ABSTRACT

ROLLINGS, A.T. Predictors of uphill riding performance in trained cyclists. MS in Adult Fitness/Cardiac Rehabilitation, August 1995, 28 pp. (J. Porcari)

Hill climbing is an important aspect of cycling, and differences in climbing ability often determine overall performance. The purpose of this study was to determine which modifiable physiological variables are most highly correlated to superior hill climbing among trained cyclists. Twenty-four male cyclists (age = 29.9 yrs, ht = 70.0 in., wt = 73.0 kg, body fat = 13.3%) rode a 2-km uphill time trial. They also performed a maximal bicycle test on a Schwinn Velodyne, from which relative and absolute VO_{2max} and VT (absolute and as a percentage of VO_{2max}) were determined. Anaerobic power was measured via the Wingate bicycle test, determining peak watts, average watts, and fatigue index (% power decline from start to finish). Other variables included average yearly training mileage and the number of years of competitive experience. It was found that the following variables were significantly correlated to 2-km time trial performance: relative VO_{2max} ($r = -.71$), absolute VO_{2max} ($r = -.60$), yearly training mileage ($r = -.57$), fatigue index ($r = .43$), years of competition ($r = -.42$), absolute VO_2 at VT ($r = -.38$), and body weight ($r = .24$). Stepwise regression analysis yielded the following equation to predict 2-km time trial performance: $Time = 15.54 - .0307(\text{body wt}) - .0918(\text{relative } VO_{2max}) + .0229(\text{fatigue index}) - .000127(\text{yearly mileage})$. Multiple $R = .79$, $R^2 = .62$, and $SEE = .638$ min. These results suggest that a cyclist's performance in a 2-km uphill time trial may be predicted by several factors influenced by the cyclist's training, and improvements such as lower body weight, higher relative VO_{2max} , increased endurance (as measured during the Wingate bicycle test), and increased training mileage may help the cyclist achieve greater success in hill climbs 2 km in length.

PREDICTORS OF UPHILL RIDING PERFORMANCE
IN TRAINED CYCLISTS

A MANUSCRIPT STYLE THESIS PRESENTED
TO
THE GRADUATE FACULTY
UNIVERSITY OF WISCONSIN-LA CROSSE

IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE
MASTER OF SCIENCE DEGREE

BY
ANNE T. ROLLINGS
AUGUST 1995

COLLEGE OF HEALTH, PHYSICAL EDUCATION, AND RECREATION
UNIVERSITY OF WISCONSIN-LA CROSSE

THESIS FINAL ORAL DEFENSE FORM

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We recommend acceptance of this thesis in partial fulfillment of
this candidate's requirements for the degree:

Master of Science in Adult Fitness/Cardiac Rehabilitation

The candidate has successfully completed her final oral
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ACKNOWLEDGEMENTS

I first need to express my gratefulness and thanks to my husband, Patrick, who must certainly be the most patient man in the world. Thank you for your constant support, not only during this project, but throughout my entire career change. I hope you know just how much I love you.

Mom and dad, you have been supportive of me the whole way through. I love you for your faith in me, and I feel that I can never fully repay you for all you've given me.

I also need to say thank you to my grandparents who have been a constant source of inspiration. I love you very much.

Thanks to all of my wonderful bicycling friends, both old and new. Without your help, this thesis would not have been possible. I hope you had some fun and learned a bit along the way.

A special thanks goes to my committee members, Drs. Porcari, Floyd, and Venneman, for their time and commitment to this project. Dr. John Porcari, you deserve thanks not only for chairing this thesis, but also for continuing to challenge me and offer me new opportunities to grow. You have my most sincere gratitude and respect.

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Introduction

Cycling is a sport which requires athletes to perform well in a wide variety of situations, including sprints, long solo efforts, and hill climbs. Although a cyclist may perform well in many areas, a strength or weakness in a particular area may play a critical role in determining that athlete's ultimate degree of success.

Cyclists who compete in road races are likely to encounter hill climbs. Road races vary in distance based on the age, category, and sex of the rider, and generally range from 50 to 150 or more km. The athletes often ride several times around a looped course of varied terrain, climbing the hill(s) several times. In some races, the "hill" on the course is actually a mountain pass many kilometers long. In other races, the hill may be only one or 2 km in length.

