

Research on the Factors Influencing the Strength of Cyclists

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Abstract. Individual Time Trial (ITT) is a road bicycle race where cyclists race alone against the clock. To minimize the total time cost, cyclists need to focus on the output power. In this paper, we develop models to analyze the output power of cyclists determine how to adjust the output power at every position of the course. Firstly, this article collects the real data of cyclists, which is used to find the power profile related to power and duration. Reasonable expressions of different types of cyclists of different gender are also concluded. Secondly, this article considers the cyclists in competition as a constantly charged battery and discharged. FTP is the power at which cyclists can work steadily for a long time. Therefore, this article uses FTP to represent the recovery rate of cyclists approximately. There is two basis of our model. First, maintaining a steady speed is the key to reducing the total time loss in the time trial. The next basis of our model is to divide the course into three types: uphill, downhill, and sharp turn and do the force analysis. Then, this article builds up a model which tells the cyclists how to adjust output power in the whole time trial. Fatigue is also considered in our model. the model applies to two real Individual Time Trials and one course designed by us and draws the power-distance curve correspondingly. Finally, this article analyzes the potential impact of the wind. The wind will affect the cyclists' air resistance f_A . The time cost at every part is calculated to determine the proposed model's accuracy. This article also analyzes the impact of improper power adjustment.

Keywords: ITT, power profile, FTP, cyclists, air resistance, road type.

1. Introduction

Individual time trial (ITT) is a road bike race in which cyclists race against time alone. The whole stage of the modern bicycle is very complex. Improper power distribution will lead to premature fatigue and affect performance. Therefore, it is very important to adjust the output power reasonably in the competition. This paper assumes that the influence of the change of bicycle on the output power of cyclists can be ignored. Assuming that the data of power and duration can represent most cyclists of the same type, three aspects of research are carried out: first, study the relationship between strength and duration, and model a power curve for cyclists of different types and genders. Second, by adding the analysis of the track, simulate how the rider should adjust the output power according to the rider's position on the track. The model is applied to specific courses to determine the potential impact of weather conditions. Finally, the consequences of cyclists' failure to generate electricity as planned are analyzed.

2. Define the Power Profile

2.1. Finding the relation between power and duration

A power profile is a curve that describes the cycling ability. Its horizontal axis is duration, and its vertical axis is the power per kilogram, which represents the maximum mean power (MMP) that the cyclist can maintain in a certain duration. In this problem, we used the power under 4 types of durations to find the power profile, which are 5 seconds, 1 minute, 5 minutes, and 20 minutes. 5-second maximum power describes the aerobic endurance ability, 1-minute maximum power describes

the anaerobic capacity, 5-minutes maximum power describes maximal oxygen consumption capability ($VO_2 \max$), 95% of the 20-minutes maximum power describes the Functional Threshold Power (FTP), represents the aerobic endurance ability. The cyclist can maintain power at FTP for a long duration.

Usually, different kinds of cyclists may have different power profiles. For example, the sprinters can output massive power within 5 seconds, which represents they have an excellent sprint ability, but cannot maintain a considerable power among 20 minutes because their aerobic endurance ability may not be good. Conversely, the Time Trial Specialists usually have a larger FTP and weaker aerobic endurance ability because the Time Trial Specialists need to maintain large amounts of power smoothly over a long duration [1].

Therefore, if we know a cyclist's power under the above four conditions, we can find the corresponding points in the power profile. Then, by smoothly connecting the points, we can find the relationship between power and duration and conclude the power profile. Power is inversely proportional to duration due to lactate tolerance and maximum lactate capacity [2]. When the duration approaches infinity, the average maximum power the cyclists can maintain is around FTP. Hence, the relationship between power and duration is approximately an inverse proportional function with a constant. The constant represents the FTP level of the cyclists.

Here are two tables that record the power of Time Trial Specialist and Sprinter of different genders [1]. Due to the effect of body fat percentage, we find that the maximum power of female cyclists of the same type was about 81% of that of males [1].

Table 1. Time Trial Specialist's power

time (s)	5	60	300	1200
power of male (W/kg)	6.8	8.74	5.5	4.98
power of female (W/kg)	3.6	7.11	4.76	4.38

Table 2. Sprinter's power

time (s)	5	60	300	1200
power of male (W/kg)	21.05	9.09	4.81	3.91
power of female (W/kg)	17.05	7.39	4.11	3.39

Using the data in 2.1, the corresponding power curves are concluded. Then we smoothed the curve and found the corresponding functional expression.

