

Research on the Optimal Strength Curve of Athletes Based on EVP Model

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Abstract. As one of the world's favorite extreme sports, bicycle racing gives people a physical workout and is in line with today's global community's advocacy of low carbon. The individual time trial and team time trial in bicycle racing is a great challenge for athletes. In this sport, different athletes have different power curves, and athletes have to adjust their power curves according to the actual situation during the ride. And when and where athletes adjust their power usually determines whether they can win the race or not. Therefore, in order to find the best power adjustment strategy, we build a mathematical model for determining the relationship between rider's position on the track and rider's power, as well as the power profiles of athletes on specific tracks, and try to apply it on any type of riders.

Keywords: EVP Model, FVP Model, Power Profiles, Cyclists.

1. Introduction

The individual time trial in a cycling road race requires each participant to complete the course alone on a defined course, with the shortest time being the winner. Every rider wants to finish the course in as short a time as possible, and the rider's power curve plays a significant role in this process.

Each rider will produce different power levels at different times and under different conditions. The power curve reflects the maximum power output of a rider over a period of time. The power curve reflects the past power output and the degree of exceeding the power curve limit, etc. All factors affect the performance of the rider and the result of the race to some extent. Studying the power curve of a rider is important to improve the scientific degree of rider training, to make a suitable race plan and to promote the better performance of a rider on the race track.

According to the literature [1] and [2], we learn that the conventional FVP model is only related to the velocity and combined external forces. Based on this model we combined the method of finding wind force based on temperature, altitude, wind speed and wind direction in thermal physics to establish an EVP model related to external conditions such as weather changes, which can constantly self-correct the equation between position and force on the track according to the actual movement of athletes, and thus determine the potential influence of weather conditions. The results show that riders are most influenced by wind speed and direction and slope during the race, and less influenced by temperature and altitude.

We applied model to the race in question, choosing two different types of athletes, time trial specialist and sprinter, to make their power curves in the race, and this power curve was also divided into male and female. Due to the diversity of the results, it will be shown in the text.

2. Model assumptions and notation

2.1. Assumptions

Assumption 1: All data in this paper are reliable and well-founded, including conjectured data.

Assumption 2: Assume that all athletes consume the same maximum amount of energy.

Assumption 3: It is assumed that all athletes have no special conditions during the sport and all play normally.

Assumption 4: It is assumed that the respiratory system of the human body consists of four compartments with the outside world and tissue cells.

2.2. Notations

Important notations used in this paper are listed in Table 1.

Table 1. Notations

Symbol	Description
F_0	The rider receives a joint external force.
v_0	The rider's own speed.
P_0	The rider's own power.
ρ_A	Atmospheric density of the rider during the race.
x	Length of the bike course
v'_m	Wind speed to riders in team counting races

3. Environment-velocity-dynamic model construction and solution

The rider will not ride under ideal conditions and will inevitably be affected by the outside environment, such as the air resistance caused by the wind power and direction, the temperature of the environment he is in and the outside atmospheric pressure. A variety of factors can have a significant impact on a rider's riding and his power curve. In order to study the extent of the influence of weather conditions, we based on the existing FVP model, combined with the corresponding physical equations to improve it, supplemented by the analysis of the influence of weather conditions and track conditions on power, thus establishing the environment-speed- power model (EVP). This model is described below.

3.1. Improvements Based on FVP Models

The FVP model is given in the literature [3] and we improved it to the Climate-Velocity- Power model (CVP model), which takes into account the influence of weather conditions. For the influencing factors we chose the wind direction and power in the title, to which we added the temperature, atmospheric density, altitude and atmospheric pressure. We also took into account the differences in the race courses in different regions in conjunction with specific regional events to make the model more realistic.