Subelite cyclists are more likely to race on hills which fit into the latter category. Regardless of the skill level of the cyclists, it is often during the hill climb that aggressive moves are made by the stronger climbers in an attempt to "drop" those riders who are weaker. In subelite cycling, a 1-km hill climb of significant steepness may divide the field of riders, especially if it must be repeated several times throughout the race.

Although most road cyclists agree that hill climbing is

an important skill to have or develop, they may not be certain of how to improve their climbing ability. Since much of the information available to cyclists is anecdotal, riders may also be unsure of which attributes are necessary for superior hill climbing performance.

Even though many studies have investigated predictors of overall cycling performance (4,5,10,12,13,23) few have isolated the area of hill climbing. Many studies which have addressed hill climbing performance have observed how it was affected by cadence (22), use or nonuse of toe clips (14), variations in body position (14,17,24), or differences in body size (19-21). It remains to be demonstrated how certain physiological variables may influence an athlete's hill climbing ability.

The purpose of this study was to determine which physiological variables most strongly predict hill climbing ability among trained, but subelite, cyclists. Although factors such as heredity, experience, and technique probably play important roles, other attributes may be modified and improved, leading to better performance climbing hills.

Methods

Subjects

Twenty-four male volunteers participated in the study. Ten of the subjects had United States Cycling Federation (USCF) racing experience, 5 were primarily off-road racers, 5 were triathletes, and 3 were nonlicensed (Citizen

category) road racers. One rider had no racing experience.

Laboratory Tests

All laboratory testing took place in the Human Performance Laboratory at the University of Wisconsin-La Crosse. Each subject completed an informed consent document prior to testing (see Appendix A). Variables measured included height, weight, maximal oxygen uptake (VO_{2max}) measured in both absolute and relative terms, absolute ventilatory threshold (VT) and VO_2 at VT, peak anaerobic power and the related values of average power and index of fatigue, and body composition. Subjects also completed a questionnaire regarding their training and racing experience (see Appendix B).

Values for VO_{2max} and VT were determined via an incremental stress test, as each subject rode his own bicycle attached to a Schwinn Velodyne ergometer (Frontline Technology, Irvine, CA) to voluntary exhaustion. The Velodyne, calibrated individually for each rider per manufacturer instructions, was programmed to display the watts (W) of resistance. Subjects were allowed to warm up at 125 W for at least 10 minutes. During the test the resistance was increased by 25 W increments every minute until subjects could no longer continue. Throughout the test, subjects were allowed to select their preferred cadence. Oxygen uptake (VO_2) was measured using a Quinton Q-Plex (A-H Robins Co., Seattle, WA) metabolic cart and a

Hans Rudolph nonrebreathing valve. Each subject's heart rate was monitored continuously using a Polar Vantage XL (Polar CIC Inc., Port Washington, NY) heart rate monitor, and was recorded every minute.

Ventilatory threshold (VT) was predicted using the simplified V-Slope method as described by Schneider, Phillips, and Stoffolano (18), with data collected from breath-by-breath measurements of oxygen consumption (VO_2) and carbon dioxide production (VCO_2) during the $\text{VO}_{2\text{max}}$ test.

Each subject was hydrostatically weighed to determine his percentage of body fat. In most cases, the subject underwent this procedure the same day as the $\text{VO}_{2\text{max}}$ test. The subject's percentage of body fat was calculated via the formula of Brozek, Grande, Anderson, and Keys (1).

Each subject performed the Wingate anaerobic power bicycle test not less than 48 hours before or after his $\text{VO}_{2\text{max}}$ test. Each subject warmed up at an intensity of his choice on a Monark cycle ergometer. The subject then transferred to a specially prepared Monark ergometer. At the subject's consent, the prescribed resistance of .7 kp per kg of body weight was applied to the flywheel and the subject pedaled as fast as possible for 30 seconds. The subject's values for peak power, average power, and index of fatigue were then computed.

Time Trial

All subjects completed their laboratory testing prior to the

uphill time trial. Twenty-one of the subjects were able to ride the time trial at one session. The remaining subjects had conflicts with the first date and performed the time trial together on a different date.

The starting order was randomly determined for each session. Each subject was assigned a number to wear pinned to his riding jersey. Riders were instructed to warm up per their own needs and arrive at the starting area 20 minutes prior to the predetermined general start time. They were then allowed to continue warming up in the general area or wait for their start. Riders started at 2-minute intervals.