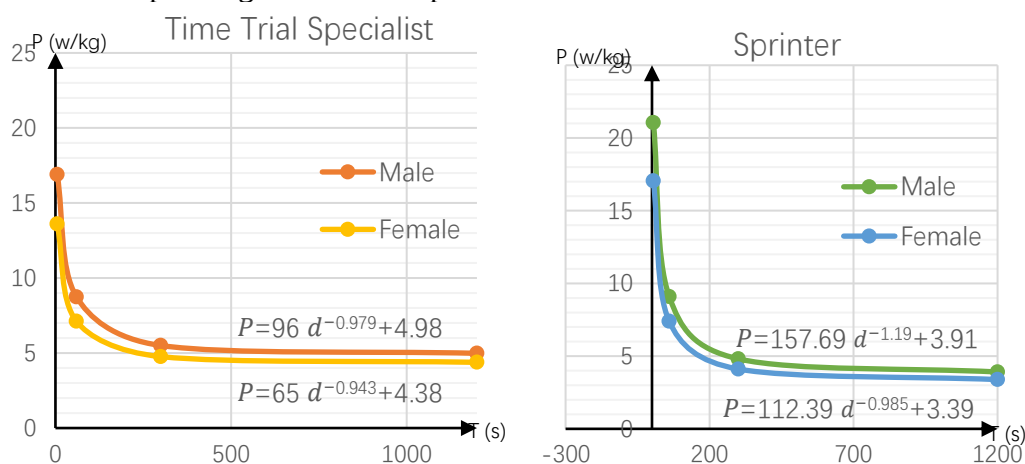


Figure 1. Power profile

As seen from the above figure, FTP represents the power that a cyclist can maintain over a long duration (for example, 1 hour). Usually, the Time Trial Specialists have a higher FTP level. Male cyclists always maintain higher power than female cyclists in the same duration. The power profile of the Male Time Trial Specialists is concluded as: $P = 96d^{-1} + FTP$. The power profile of the Male Sprinter is concluded as: $P = 157.7d^{-1} + FTP$.

3. Apply the model to time trial courses

Cyclists all hope to achieve better results in the competition, but we know that his lactic acid threshold and lactic acid tolerance are determined for a specific cyclist. Therefore, to finish the race in a shorter time means consuming less energy in this race. Therefore, it is essential to reduce the energy loss as much as possible in this game.

Most of our energy consumption is spent on air resistance and ground friction. For everyone, the work done by ground resistance is almost the same. Therefore, reducing air resistance loss as much as possible is the key to solving this problem. It is the key to reducing the energy loss caused by air resistance to keep the motion at a constant speed as much as possible [3]. Therefore, we need to try our best to avoid the extra energy loss caused by going downhill too fast and at the same time ensure that the speed will not be too slow when going uphill.

3.1. Force Analysis

Usually, the time trial courses consist of nontrivial road grades (uphill), downhill, Horizontal roads, and sharp turns. Relevant environmental impacts can be queried for different stages. Deduce the physical energy consumption of wind resistance and terrain through the physical model. The relationship among terrain, speed, and physical power is obtained by deriving the formula connected to 2.1.

The force analysis on the horizontal road is as follow:

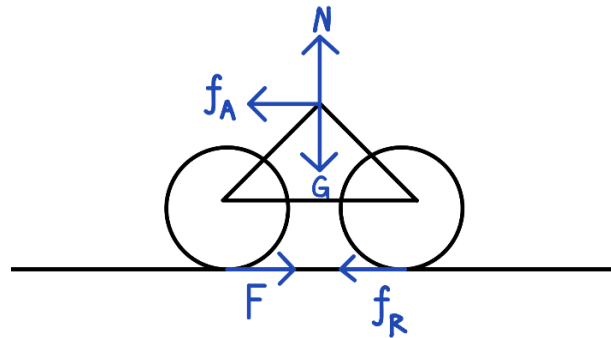


Figure 2. Horizontal Road force analysis

Using Newton's third law, when the cyclists ride, the main force in the horizontal direction:

$$F = f_A + f_R + ma \quad (1)$$

Which "N" represents the force applied by the cyclists to the rear wheel, "G" represents the air resistance, "f_R" represents the rolling friction. "m" represents the quality of the cyclists, and "a" represents the acceleration. The main force in the horizontal direction is:

$$N = G \quad (2)$$

Which "N" represents the support force, "G" represents the gravity.

