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Cycling Time Trial Strategies Considering Peak Power-Time Curve and Acceleration

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ABSTRACT

The constant power pacing strategy is typically recommended for long, flat, and windless cycling time trial races. For courses with wind or hills, a variable power pacing strategy is often suggested—one that increases power during headwind or uphill sections and decreases it during tailwind or downhill sections. We analyzed 10 km and 1 km courses under various conditions, including flat and windless, windy, and hilly scenarios, and compared different pacing strategies by considering peak power–time curves and acceleration. For 10 km courses, a fast-start strategy followed by constant power was found to be effective. In contrast, the variable power pacing strategy showed no significant advantage and even worsened finish times when the course started with a downhill followed by an uphill section. For 1 km courses, the variable power pacing strategy improved performance except for the tailwind-then-headwind scenario, where it actually worsened the finish time. In contrast to 10 km courses, the downhill-then-uphill case saw a marked improvement with the variable power pacing approach.

Keywords: Cycling time trial; Peak power-time curve; Acceleration; Simulation, Variable power pacing strategy

1. Introduction

Power management is critical to success in cycling time trial races. Several studies have demonstrated that a variable power pacing strategy—characterized by increasing power output during headwinds and uphill sections, and reducing it during tailwinds and downhill segments—can significantly reduce race times on realistic courses.[1-6]

Among these studies, Cangley et al. (2011) specifically validated the uphill and downhill aspects of this strategy through field experiments on a hilly course.[4] While their results confirmed the potential for time savings, the actual improvement observed was smaller than that predicted by simulations. A key reason was that some participants struggled to sustain the increased power required during uphill sections.

In actual time trial races, riders adopting a constant power pacing strategy typically aim to maintain the highest power they can manage throughout the race. If however, they increase their power output during uphill segments or headwinds, they risk early fatigue, which may prevent them from sustaining their effort to the finish.

Therefore, it is essential to consider the relationship between power output and the duration for which a rider can sustain it in order to produce more realistic simulations. Gordon (2005) simulated 40-km cycling time trials by incorporating exertion based on the peak power–time curve.[7] He calculated optimal power distributions and corresponding finishing times for scenarios such as uphill-then-downhill and headwind-then-tailwind courses. On a course featuring a single climb followed by a descent, the variable power pacing strategy was found to be infeasible due to exertion constraints. However, significant performance gains were demonstrated on courses consisting of repeated 1-km climbs and 1-km descents. In contrast, varying power output for headwind-then-tailwind scenarios yielded no meaningful advantage.

Dahmen et al. (2012) simulated a 4-km uphill time trial with a constant gradient, as well as a 3.6-km uneven uphill course simulating the Schienerberg, taking into account both exertion and acceleration.[8] They mathematically optimized the power profiles. For constant-gradient slopes, they showed that the optimal profile involved high power at the beginning and decreasing toward the end for a 1% slope, while for a 10% slope, the optimal profile involved slightly reduced power both at the beginning and the end. For the uneven slope, they demonstrated that a rider following a power profile optimized for time could reduce finishing time without increasing exertion, and that following a profile optimized for exertion could reduce effort while maintaining the same finishing time, compared to an unregulated (free) ride. However, their study did not include a comparison with the constant power pacing strategy.

Short time trial courses of around 1 km are common in track cycling, and local amateur races are sometimes similarly short and hilly. Wilberg and Pratt (1988) analyzed lap times of 1-km and 3-km race winners in world-class competitions and identified optimal pacing profiles.[9] In 3-km races, the first lap (333.33 m) was slower than the mean lap time (MLT), while the second lap was the fastest. From the third to sixth laps, lap times remained below the MLT. The seventh lap was approximately equal to the MLT, and the remaining laps were slower. In 1-km races, the first lap was slower than the MLT, the second lap faster, and the final lap again slower than the MLT.

These findings suggest that in short time trials, an initial increase in power to rapidly reach top speed—followed by an attempt to maintain that speed, albeit with some decline—is an effective pacing strategy. Moreover, comparisons with optimal pacing profiles revealed that riders who accelerated too aggressively early on were ultimately outperformed by those who paced themselves more evenly. This highlights the need to determine, through simulation, an appropriate level of initial power output that balances acceleration demands with sustainable exertion, accounting for the peak power–time relationship.