3.1.1. Velocity-Power (VP) Model

The FVP model given in the literature [4] is derived under the condition that the wind speed is zero and the $F-v$ relationship is determined by least squares linear regression. Since $P=Fv$, they can be logically described by a quadratic polynomial function. This gives us good ideas, and the linear regression ($r^2=0.75-0.99$, $P\leq 0.012$) and quadratic polynomial ($r^2=0.70-1.00$, $P\leq 0.024$) of $F-v$ and $P-v$ have been verified in the paper to fit well. Without considering the weather conditions F has the following relationship with v .

$$-k_{Fv} = \frac{F_0}{v_0} \quad (1)$$

Where k_{Fv} is the $F-v$ relationship coefficient.

$$P_0 = F_0 v_0 \quad (2)$$

The question requires our model to show some sensitivity to weather and environment. In addition to the two factors of wind power and wind direction required by the question, we decided to choose

four factors, namely temperature, atmospheric density, altitude and atmospheric pressure, after careful consideration of the actual situation. It is also known that.

$$\rho_A = \rho_0 e^{-0.0001z} \quad (3)$$

In the literature [5], we know that the wind pressure W_W can be derived from Bernoulli's formula.

$$w_W = \frac{\rho_A v_W^2}{2} \quad (4)$$

Combining equation (2) (3) (4), we can derive the power profiles of the cyclist during the race, which can be related to the force, wind speed, temperature and air pressure to which the athlete is subjected. Let the direction of athlete's movement be positive. Taking into account the wind direction, the formula is modified as following.

$$P_0 = \begin{cases} v_0 \left(F_0 - \frac{\rho_0 e^{-0.001z} v_W^2 \cos^2 \alpha}{2} S_1 \right), \pi < \alpha < 2\pi \\ v_0 \left(F_0 + \frac{\rho_0 e^{-0.001z} v_W^2 \cos^2 \alpha}{2} S_1 \right), 0 < \alpha < \pi \end{cases} \quad (5)$$

Where $\cos \alpha$ is the cosine of the angle between the wind direction and the direction of the athlete's motion. Equation (5) can show some sensitivity to small differences in weather and environment.

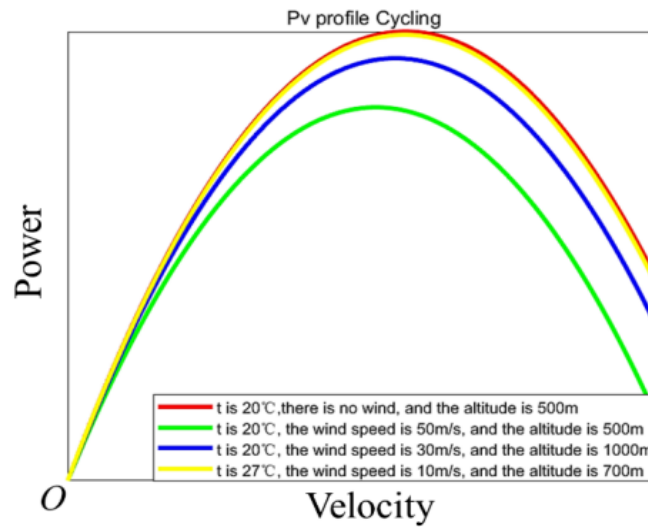


Figure 1. Sensitivity of the P-v function to environmental changes

Sensitivity of the P-v function to environmental changes is shown in Figure 1. Once the weather conditions were determined to affect the model, we were able to simulate the outside environment. After this we can build a model to reflect the power and time relationship of the riders during the race. Considering the ability of the cyclist to exceed the power curve limit in a short period of time, the limited physical strength of the cyclist, and the topography of the course, we first determined that the cyclists (note that in this case, the cyclists were the only ones who had the ability to exceed the power curve limit) had the ability to exceed the power curve. We first determined the power profiles of the cyclists and we analyzed the model, which can be applied to various time trial events [6].

3.2. Energy allocation optimization model

The goal of the model is to obtain the minimum time under the given constraints, so it can be solved optimally by a genetic algorithm. We note that there is a limit to the amount of energy a driver can consume in a race, and it is free to choose when and what level of power to output, while the different conditions of the track also determine what kind of power a driver outputs. Therefore, we

consider to build the model based on the driver's energy allocation during the race and the terrain conditions [7].

