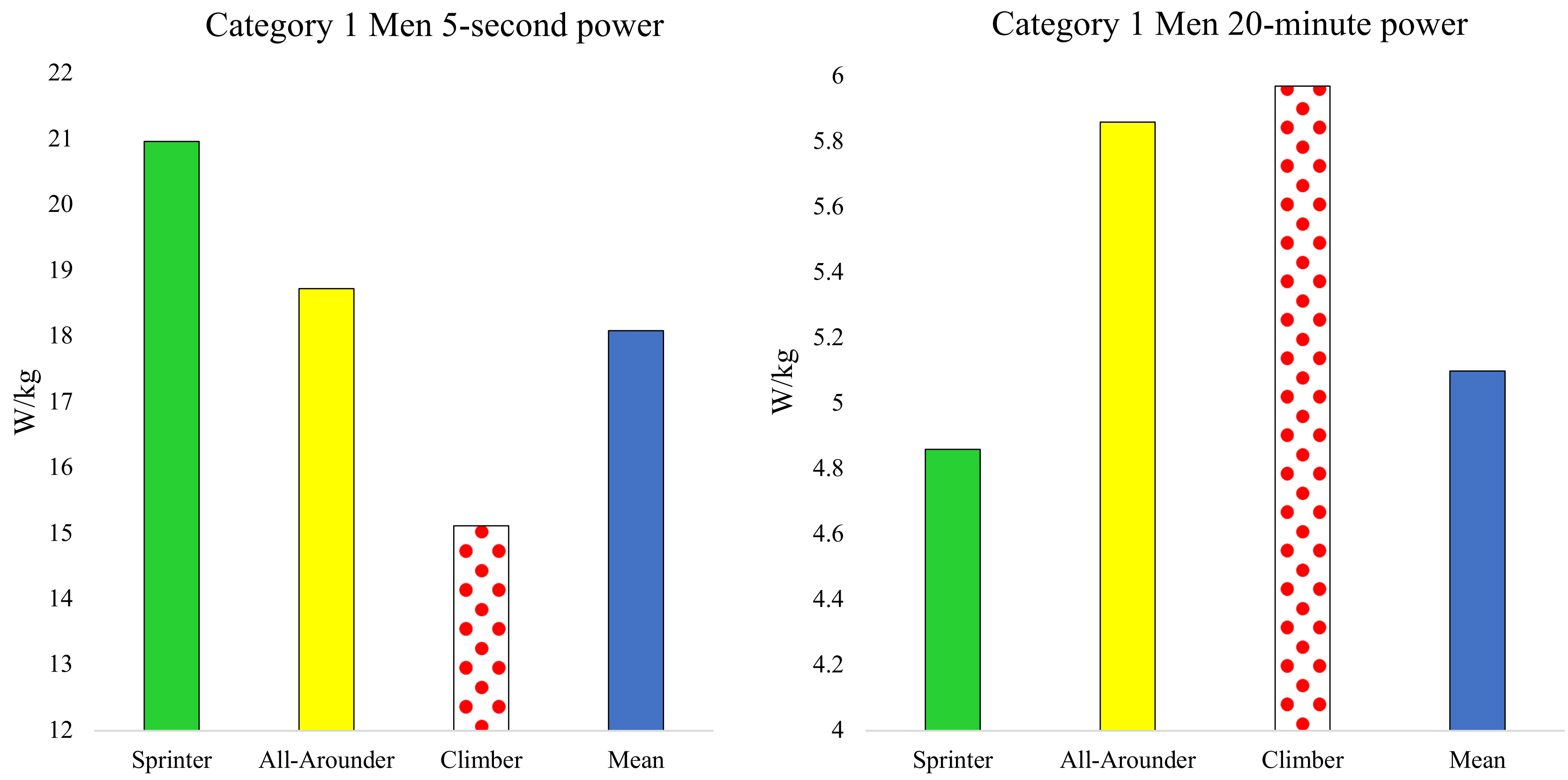
Figure 5. Number of days raced by USAC road cyclists in 2019.
*Indicates significant differences between men and women within the respected category ($p < 0.05$).