The course consisted of a 2-km uphill section of County Highway 3 in Winona County, Minnesota. The start and finish lines were marked by electrical tape on the ground, surrounded by orange construction cones on each side. Two stop watches were simultaneously started 10 minutes before the predetermined beginning of the time trials. One stop watch remained with the experimenter at the start line and the other was taken to the finish line by two recorders.

Each subject was held upright while seated on his bicycle 1 minute before his start, per usual time trial protocol. The experimenter announced when the rider had 30 and 15 seconds before his start, and counted down from 10 to 1 seconds before the start. When the chief timer said "start", the volunteer bicycle holder released the bicycle and the rider began the time trial.

At the top of the hill, the two recorders noted the time on the stop watch when each rider crossed the finish line. After all time trials were completed, actual race times were calculated by subtracting the rider's known start time from his recorded finish time.

Statistics

Multiple regression analysis and Pearson product moment correlations were used to determine which variables best predicted performance time in the uphill time trial. Independent variables used were body weight, percentage of body fat, absolute and relative VO_{2max} , absolute VT and VO_2 at VT, peak and average anaerobic power, index of fatigue from the Wingate test, years of cycling experience, and yearly training mileage.

Results

Demographic information and pertinent laboratory test results for each subject are presented in Table 1. The 24 male subjects (age = 29) were found to have VO_{2max} values ($VO_{2max} = 64 \text{ ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$) comparable with those of other amateur competitive cyclists (23), but less than those noted for elite cyclists (5,23).

Table 2 shows the correlation coefficients derived from the analysis relating hill climb results (minutes:seconds) with pertinent variables listed in Table 1. The highest coefficient was found between relative VO_{2max} and time trial time ($r = -.71$). Other variables showing significant

Table 1
Descriptive Characteristics of Subjects

Variable	M	SD
Age (yrs)	29.75	7.71
Height (cm)	178.00	7.00
Weight (kg)	73.01	2.71
Relative VO_2 ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	63.99	6.40
Absolute VO_2 ($\text{L} \cdot \text{min}^{-1}$)	4.65	0.41
Absolute VT ($\text{L} \cdot \text{min}^{-1}$)	3.50	0.45
Relative VT (as % of absolute VO_2)	5.37	7.35
Body Fat (%)	13.27	4.68
Average Power (W)	582.04	59.57
Peak Power (W)	709.13	87.10
Average Power (W/kg)	7.97	0.60
Peak Power (W/kg)	9.70	0.75
Fatigue (% decline)	33.10	7.36
Training (km/yr)	5187.26	3027.45
Racing Experience (yrs)	4.21	4.34

Table 2
Correlation Coefficients Between Selected Variables
and Time Trial Performance

Variable	r	p
Weight (kg)	.24	.263
Relative VO_2 ($\text{ml} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)	-.71	.001
Absolute VO_2 ($\text{L} \cdot \text{min}^{-1}$)	-.60	.002
Absolute VT ($\text{L} \cdot \text{min}^{-1}$)	.07	.070
Relative VT (as % of absolute VO_2)	-.38	.764
Body fat (%)	.21	.322
Average Power (W)	.10	.364
Peak Power (W)	.21	.337
Average Power (W/kg)	-.17	.425
Peak Power (W/kg)	.004	.986
Fatigue (% decline)	.43	.037
Training (km/yr)	-.57	.004
Racing Experience (yrs)	-.42	.044

($p < .05$) correlation with time trial performance included absolute VO_{2max} ($r = -.60$), yearly training mileage ($r = -.57$), fatigue index from the Wingate bicycle test for anaerobic power ($r = .43$), years of competition ($r = -.42$), and absolute VO_2 at VT ($r = -.38$). Body weight, though not showing significant correlation ($r = .24$), was a component of the equation to predict time trial performance on a 2-km hill. Stepwise regression analysis (BMDP 2R) yielded the following prediction equation: $\text{Time} = 15.54 - .0307(\text{body weight}) - .0918(\text{relative } VO_{2max}) + .0229(\text{fatigue index}) - .000127(\text{yearly mileage})$. [Multiple $R = .79$, $R^2 = .62$, and $SEE = .638 \text{ min}$].