We first define the maximum output power of the rider and consider the output power of the rider during the sprint to be this value. This can be improved by increasing the ability to develop high level power at low speed (power capacity or strength) and low level power at high speed (speed capacity). Afterwards, consider the energy allocation strategies of the riders. Different energy allocation strategies reflect the strengths of different athletes and have a significant impact on race performance. In cycling individual time trials, athletes need to combine endurance runs with sprint runs in order to achieve the goal of maximum power output across the board. Time Trial Specialists (TTS) have the ability to make more decision-making power allocations, deciding when to expend energy, when to recover energy, and being able to finish the race with minimal energy expenditure. Finally we randomly selected the average speed of several Time Trial Specialists riding [8]. Country and average speed of each athlete is shown in Table 2.

Table 2. Country and average speed of each athlete

Name	Velocity(km/h)	Name	Velocity(km/h)
G.BENNETT (NZL) 	41.3	N.ARNDT (GER) 	42.6
L.CRADDOCK (USA) 	41.6	S.DE BOD (RSA) 	42.9
H.HOULE (CAN) 	43.6	T.KANGERT (EST) 	41.7
N.ROCHE (IRL) 	41.2	M.KUKRLE (CZE) 	41.3
A.BETTIOL (ITA) 	43.9	P.ROGLIC (SLO) 	44.9

The average speed of a typical Time Trial Specialists ride is 42.5km/h. This can be used as an important reference data.

According to hypothesis 1 (assuming that all athletes consume the same maximum energy), we can set the same maximum limit of total energy consumed by both, which is 1.32×10^7 J. According to hypothesis 2 (hypothesis 2: assuming that all athletes do not have special conditions while exercising and all play normally), we only need to know the state of the athlete on that day, the maximum speed that can be reached, the time to recover energy, and the slope. In order to simplify the problem and reduce unnecessary and tedious operations, the slope is uniformly assumed to be 30 degrees.

3.2.1. Optimization Model Building

Let the average power of athletes riding on the flat is P_1 and time is t_1 ; the average power when riding uphill is P_2 and time is t_2 ; the average power when riding downhill is P_3 and time is t_3 . The average power when sprinting is P_m , and the average power when relieving stamina is P_r . When Specialists sprint for a period of time t_m , it takes time t_r to buffer. Due to the effect of centripetal force when specialists make turns, energy will be consumed, with n_1 sharp turns, each time over the sharp turn consumes energy E_1 ; there are n_2 sharp turns, each time over the sharp turn consumes energy E_2 . then there are as follows [9].

$$\begin{aligned} \min t &= t_1 + t_2 + t_3 + t_m + t_r \\ \text{s.t.} \quad &\begin{cases} P_1 t_1 + P_2 t_2 + P_3 t_3 + P_m t_m + P_r t_r + n_1 E_1 + n_2 E_2 \leq E_m \\ t_m \leq t'_m \\ t_m \leq t_r \\ \bar{v}(t_1 + t_2 + t_3) + v_m t_m + v_r t_r = x \end{cases} \end{aligned} \quad (6)$$

The $\bar{v}$ handle is the average speed during normal riding, v_m is the average speed during sprinting, and v_r is the average speed during recovery. When Specialists' power briefly exceeds P_m , it takes

more time to recover at a lower energy level. It is important to note that the sprint time cannot be greater than the recovery time, otherwise Specialists' stamina would not be recovered in time.

According to equation (5)(6), a power allocation model related to weather conditions and Specialists' own situation can be obtained. We wrote a program for this model to facilitate the results.

3.3. Model Validation

In the following we explore the differences in power allocation between these two athletes from three different races of the same event, while also considering gender differences.

3.3.1. 2021 Olympic Time Trial course in Tokyo, Japan

Time: July 28, 2021

Venue: Fuji International Speedway.



Figure 2. Man's Individual Time Trial (left) and Woman's Individual Time Trial (right) at the Tokyo Olympics [10]

Man's Individual Time Trial (left) and Woman's Individual Time Trial (right) at the Tokyo Olympics is shown in Figure 2.