Category 1 Women 5-second power

Category 1 Women 20-minute power

Figure 6. Category 1 women 5-second and 20-minute power, mean and select individuals.
(The selected sprinter is the same rider in both conditions, the all-arounder the same rider in both conditions, the climber the same rider in both conditions)


Category 1 Men 5-second power

Category 1 Men 20-minute power

Figure 7. Category 1 men 5-second and 20-minute power, mean and select individuals.
(The selected sprinter is the same rider in both conditions, the all-arounder the same rider in both conditions, the climber the same rider in both conditions

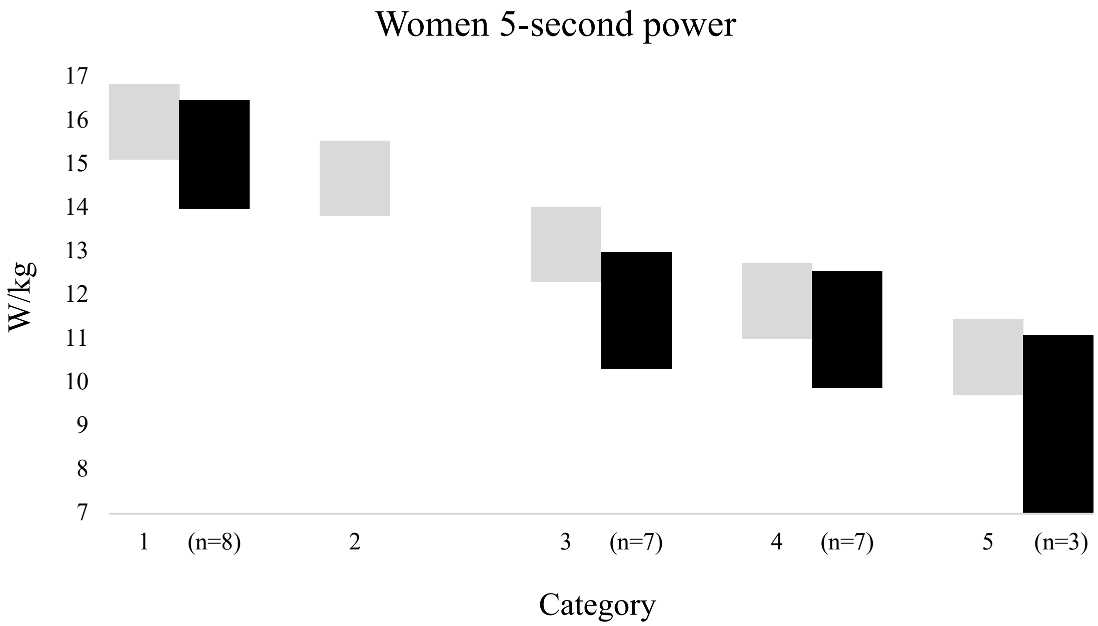


Figure 8. Cycling category vs. 5-second power in women cyclists.
Black bars indicate data from the current study expressed in mean ± 2 SE, gray bars indicate reference data from Coggan (13).