Discussion

The results of this study are in agreement with other research which found high negative correlations between VO_{2max} and overall performance in cycling (2,10,13,16) as well as success in other endurance sports, including distance running (3,8,9). Pfeiffer et al. (16) found significant negative correlations between finish times and both absolute and relative VO_{2max} in a multiday stage race. VO_{2max} was the best predictor of overall success, and accounted for approximately 71% of the variability in a cyclist's performance in the event's hilliest road races. Although the present study also found relative VO_{2max} to be the strongest predictor of performance, it only accounted for 50% of a cyclist's success.

Not all research has found VO_{2max} to be as reliable a predictor of performance. Numerous studies have found that there is little difference between VO_{2max} values of highly trained athletes in comparison to subelite athletes (4,5,12,23). Krebs et al. (12) observed that although VO_{2max} was an important predictor in a 40-km time trial, the main factor setting the expert cyclists apart from the novices was the experience level of the experts. Expert cyclists tended to train longer, at higher percentages of maximal effort, compete more often, and own better equipment.

Other researchers investigating predictors of triathlon performance also found VO_{2max} to be a poor predictor of performance time (6,15). Dengel et al. (6) observed that substrate utilization and the body's response to thermoregulatory or cardiovascular demands played a greater role in performance than VO_{2max} .

Hawley and Noakes (11) found peak power to be the best predictor of success in a flat 20-km time trial. This observation agrees with the findings of White and Al-Dawalibi (25), who found that international and elite cyclists have superior abilities to reach peak power faster and hold that power longer than subelite cyclists. The results of the present study suggest that a cyclist's ability to hold peak power, measured by the fatigue index of the Wingate bicycle test, although not a primary determinant of hill climbing success ($r = .43$), is also useful.

Many researchers have linked cycling performance to anaerobic threshold. Faria, Faria, Roberts, and Yoshimura (7) found that in addition to a high VO_{2max} , elite cyclists have the ability to sustain a high percentage of their VO_{2max} for extended period of time. Although VO_2 at VT was not a strong predictor of hill climbing ability ($r = -.38$) in the present study, the ability to maintain peak power, as measured by the fatigue index, appeared to play a role.

Research pertaining to hill climbing in particular has emphasized the effect of body weight on performance. Uphill riding is much different than riding on level ground, since air resistance is no longer a major factor. Rather than fight air resistance, the cyclist must move both his own weight and that of the bicycle against gravity. Swain et al. (21) reported that although a large cyclist may have an advantage over a smaller cyclist riding on level roads, the same rider may be disadvantaged when climbing hills. The researchers found that the reason for the larger cyclist's advantage on level roads is based on his lower ratio of frontal area to bodyweight in the United States. Although the heavier cyclist's weight, which in turn leads to a lower ratio of VO_2 to body weight.

The results of Stovall et al. (19) seemed to agree with these conclusions by finding statistically significant positive correlations between body mass and finish times of certain hilly stages of the Tour Du Pont, a multistage road

were slower on the hills, they tended to perform better on the time trials than the lightweight climbers. The present study found little correlation between body weight and hill climbing success ($r = .24$). However, the regression equation to predict performance in the 2-km hill climb did include body weight as an important factor.

Swain (20) theorized that the relative advantage of heavy cyclists evident on level ground is negated when cycling in the hills, due to the larger cyclist's smaller relative VO_{2max} .

While the results of the current study imply a relationship between VO_{2max} and hill climbing performance, they are less conclusive about other possible predictors, such as body weight. This group of cyclists displayed a wide range of abilities and experience levels, despite all fitting this study's definition of "trained." For this reason, it is possible that a given variable could have been a stronger predictor of performance in a more homogeneous group.

Practical Application

The results from this study suggest that a cyclist's ability to climb hills 2 km in length may be predicted by several factors which are strongly influenced by the cyclist's training. A cyclist wishing to improve his climbing on hills of this length may aim to maintain an optimal body weight, increase his VO_{2max} , increase his

anaerobic endurance (as measured by the Wingate anaerobic power bicycle test), and increase his training mileage.

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APPENDIX A
INFORMED CONSENT FORM

INFORMED CONSENT

Predictors of uphill riding performance in trained cyclists
University of Wisconsin-La Crosse
La Crosse, Wisconsin 54601

Principal Investigator: Anne Rollings

I, _____ (name), being of sound mind and _____ years of age, do hereby consent to, authorize and request the person named above, and her coworkers, to undertake and perform on me the proposed research procedures.