Terrain features: The course is located in the suburbs of Tokyo and requires a total of four hills to be climbed, with many small hills and large changes in gradient along the way. There are 6 sharp turns in the front section of Fuji International Circuit, which is a track bounded by guardrails, and then enters the highway and faces a long, flat, wide road. After passing through the main road, we come to the first hill with a slope of almost 30 degrees and six sharp turns in between, and the road is narrow. The middle ushers in a section of flat road with 4 big turns waiting for the runners, and after turning 4 turns, they have to face a series of steep slopes, which are bumpy and accompanied by 6 sharp turns. And then enter a section of flat road, next start uphill. During the uphill we need to face 3 sharp turns, 2 big turns, and finally start downhill, accompanied by 4 sharp turns and 1 big turn, and cross the finish line. The men's race cover 44.2 kilometers and the women's race cover 22.1 kilometers. On the day of the race, the temperature was 30 degrees and the wind speed was 20km/h and the altitude was 37m.

Result: For the men's race, t_m is taken as 150s; for the women's race, t_m is taken as 120s, and the acceleration of gravity g is taken as 9.8m/s. The final results are.

$$\left\{ \begin{array}{l} t = 3264.3 \\ t_1 = 1064 \\ t_2 = 1437.4 \\ t_3 = 465 \\ t_m = 149 \\ t_r = 149 \end{array} \right\} \left\{ \begin{array}{l} t = 2439.8 \\ t_1 = 956 \\ t_2 = 735.9 \\ t_3 = 117 \\ t_m = 315.45 \\ t_r = 315.45 \end{array} \right. \quad (7)$$

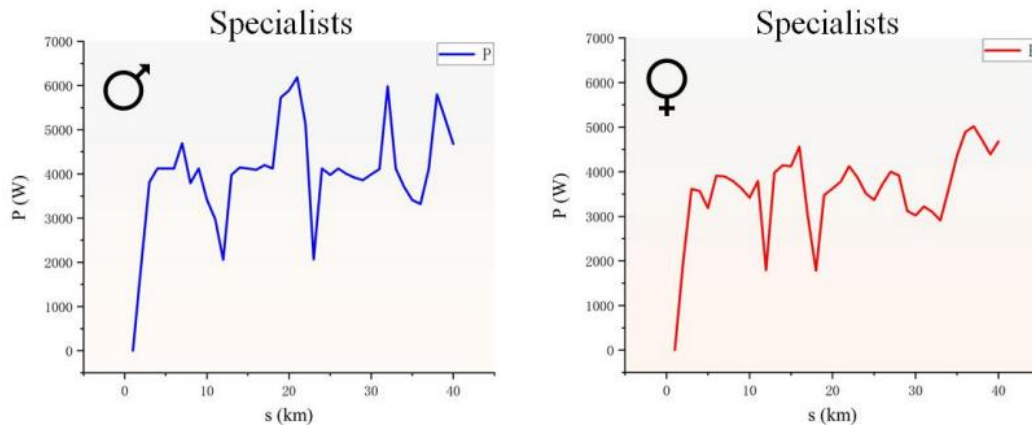


Figure 3. Power-distance curves of male and female specialists

Power-distance curves of male and female specialists is shown in Figure 3.

3.3.2. 2021 UCI World Championship time trial course in Flanders, Belgium

Time: September 19, 2021

Location: North Sea beach, near the casino.

Man's Individual Time Trial (left) and Woman's Individual Time Trial (right) at the World Cup in Flanders, Belgium [5] is shown in Figure 4.



Figure 4. Man's Individual Time Trial (left) and Woman's Individual Time Trial (right) at the World Cup in Flanders, Belgium

Terrain Features: The start of the time trials is situated on the North Sea beach, near the casino. During the first 1.5km the riders will ride along the sea, followed by a passage in the center of Knokke-Heist. After that it goes inland, it then faces an uphill climb, with 3 slopes on the way, 7 sharp turns and 9 big bends throughout and accompanied by sea breezes. After 5 almost straight kilometers in Dudzele and a pass in the picturesque town of Damme, it heads towards Bruges, the city of art, and the finish in 't Zand. The men's race cover 43.3 kilometers and the women's race cover 30.3 kilometers. On race day, the temperature was 22 degrees and the wind was 4km/h and the altitude is 78m.