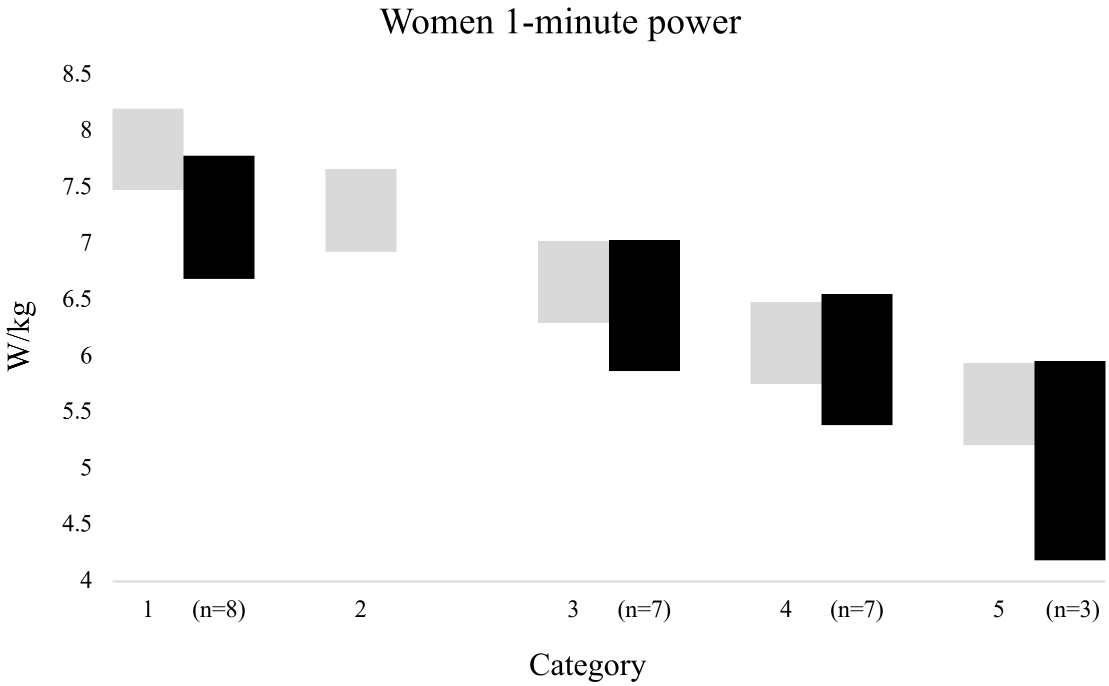


Figure 9. Cycling category vs. 1-minute power in women cyclists.
Black bars indicate data from the current study expressed in mean ± 2 SE, gray bars indicate reference data from Coggan (13).

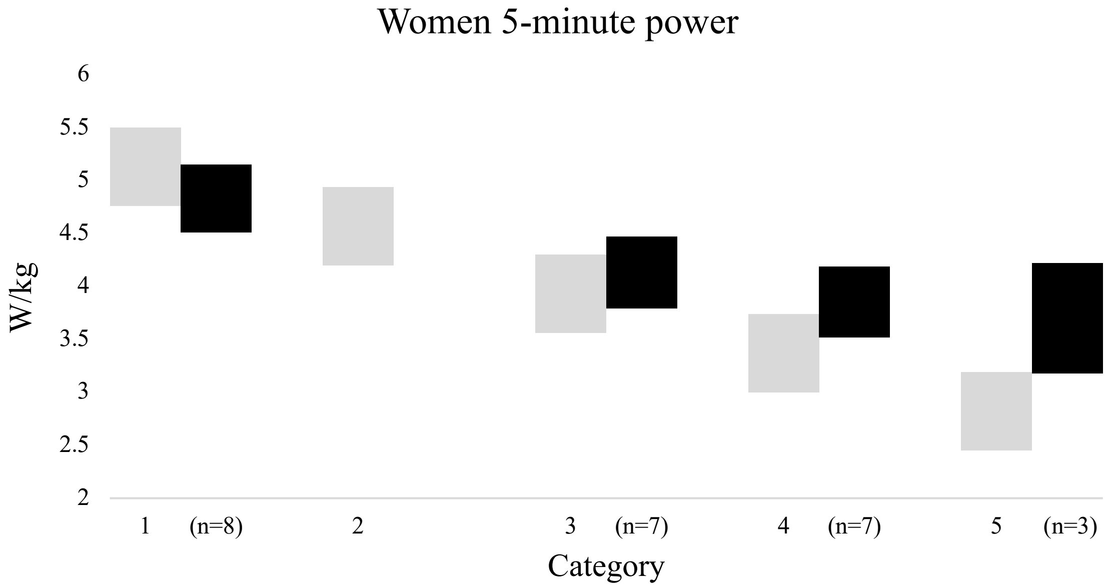


Figure 10. Cycling category vs. 5-minute power in women cyclists.
Black bars indicate data from the current study expressed in mean ± 2 SE, gray bars indicate reference data from Coggan (13).