The air resistance is proportional to the square of the velocity. Moreover, the rolling friction is proportional to the support force.

$$f_A = \frac{1}{2} \rho * C_d * A * v^2 \quad (3)$$

$$f_R = e * N \quad (4)$$

"ρ", "C_d", "A" are all parameters, "A" represents the windward area

The force analysis on the nontrivial road grade is as follows:

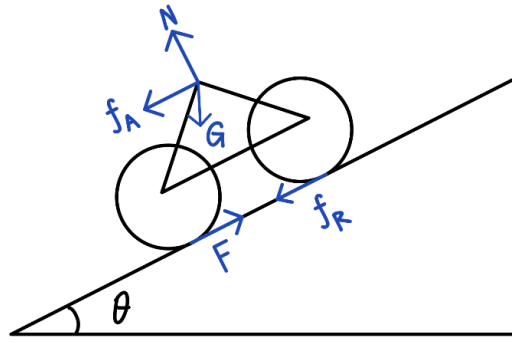


Figure 3. Nontrivial Road Grade force analysis

The main force along the slope:

$$F = f_A + f_R + ma + G \sin \theta \quad (5)$$

It is assumed the included angle between slope and the horizontal plane is θ . The main force perpendicular to the slope:

$$N = G \cos \theta \quad (6)$$

Hence, the force applied by the cyclists can be:

$$F = \frac{1}{2} \rho * C_d * A * v^2 + e * G \cos \theta + ma + G \sin \theta \quad (7)$$

The force analysis on the sharp turn is as follow:

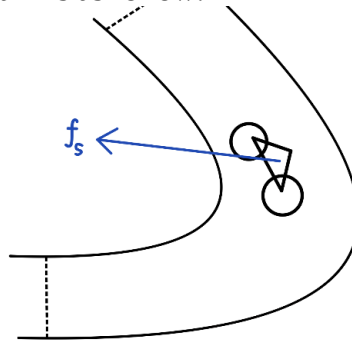


Figure 4. Sharp Turn force analysis

When entering a sharp turn, the static friction force acts as a centripetal force. At this point, there is a critical velocity v_c , and the cyclists need to reduce the power output to zero before entering the corner to reduce the velocity to the critical speed to prevent falling.

$$\begin{aligned} m \frac{v_c^2}{R} &< \mu mg \\ v_c &< \sqrt{\mu g R} \end{aligned} \quad (8)$$

The following formula can calculate the distance x from the start of the sharp turn at which the power is reduced to 0.

$$\frac{1}{2} m v_{balance}^2 - \frac{1}{2} m v_c^2 = \int_0^x (\mu mg + f_A) dx \quad (9)$$

3.2. Modeling energy changes and output power

The energy reserve of cyclists in a race is limited. In the same road section, driving at a relatively stable speed will consume less energy than driving at a fluctuating speed because the air resistance is proportional to the square of the velocity, which means the cyclists have to expend extra power

against significantly increased air resistance. If a cyclist wants to achieve better results, he should keep a steady speed in the race [3].

ATP is a direct substance for human energy supply. In the road time trial, the process of cyclists producing ATP and consuming ATP can be regarded as battery charging and discharging. The initial total energy inside is $W_{initial}$, and the current energy is W_0 . When the cyclists' current output power equals FTP, the energy's consumption rate equals to generation rate. When the current output power is less than FTP, the energy's consumption rate is less than the generation rate, W_0 will increase. When the current output power exceeds FTP, the energy's consumption rate is greater than the generation rate, W_0 will decrease.

Therefore, whether current output power is larger than FTP or not judges whether W_0 's decrease or increase. Here is the equation between the energy and output power.

$$W_0 = W_{initial} - \int (P - FTP) dt \quad (10)$$

3.3. Modeling power adjustment

First of all, using the relation equation among power, velocity, and force, and the equation (1) (2) (3), this article get the equation of maximum velocity at which cyclists can ride on a horizontal road without expelling W_0 (here the output power equals FTP). Then we can get the velocity “ ” which is determined by the cyclists' weight, height, and the road. For example, a 70kg 180cm cyclists' V_{end} is almost 42.1km/h.

$$p = Fv$$

$$FTP = \left(\frac{1}{2} \rho C_d * A * v_{balance}^2 + e * mg * \cos \theta + G \sin \theta \right) * v_{balance} \quad (11)$$

The cyclists need to maintain their velocity around V_{end} in the horizontal road and nontrivial road grade as possible to maximize the average velocity to minimize the total time required [3]. We use this conclusion as a premise for our model.