Result: Similarly, the final results of the men's and women's races are.

$$\left\{ \begin{array}{l} t = 3264.3 \\ t_1 = 1064 \\ t_2 = 1437.4 \\ t_3 = 465 \\ t_m = 149 \\ t_r = 149 \end{array} \right\} \left\{ \begin{array}{l} t = 2439.8 \\ t_1 = 956 \\ t_2 = 735.9 \\ t_3 = 117 \\ t_m = 315.45 \\ t_r = 315.45 \end{array} \right. \quad (8)$$

3.3.3. Self-designed track

Before designing the course, we needed to prove the feasibility of our model, we consulted the data of the 2021 Olympic Time Trial course in Tokyo, Japan (hereinafter referred to as Tokyo Olympics) and the 2021 UCI World Championship Time Trial in Flanders, Belgium (hereinafter referred to as UCI World Championship) to get the then participating athletes' The race results. After the comparison, it can be seen that the results we obtained are in line with the average of Time Trial Specialists in general. This is a good proof that the model has some accuracy.

The course required by the title included at least four sharp turns and at least one uneventful road grade, while the finish should be near the start. On top of that, we also took into account the weather factor. The Tokyo Olympics course is characterized by hills and long distances in hot weather, while the UCI World Championship course is characterized by flatter roads and warmer weather. The course we designed is located in Innsbruck, Austria, where the summer temperature is about 19 degrees Celsius. The elevation changes during the ride are obvious, with a minimum of 53 meters and a maximum of 863 meters, with an average elevation of about 570 meters. The course is hilly, with a total of 7 hills, 28 sharp turns, 11 big bends and a total length of 51.2 km. It starts from Innsbruck and ends in Innsbruck. Circuit of Innsbruck, Austria is shown in Figure 5.

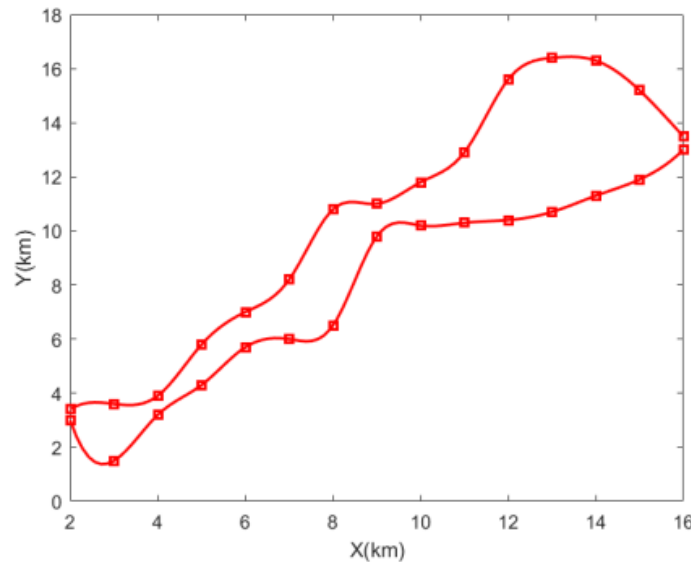


Figure 5. Circuit of Innsbruck, Austria

The results obtained for the men's race were.

$$\left\{ \begin{array}{l} t = 3927.7 \\ t_1 = 1431.2 \\ t_2 = 1886.5 \\ t_3 = 386 \\ t_m = 112 \\ t_r = 112 \end{array} \right. \quad (9)$$

In the previous discussion, we have explored the differences between male and female power profiles, so here we only explore the differences between different types of athletes. Power-distance curves of male and female sprinters is shown in Figure 6.