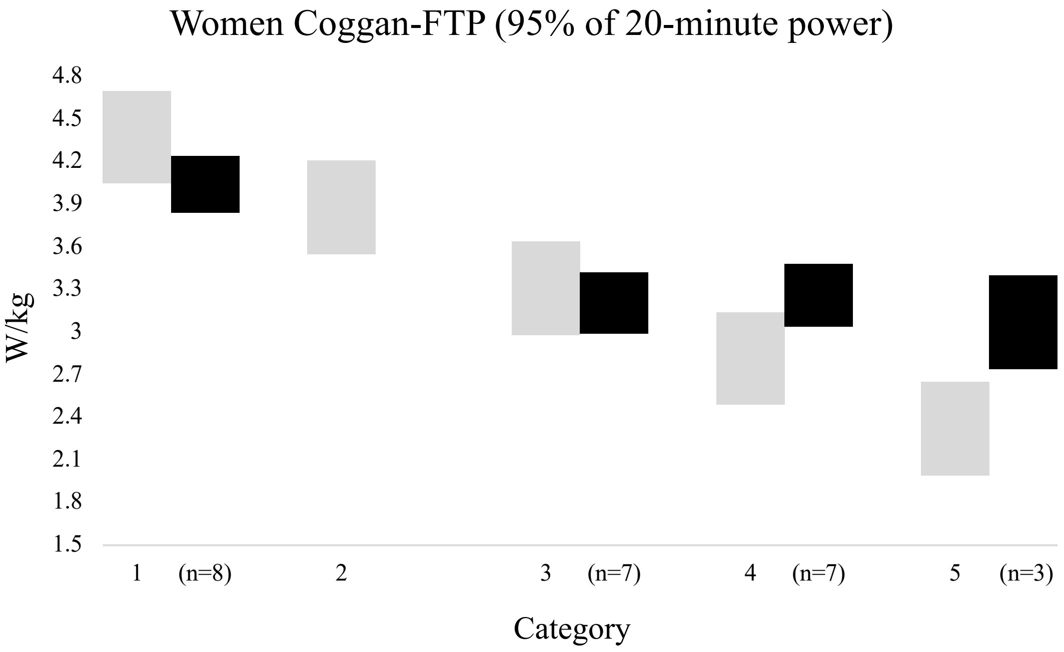


Figure 11. Cycling category vs. Coggan-FTP power in women cyclists.
Black bars indicate data from the current study expressed in mean ± 2 SE, gray bars indicate reference data from Coggan (13).

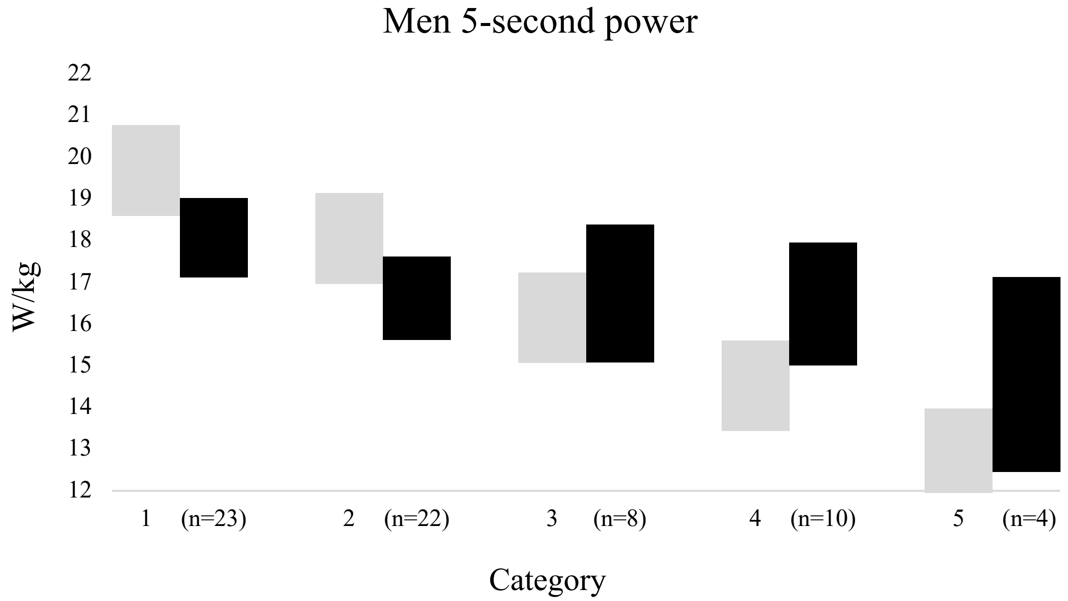


Figure 12. Cycling category vs. 5-second power in men cyclists.
Black bars indicate data from the current study expressed in mean ± 2 SE, gray bars indicate reference data from Coggan (13).