The purpose of this study is to determine which variables are the best predictors of performance in an uphill time trial for trained, subelite cyclists. The results from this study may be used to help cyclists of varying abilities improve their proficiency in climbing hills.

I will perform tests to determine my maximal oxygen uptake (VO_{2max}) and peak anaerobic power. The VO_{2max} test will consist of my pedalling my own bicycle attached to a Schwinn Velodyne stationary trainer at progressively greater workloads until voluntary exhaustion. Throughout the test, my heart rate will be monitored via a heart rate monitor strapped to my chest. I will wear a headgear and mouthpiece to collect my expired air, which will be analyzed during the test. The peak anaerobic power test will take place on a different day than the VO_{2max} test, and will consist of my riding a Monark ergometer at maximal effort for 30 seconds at a workload determined by my body weight.

Even though both of these tests are maximal efforts, I may terminate either of them at any time. As with any exercise, there is a possibility that I may experience adverse effects such as dizziness or shortness of breath. I will probably feel very tired after both of the tests. I understand that if any abnormal observations are noted at any time by the experimenter, the test will be terminated immediately.

I agree to have my body composition determined via the hydrostatic weighing method, which involves my submerging myself entirely in a tank of water and exhaling maximally, at which time my body weight will be measured. If I am not comfortable with the procedure of hydrostatic weighing, my body fat may be measured in the laboratory through the use of skinfold calipers.

The second phase of the project will be a 2-km uphill time trial on Hwy 3 in Winona County, MN. If I feel any adverse symptoms during the time trial which are not consistent with the stress to which I am accustomed during a maximal effort, I may discontinue the ride. I am aware that there are certain inherent dangers associated with bicycle riding on an outdoor course, including traffic hazards and possible injury to falls, both of which could result in serious injury or death. I agree to wear an ANSI and/or SNELL approved helmet during the time trial, as well as during related warm up and cool down time. I agree to abide by the rules of the road during all portions of the time trial phase of this study.

I consider myself to be in good health, and am not infected with any infectious disease. I do not have any condition, especially pertaining to my heart, which would preclude my participation in these tests.

I have read the above document, and I have been fully advised of the nature of this research procedure and the possible risks and complications involved in it, all of which risks and complications I hereby assume voluntarily.

I understand that I may ask questions of the principal investigator at any time during the project. I also understand that I may withdraw from the study at time.

I hereby acknowledge that no representations, warranties, guarantees or assurances of any kind pertaining to this research study have been made to me by the University of Wisconsin-La Crosse, the officers, administration, employees or by anyone acting on behalf of any of them.

Signed on (date) _____ in the presence of the witnesses whose signatures appear below opposite my signature.

WITNESSED BY:

(Subject)

APPENDIX B
SUBJECT QUESTIONNAIRE

SUBJECT QUESTIONNAIRE

NAME _____ PHONE _____ Home

_____ Work

ADDRESS _____

BIRTH DATE _____

Please answer the following questions:

1. How many years have you been bicycling?
2. What is your average weekly training mileage in mid-season?
Yearly mileage?
3. Approximately how many miles have you accumulated in the past five months (March - present)?
4. Do you currently compete?
If yes, USCF _____ Citizen _____ Triathlon _____ off-road _____
If yes, how many years have you competed?
If USCF, Category _____
5. On the scale below, with 10 indicating a very high level of skill, rate your hill climbing ability compared to other trained cyclists in your age group and/or category.

1 2 3 4 5 6 7 8 9 10

APPENDIX C
REVIEW OF LITERATURE

REVIEW OF LITERATURE

VO_{2max} and Athletic Performance

Previous research has linked athletic performance to an athlete's maximal oxygen uptake (VO_{2max}), especially in endurance events such as distance running (2,7,8). Other research has also found VO_{2max} to be a valid predictor of performance in cycling events (1,9,12,14). Pfeiffer, et al. (14) found significant negative correlations ranging from -.56 to -.91 between finish times in a very difficult, hilly stage race and values of absolute and relative VO_{2max}. The researchers suggested that up to 82% of a cyclist's performance in a hilly event could be accounted for by the athlete's relative VO_{2max}. However, the experiment was performed using only female cyclists.