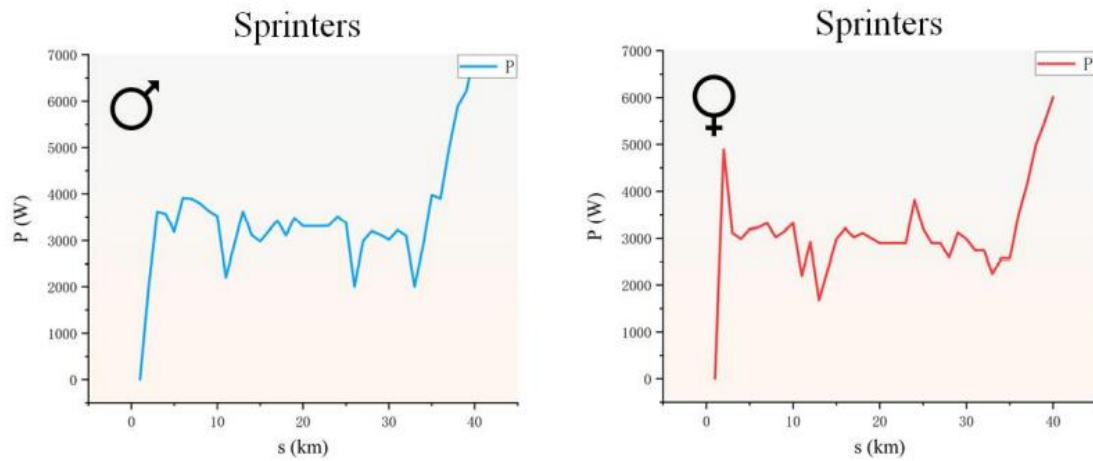


Figure 6. Power-distance curves of male and female sprinters

The question asks us to define that one of the power profiles of riders should be Time Trial Specialists, and the other should be different types of riders. The power profiles of different athletes are different, mainly in the speed of different sections of the same course and the different power levels that can be generated in different times. In this paper, we choose sprinters (Sprinter), who produce higher power levels when sprinting on flat roads, and thus are much faster than Time Trial Specialist, but are significantly weaker than Time Trial Specialist in energy recovery and uphill endurance running due to lower power. So in this paper the Trial Specialist and Sprinter are chosen to investigate the differences between the two types of athletes.

The result of Sprinter is obtained as.

$$\left\{ \begin{array}{l} t = 5161.1 \\ t_1 = 260 \\ t_2 = 4549.1 \\ t_3 = 145 \\ t_m = 180 \\ t_r = 27 \end{array} \right. \quad (10)$$

It should be noted here that the recovery time is less than the sprint time, indicating that Sprinter seldom sprinted at maximum speed in the early stages and kept trying to maintain his strength, playing to his advantage at the last moment and sprinting across the finish line, leaving the recovery time for after the race. Despite this, the final time was still much slower than Time Trial Specialist. Terrain and altitude in Innsbruck, Austria is shown in Figure 7.

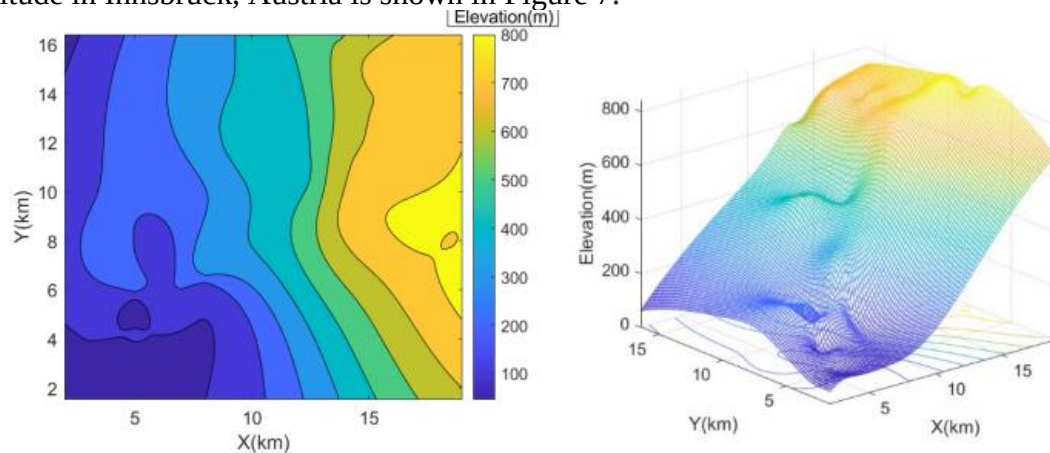


Figure 7. Terrain and altitude in Innsbruck, Austria

4. Conclusion

Figures 2 and 5 show the power profiles for two types of riders. one of them is a time trial specialist and the other is a sprinter. different genders of riders are also considered. The overall results show that the female athlete's maximum power and average power throughout the race is about 350 W lower than the male. sprinter's power is significantly slower than the expert in the early stages, but significantly faster in the later stages, even surpassing the expert.

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