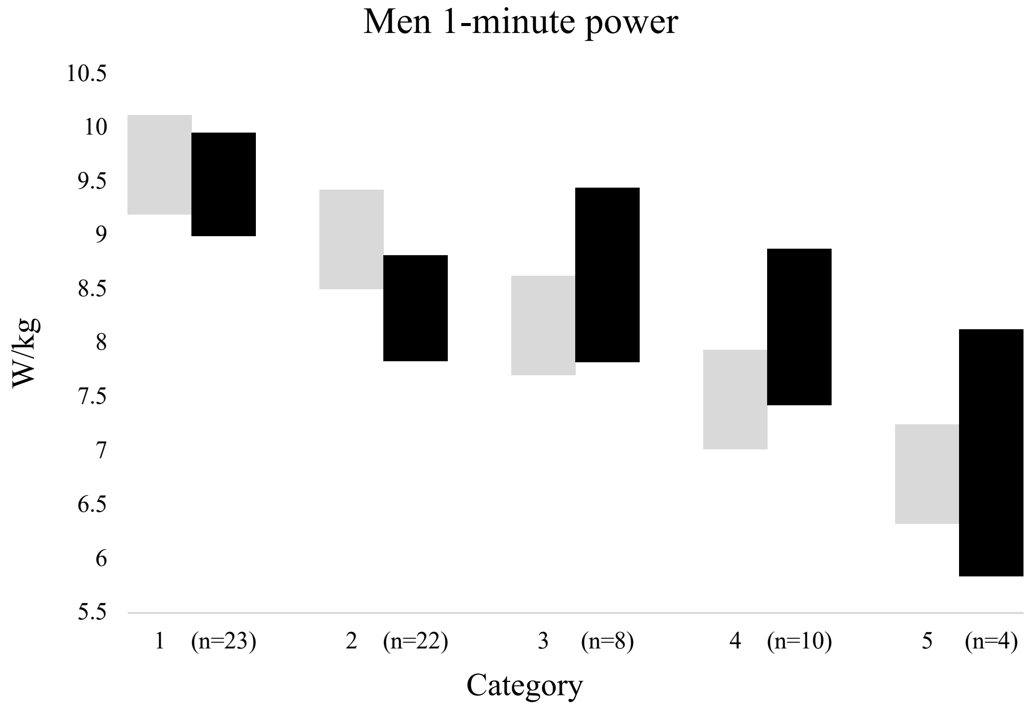


Figure 13. Cycling category vs. 1-minute power in men cyclists.
Black bars indicate data from the current study expressed in mean ± 2 SE, gray bars indicate reference data from Coggan (13).

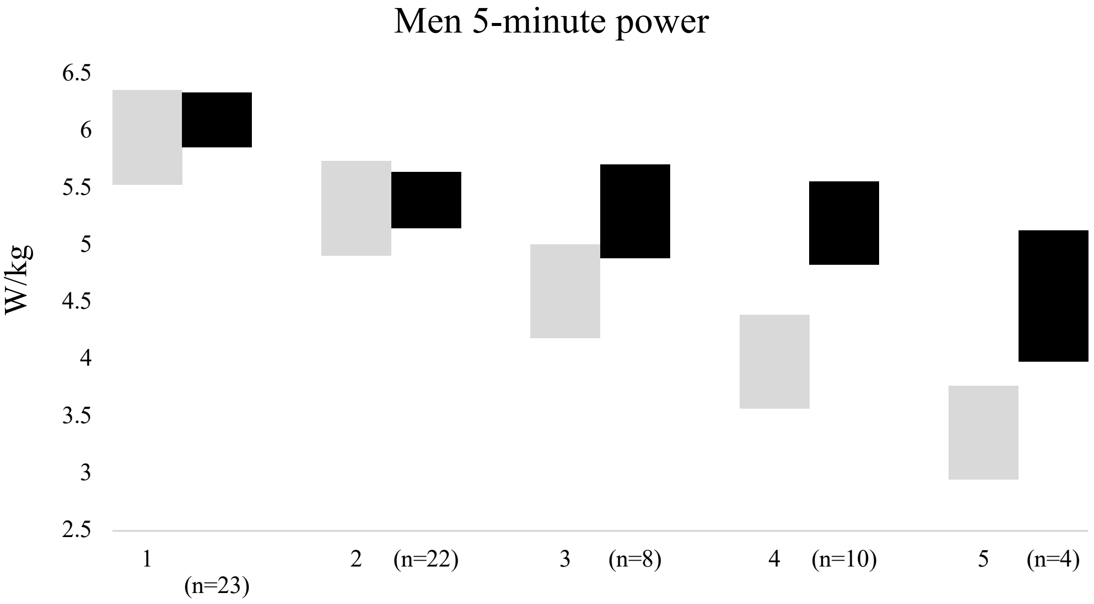


Figure 14. Cycling category vs. 5-minute power in men cyclists.
Black bars indicate data from the current study expressed in mean ± 2 SE, gray bars indicate reference data from Coggan (13).