Although acceleration plays a crucial role in short-distance time trials, it has been largely overlooked in prior research on longer events, with a few notable exceptions.[5, 6, 8, 10]

In this study, we developed a program to simulate cycling time trial performance while incorporating both exertion based on the peak power–time curve and the effects of acceleration. We evaluated the effectiveness of different power variation pacing strategies, including an initial sprint. Although no sophisticated optimization techniques were used, we aimed to identify simple and practical pacing strategies that cyclists can realistically adopt, rather than relying on precisely optimized power profiles tailored to specific course characteristics.

2. Methods

The acceleration a of the cycle and rider, with a total mass of m and M, respectively is represented as:

$$a = \frac{F}{M + m + m'}. \quad (1)$$

The resultant force F is given by:

$$F = F_{\mathrm{D}} - F_{\mathrm{A}} - F_{\mathrm{R}} - F_{\mathrm{G}} \tag{2}$$

The driving force F_{D} generated by pedaling is:

$$F_{\mathrm{D}} = \frac{f_{\mathrm{P}}}{R_{\mathrm{G}}} \frac{L}{r_{\mathrm{W}}} \tag{3}$$

where f_{P} is the pedaling force, R_{G} is the gear ratio, L is the crank length, and r_{W} is the wheel radius. The air drag F_{A} is expressed as:

$$F_{\mathrm{A}} = \frac{1}{2} \rho C_{\mathrm{D}} A v_{\mathrm{R}}^{2} \tag{4}$$

where v_{R} is the relative speed, ρ is the air density, C_{D} is the drag coefficient, and A is the projected frontal area. The rolling resistance F_{R} is:

$$F_{\mathrm{R}} = C_{\mathrm{R}} (M + m) g \tag{5}$$

where C_{R} is the rolling resistance coefficient and g is the gravitational acceleration. The gravity force component along the slope F_{G} is:

$$F_{\mathrm{G}} = (M + m) g \sin\theta \tag{6}$$

where θ is the slope angle, and $\tan\theta$ represents the gradient. Only headwinds and tailwinds were considered in this model. Inclined winds and the associated sailing effect were excluded. Additionally, frictional losses from the chain and bearings were ignored. The virtual mass m', according to the wheels' moment of inertia I is defined as:

$$m' = \frac{I}{r_{\mathrm{W}}^{2}}. \tag{7}$$

Human output power P is calculated as:

$$P = f_{P} \omega L \tag{8}$$

where ω is the angular velocity of the crank.

For the relationship between P and maximum duration t_{c}, the 3-parameter critical power model by Morton (1966) was adopted:

$$t_{\mathrm{C}} = \mathrm{AWC}\left(\frac{1}{P - P_{\mathrm{C}}} - \frac{1}{P_{\max} - P_{\mathrm{C}}} \right) \tag{9}$$

where AWC is the anaerobic work capacity, P_{C} is the critical power (the asymptotic power for infinite duration), and $P_{\max}$ is the maximum power (where t_{C} becomes zero).[11] Cumulative anaerobic work AW for varying power can be calculated as:

$$\mathrm{AW} = \sum_{i=1}^{n} \frac{(P_i - P_\mathrm{C})(P_\mathrm{max} - P_\mathrm{C})}{(P_\mathrm{max} - P_i)} \Delta t \tag{10}$$

for a data series at t_i, (i = 1, 2, , , n), with a time interval of Δt. The exertion E is defined as

$$E = \frac{\mathrm{AW}}{\mathrm{AWC}} \tag{12}$$

(Gordon, 2005).[7] It is assumed that the rider is no longer able to sustain the required power level when $E = 1$. Recovery occurs when $P < P_\mathrm{C}$, leading to a decrease in AW. However, E immediately reaches 1 if P reaches P_max.