Other studies have found VO_{2max} to be a less important predictor of performance, in comparison to other factors. A number of studies have found that there is little difference between the VO_{2max} values of highly trained elite athlete in comparison to subelite athletes (3,4,11,18).

Krebs, et al. (11) observed that although VO_{2max} was an important predictor of cycling performance in a 40-km time trial, the main factor setting the expert cyclists apart from the novices was the level of experience of the experts. Expert cyclists tended to train longer, at higher percentages of maximal effort, compete more often, and own better equipment, including lighter bicycles.

Dengel, Flynn, Costill, and Kirwan (5) found that VO_{2max} was a poor predictor of finish times in a triathlon. Likewise, O'Toole, Douglas, and Hiller (13) observed that VO_{2max} was not a strong predictor of performance in the bicycling leg of the Iron Man triathlon competition. They claimed that factors such as substrate utilization and the body's response to thermoregulatory or cardiovascular demands played a greater role in performance.

Power and Cycling Performance

Hawley and Noakes (10) found that peak power was a good predictor of performance in a flat 20-km time trial course. This observation agrees with the findings of White and Al-Dawalibi (19), who concluded that international and elite cyclists have superior abilities to reach peak power faster and hold that power level longer than subelite cyclists. The researchers noted that elite cyclists also have greater explosive leg strength, as measured via a vertical jump test.

Coyle, et al. (4) found that elite racers were able to generate greater absolute power compared to the "good" racers in a laboratory-simulated 40-km time trial. The higher power output was related to these cyclists' high VO_2 values at lactate threshold.

Anaerobic Threshold and Cycling Performance

A number of other studies linked anaerobic threshold (AT) to performance. Faria, Faria, Roberts, and Yoshimura

(6) found that in addition to a high VO_{2max} , one of the best predictors of a strong performance is the ability to sustain a high percentage of one's VO_{2max} for an extended period of time. They found that elite cyclists also tend to reach their ventilatory threshold at a higher percent of VO_{2max} compared to less experienced cyclists.

Similarly, Coyle, et al. (3) found that endurance varied greatly among cyclists with similar VO_{2max} values, due to the percent of VO_{2max} at which anaerobic threshold was attained. They concluded that certain factors are associated with an increase in this value, including years of cycling experience, and the athlete's percentage of Type I muscle fibers.

Vrijens, Pannier, and Bouckaert (18) found a significant difference between professional cyclists and high level amateurs in terms of their physical work capacity (PWC), or endurance. They reported that the PWC of a cyclist is closely related to his or her anaerobic threshold, which tends to increase as the cyclist advances from junior level to senior level racing and from novice to amateur.

Effect of Body Mass on Uphill Cycling

It has been suggested that body mass is a critical element in uphill cycling. Riding uphill is a different situation than cycling on level ground, since air resistance is no longer a major factor. Rather than fight air

resistance, the cyclist must move both his own weight and the bicycle's weight against gravity. Swain, Coast, Clifford, Milliken, and Stray-Gundersen (17) reported that although a large cyclist may have an advantage over a smaller cyclist when riding on level roads, the same rider may be disadvantaged when climbing hills. The researchers found that the reason for the larger cyclist's advantage on level roads is based on his lower ratio of frontal area to body weight, which in turn leads to a lower ratio of VO_2 to body weight.

Stovall, Swain, DeBenedetti, Pruitt, and Burke (15) found statistically significant positive correlations between body mass and finish times of certain hilly stages of the Tour Du Pont, a multistage road race in the United States. Although these heavier cyclists were slower on the hills overall, they tended to perform better on the time trials than the lightweight climbers.

Swain (16) theorized that the relative advantage of heavy cyclists evident on level ground is negated when climbing hills, due to the larger cyclist's smaller relative VO_{2max} .

Summary

The research suggests that while physiological variables such as VO_{2max} or peak power may play a role in cycling performance, they may not predict success as well as a cyclist's anaerobic threshold or years of racing

experience. Elite cyclists have been found to maintain their peak power longer, and at a higher percentage of VO_{2max} , compared to amateurs.

Many of these variables have been investigated as predictors of overall success in cycling, or in specific events such as time trials. When specifically addressing hill climbing, it appears that body mass plays a critical role in performance, with the lighter cyclist having the advantage.

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