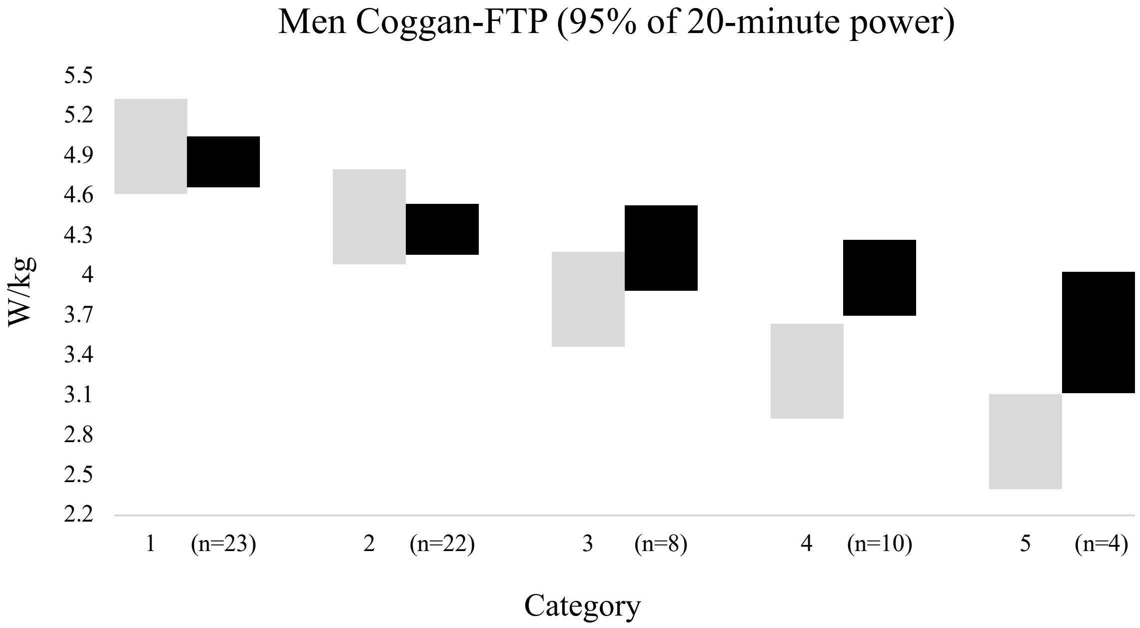


Figure 15. Cycling category vs. Coggan-FTP power in men cyclists.
Black bars indicate data from the current study expressed in mean ± 2 SE, gray bars indicate reference data from Coggan (13).

APPENDIX C: RECRUITMENT MESSAGE

Direct Message on Strava

Greetings,

I am working on a Master of Science degree at the University of Tennessee, Knoxville and am completing a study on "Training characteristics & power profiles of USACycling road cyclists." I noticed that you frequently use a power meter and was wondering if you would be willing to share some further power data for my project? It should only take a few minutes of your time and will help provide a greater understanding of power profiles of cyclists in different categories. If you agree to participate, I will send you a brief summary of the results within a year. If you are interested please respond "YES" to this comment or to my email (rsroka@vols.utk.edu) Thanks!

Sincerely,
Robert Sroka
University of Tennessee graduate student and cyclist

Direct Message on Strava

Greetings,

I am working on a Master of Science degree at the University of Tennessee, Knoxville and am completing a study on "Training characteristics & power profiles of USACycling road cyclists." I noticed that you frequently use a power meter and was wondering if you would be willing to share some further power data for my project? It should only take a few minutes of your time and will help provide a greater understanding of power profiles of cyclists in different categories. If you agree to participate, I will send you a brief summary of the results within a year. If you are interested please respond "YES" to this comment or to my email (ssims15@vols.utk.edu) Thanks!

Sincerely,
Sierra Sims
University of Tennessee graduate student and cyclist

APPENDIX D: CONSENT FORM FOR RESEARCH PARTICIPATION

Consent for Research Participation

Research Study Title: Training Characteristics & Power Profiles of Road Racers in USACycling

Researcher(s): Robert Sroka, Graduate Student, University of Tennessee, Knoxville
David Bassett, Jr. PhD, University of Tennessee, Knoxville
Jessica Kutz PhD, University of Tennessee, Knoxville
Dawn Coe PhD, University of Tennessee, Knoxville

I/We are asking you to be in this research study because you are an active member of USAC and use Strava with a power meter. You must be age 18 or older to participate in the study. The information in this consent form is to help you decide if you want to be in this research study. Please take your time reading this form and contact the researcher(s) to ask questions if there is anything you do not understand.

Why is the research being done?

The purpose of the research study is to explore the training habits and power profiles for each category of bicycle road racers in the United States. There are 10 total categories that will be observed (Pro/1, 2, 3, 4, and 5) in men and women racers. A smaller subset of riders will be analyzed for power profiling.

What will I do in this study?

If you agree to be in this study, we will ask you to you will be filling out this survey and creating a power profile from your Strava files from 2018 and 2019. NO GPS DATA WILL BE USED IN THIS STUDY.

This study will be completed entirely online with no setting meetings or activities occurring. You are asked to fill out the survey and follow the instructions on sending power files attached at the end of the survey.

How long will I be in the research study?

If you agree to be in the study, your participation will require about 10 minutes.

Can I say "No"?