The parameters AWC, P_max and P_C in Eq. (9) can be calculated using at least three, preferably four or more, average power-maximum duration data points. Many serious cyclists today utilize power meters and web-based analysis tools to create their own power profiles. By substituting multiple pairs of duration and peak power data from an amateur male cyclist (62 years old, 171 cm, and 59 kg) into Eq. (9), the parameters AWC, P_max, and P_C can be derived. For instance, the solver function in Microsoft Excel can be employed for this task. Assuming the obtained AWC = 9267 J, P_max = 1075 W, and P_C = 252 W, the resulting power profile is illustrated in Fig. 1. These parameters will be used for subsequent calculations.

The other parameters used in the simulation are listed in Table 1. These values lie within typical ranges and are not customized for specific riders or equipment. Changes in temperature and air pressure were not considered. The simulation proceeded as follows.

(1) Initial values are assigned to variables.
(2) The pedaling force is calculated for the given power. An upper limit of Mg is imposed on the pedaling force, which is typically active at low velocities during the start. As a result, the power may not reach the target value in the early stage.
(3) The resultant force is calculated, followed by the acceleration.
(4) The velocity v at the time step i is calculated using:

$$v_i = v_{i-1} + \frac{a_{i-1} + a_1}{2} \Delta t\,. \tag{11}$$

(5) Distance x at the time step i is calculated as:

$$x_i = x_{i-1} + \frac{v_{i-1} + v_1}{2} \Delta t \,. \quad (12)$$

(6) Exertion is calculated. Exertion is set to 0 when AW becomes negative, particularly at the start.

(7) Steps (2) to (6) are repeated, incrementing i.

The simulations focused on 10 km and 1 km time trial races. For the 10 km simulations, the time step Δt was set to 10 ms. However, for the 1 km simulations, a smaller time step of 1 ms was used, as preliminary calculations revealed that a 10 ms interval was not sufficiently small to ensure accurate results.

3. Results and discussion for the 10 km case

3.1 Windless and flat course

A windless and flat 10 km course was simulated. First, the constant power pacing strategy was analyzed. The maximum constant power that allowed the rider to complete the 10 km distance without exceeding an exertion level of 1 was determined by a trial-and-error method with a resolution of 0.1 W. The optimal power was found to be 262.6 W, resulting in a completion time of 857.99 seconds (Fig. 2, 10C in Table 2). At power levels below this, the completion time increased, while at higher power levels, the rider could not finish the course due to excessive fatigue.

Next, power variation pacing strategies were investigated. In the first scenario, power output was increased during the first half of the course. The maximum power sustained over the initial 5 km was determined to be 273.0 W. Although the rider could maintain the critical power level (252 W) needed to complete the race, the finishing time was 858.43 seconds (10IDmax; "max" refers to the maximum value sustained during the first half), which was 0.44 seconds slower than the constant power pacing strategy. This indicates that the slight advantage gained by faster acceleration at the start was insufficient to offset the overall increase in fatigue.

In the second scenario, power during the first half of the course was decreased by the same amount of 10.4 W, with a corresponding increase in the second half raising the maximum power to 273.4 W. This resulted in a completion time of 858.69 seconds (10DI), which was slightly slower than the constant power pacing strategy.

The effects of a start sprint were also analyzed, as time trial riders often produce higher power outputs at the beginning of a race than during steady cruising. Starting powers ranging from 200 to 500 W over the first 5 seconds were tested. The results showed that a starting power of 400 W improved the finish time by 1.01 seconds (10S+137.4, Table 3), whereas higher starting powers, such as 500 W (10S+237.4), reduced the cruising power and worsened overall performance. Conversely, starting power levels below the cruising power also degraded completion times (10S-062.6).

These findings confirm that a constant power pacing strategy remains fundamentally the most effective approach for a windless and flat 10 km time trial, even when acceleration effects are considered. Although a fast start with a moderate start sprint can yield slight improvements, excessive power output at the start reduces sustainable cruising power and ultimately leads to poorer performance. Since riders frequently apply excessive power unintentionally at the start, careful management of the start sprint is crucial to avoid performance degradation.[2] To simplify subsequent analyses and isolate the effects of other variables, the start sprint was excluded in further simulations.