Then, we define the road whose initial direction and departure direction have a difference greater than 30 degrees as sharp turns. It is defined when the included angle θ between the current part's slope and horizontal plane no smaller than 0 is uphill or downhill. It means horizontal roads are included in uphill.

$$\begin{aligned} Uphill : \theta &\geq 0 \\ Downhill : \theta &< 0 \end{aligned} \quad (12)$$

After getting $v_{balance}$ and defining the three types of roads, we relate the remaining energy W_0 , the road's type of current position, the road's type of next position, and the output power P into one model. Consider the cyclists as a battery that constantly uses ATP and glycogen to charge and discharge. The charging rate is approximately equal to FTP, and fatigue will reduce the charging rate. The following are the coping strategies of cyclists in different sections during the course and the text explanation of our model. The downhill roads can be used to charge the body energy W_0 . Because gravity works on the cyclists during the downhill, the proper posture can well reduce the air resistance so that the power output is less than FTP. To achieve good results, cyclists must expend all their energy on the acceleration at the beginning, the uphill, and the final sprint. When facing a sharp turn, the cyclist needs to reduce the power output to almost zero at some point before entering the turn to control the speed so as not to fall.

The following model will decide how to adjust output power at every part of the course.

First of all, the cyclists should use almost 1 minute to accelerate. The output power can be found through the power profile in 2.1.

Then, except for the sharp turns, every part i of the course can be seen as a collection of four elements: $(S_i, \theta_i, H_i, v_i)$. S_i represents the length of the current part, θ_i represents the angle between

the current part and horizontal plane, H_i represents the altitude change, v_i represents the initial velocity when it comes to the current part of the course. The model starts with the first part (S_1, θ_1, H_1, v_i) and iterates. It will judge whether the next part's road type is the same as the current by multiplying the current part's θ_i and the next part's θ_{i+1} .

$$\begin{aligned} &\text{If } \theta_i * \theta_{i+1} \geq 0 \text{ then continue} \\ &\text{Else, stop iterate} \end{aligned} \quad (13)$$

After the iteration, the model can know whether the next part is continuous uphill or continuous downhill or sharp turn. The handling of sharp turns has the highest priority. The cyclists will reduce the output power to zero at position x away from the sharp turn's beginning. This part is explained in 3.1. After exiting the sharp turn, the cyclists must increase the velocity $v_{balance}$ immediately. The current output power is the power that represents the aerobic endurance ability.

For the front is a continuous uphill ($H_i, H_{i+1}, \dots H_k$), the model increases the cyclists' output power P to ensure that the speed will not change too much during the uphill process will consume the remaining energy W_0 in the body. The total energy allocated on this continuous hill is W_{total} .

$$W_{total} = \min(W_0, mg * (H_k - H_i)) \quad (14)$$

The portion of the output power that exceeds FTP will consume energy in the body. The energy W_i allocated to every part H_i of the uphill can be calculated by this:

$$W_i = \frac{(H_{i+1} - H_i)}{H_k - H_i} * W_{total} \quad (15)$$

Then this article can get the power allocated on this part.

$$p_i = FTP + \frac{W * v_i}{S_i} \quad (16)$$

For the situation that the front is a continuous downhill ($H_i, H_{i+1}, \dots H_k$), the gravity will work on the cyclists. Hence, the model will decrease the output power to less than FTP to charge the internal energy according to the altitude of each part. The energy that can be stored through the downhill is W_{store} .

$$W_{store} = \min((W_{initial} - W_0), mg * (H_i - H_k)) \quad (17)$$

The power allocated on this continuous downhill can be too small because the massive velocity change will cause useless energy waste [3]. The following equation can calculate the power on this part of courses.

$$P_i = FTP - \frac{W * v_i}{S_i} \quad (18)$$

The model also judges whether the next part is the end of the course. If so, the model will use up all the energy left W_0 , and the output power is the same as equation (16). The model will be applied to every part of the course. Then we can get the power's adjustment and know how much power should be used in every part.

4. Conclusion

The research content of this paper can be divided into three aspects. The first point: if the cyclist does not reduce his power output is sharp, he will remain a high speed into the curved. High speed corresponds to the strong centripetal force, but the wheels and road surface friction force is limited, which cannot provide the centripetal force. The cyclist and his bike will make the centrifugal motion

in the corner. Second point: if the cyclist continues to run at maximum power output during the uphill part of the course, his power will be exhausted in a short time, and he will not be able to finish the course later. Third point: if the cyclist does not reduce the power output in the downhill part, he will reach a high speed and suffer from excellent wind resistance, which means that his power is wasted in overcoming the wind resistance. It is harmful to the recovery of the cyclist's power.

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