Being in this study is up to you. You can say no now or leave the study later. Either way, your decision won't affect your relationship with the researchers or the University of Tennessee.

What happens if I say "Yes" but change my mind later?

Even if you decide to be in the study now, you can change your mind and stop at any time. If you decide to stop before the study is completed, any answers provided will be removed.

Are there any risks to me?

There are few risks of you participating since your training/racing data, including power profiles, have been previously collected by Strava® and USA Cycling for non-research purposes. Your survey responses are the only new data being collected. While loss of confidentiality poses a minor risk, the data will be de-identified and participants will be assigned an ID number to protect against this risk.

Are there any benefits to me?

No financial compensation will be provided to you for participating in this study. However, the information gathered will provide useful information on the current training habits and power profiles of USA Cycling racers in various categories. You will be provided with a brief summary of the report within one year.

What will happen with the information collected for this study?

We will protect the confidentiality of your information by assigning an ID number to de-identify participants. If information from this study is published or presented at scientific meetings, your name and other personal information will not be used.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information or what information came from you. Although it is unlikely, there are times when others may need to see the information we collect about you. These include:

- People at the University of Tennessee, Knoxville who oversee research to make sure it is conducted properly
- Government agencies (such as the Office for Human Research Protections in the U.S. Department of Health and Human Services), and others responsible for watching over the safety, effectiveness, and conduct of the research
- If a law or court requires us to share the information, we would have to follow that law or final court ruling

What will happen to my information after this study is over?

Future use by the research team, we will keep your information to use for future research. Your name and other information that can directly identify you will be deleted from your research data collected as part of the study. We may share your research data with other researchers without asking for your consent again, but it will not contain information that could directly identify you.

Who can answer my questions about this research study?

If you have questions or concerns about this study, or have experienced a research related problem or injury, contact the researchers:
Robert Sroka
rsroka@vols.utk.edu
Dr. David Bassett Jr.
dbassett@utk.edu
For questions or concerns about your rights or to speak with someone other than the research team about the study, please contact:
Institutional Review Board
The University of Tennessee, Knoxville
1534 White Avenue
Blount Hall, Room 408
Knoxville, TN 37996-1529
Phone: 865-974-7697
Email: **utkirb@utk.edu**

Statement of Consent

I have read this form, been given the chance to ask questions and have my questions answered. If I have more questions, I have been told whom to contact. By clicking the "I Agree" button below, I am agreeing to be in this study. I can print or save a copy of this consent information for future reference. If I do not want to be in this study, I can close my internet browser.

APPENDIX E: SURVEY

Qualtrics

Approximately what percentage of your annual ride time (hours) is spent riding indoors?

- 0
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80
- 90
- 100

Do you upload to STRAVA when riding indoors?

- Yes, all the time
- Some of the time
- No, but I do ride indoors
- No, but I don't ride indoors

Do you engage with the exercise related app Zwift virtual reality platform on a regular basis?

- Yes
- No

If you do use Zwift, what percentage of your total training volume is on the platform?

Please specify your level of education:
___ Some High School
___ High School Diploma/GED
___ Some College Credit, no degree
___ Associate's Degree
___ Bachelor's Degree
___ Master's Degree
___ Doctoral or Professional degree

Please specify your job status:
___ Employed for wages
___ Self-employed
___ Out of work and looking for work
___ Out of work but not currently looking for work

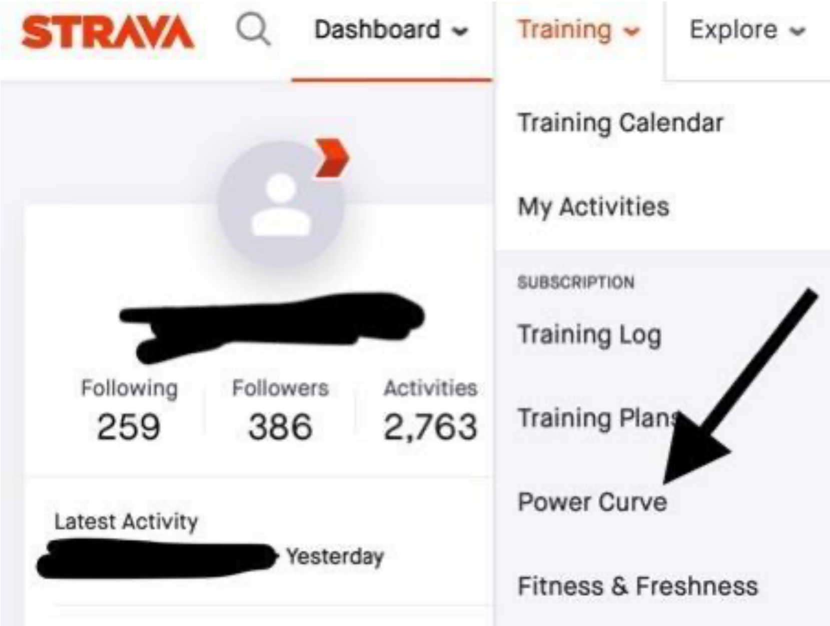
___ A homemaker
___ A student
___ Military
___ Retired

Please indicate your height in inches ________ and weight in pounds __________

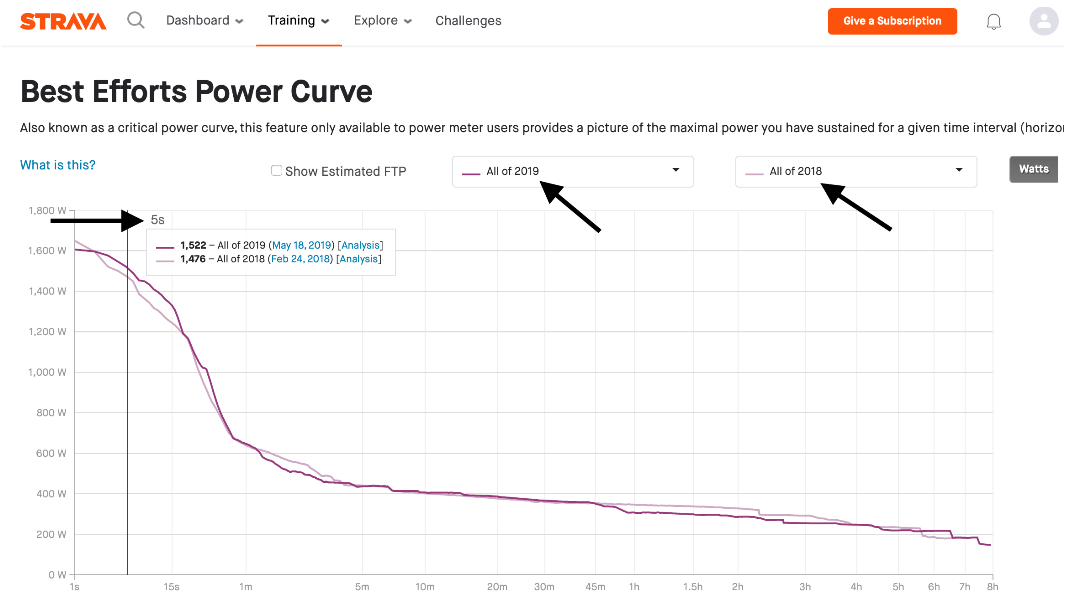
Power Profile

Please provide screenshots of your peak power data from 2018 and 2019. You are asked to send 5 screenshots via email to the primary investigator, rsroka@vols.utk.edu

Log into your personal Strava account. Click on “Power Curve” under the “Training” tab.



Select “All of 2018” and “All of 2019” for the time period.



Best Efforts Power Curve

Also known as a critical power curve, this feature only available to power meter users provides a picture of the maximal power you have sustained for a given time interval (horizo

☐ Show Estimated FTP

All of 2019

All of 2018

5s

1,522 – All of 2019 (May 18, 2019) [Analysis]

1,476 – All of 2018 (Feb 24, 2018) [Analysis]

You then will then take a screenshot of each of your peak 5-second, 1-minute, 5-minute, 20-minute, and 60-minute power values from the last two years by dragging the cursor over those given time intervals. There will be five total screenshots.

If you do not have your weight published on Strava, we request that you either update that setting so that we can express the power as Watts per kilogram of body weight, or include your weight in the email.

VITA

Robert Jay Sroka was born in New Britain, Connecticut on January 15, 1995 to Rudolph Joseph Sroka and Lori Ann Erwine. He was raised in North Royalton, Ohio where he attended school and graduated from North Royalton High School in 2013. In 2017, Robert graduated from Kent State University (Kent, Ohio) with a Bachelor of Science in Exercise Science with a minor in Sports Medicine. Robert raced his bicycle competitively across four different countries for the next two years before he accepted a teaching assistantship at the University of Tennessee (Knoxville, Tennessee) in the Department of Kinesiology, Recreation, and Sports Studies. He graduated with a Master of Science degree in Exercise Physiology in August 2021. Robert is currently planning to work in a coaching business with an emphasis on road cyclists