3.2 Flat but windy course

The effects of wind conditions on time trial performance were analyzed by simulating cases with headwind and tailwind on a flat 10 km course. In the first scenario, the rider encountered a headwind during the first half and a tailwind in the latter half, with a wind speed of 10 m/s. The constant power pacing strategy resulted in a slightly reduced optimal power of 260.7 W, due to the increased time spent in the headwind section (10HTC, Table 4). When a variable power pacing strategy was employed, the optimal configuration involved increasing power to 263.9 W during the headwind section and decreasing it to 252.1 W during the tailwind section (10HTIDmax). This adjustment improved the total time by 3.0 seconds compared to the constant power pacing strategy. In contrast, decreasing the first-half power by the same 3.2 W required increasing the second-half power to 269.1 W (10HTDI), resulting in a finish time 3.6 seconds slower than the constant power pacing strategy.

The opposite scenario, in which the rider experienced a tailwind in the first half followed by a headwind in the second half, was also simulated (Table 5). The optimal constant power in this case was 260.8 W, and the completion time was significantly shorter than that in the headwind-first scenario—primarily due to the tailwind facilitating initial acceleration. When the first-half power was reduced to the critical power of 252 W, the second-half maximum power could be increased to 264.2 W, yielding a modest time improvement of 0.47 seconds (10THDImin; "min" refers to the minimum power value during the first half). On the other hand, increasing the first-half power by 8.8

W reduced the allowable power in the latter half to 257.4 W (10THID), worsening the time by 4.83 seconds.

Atkinson et al. (2007) proposed that increasing power output during headwinds and decreasing it during tailwinds by equal amounts could reduce race time.[3] However, the present findings suggest that such a strategy may be too simplistic in real-world conditions, as it fails to account for human fatigue and exertion limitations.

3.3 Uphill and Downhill Course

In the next scenario, the rider encountered a 10% uphill gradient for the first half of the course, followed by a 10% downhill gradient for the second half, with no wind. The slant distance was used instead of the planar distance. Under a constant power pacing strategy, the finish time was significantly worsened due to the increased resistance from gravitational force during the uphill section and from air drag during the downhill section (10UDC, Table 6). The maximum constant power was reduced to 257.1 W because of the prolonged effort, bringing the rider close to their exertion limit. Due to fatigue constraints, the rider could increase uphill power by only 0.7 W from the constant power pacing strategy. Nevertheless, this modest adjustment improved the finish time by 1.8 seconds (10UDID). In contrast, decreasing the uphill power to the critical power of 252 W drastically worsened the time by 30.3 seconds (10UDDImin), highlighting the sensitivity of performance to reduced power on steep inclines.

The reverse case—starting with a 10% downhill followed by a 10% uphill—was also simulated (10DUC, Table 7). In this configuration, the constant power remained nearly unchanged, but the finish time was substantially shorter compared to the uphill-first scenario. The downhill start allowed the rider to accelerate rapidly and sustain higher speeds into the initial part of the climb. When the power during the downhill section was reduced to the critical power of 252 W, the rider could increase power on the uphill by 0.8 W. This led to a negligible increase in time—only 0.2 seconds (10DUDImin). Conversely, increasing the downhill power by 5.2 W necessitated a reduction in uphill power by 0.7 W from the constant power pacing strategy, which significantly worsened the time by 13.8 seconds (10DUID). These results indicate that power distribution in long, hilly time trials requires careful balancing. In particular, reducing power output on steep uphill sections can result in substantial time losses. Understanding this can help cyclists refine their pacing strategies and improve overall performance.

4. Results and discussion for the 1 km case

4.1 Flat and windless course

The maximum constant power that allowed the rider to complete the 1 km course without exceeding the exertion threshold was determined to be 346.9 W (1C, Table 8). When power was increased to 417.0 W for the first half and decreased to 252 W for the second half, the finish time improved by 1.1 seconds (1IDmax8). In contrast, reducing the first-half power by the same 70.1 W and increasing the second-half power to 419.7 W worsened the time by 3.2 seconds (1DI). These results suggest that elevated power early in the race—facilitating initial acceleration and higher speeds into the latter half—is particularly beneficial in short time trials (Fig. 3).

To further investigate time reduction strategies, simulations were conducted in which the power transition point was varied from 100 m to 900 m in 100 m increments, excluding 500 m, which had already been analyzed. For each change point, a range of power levels—from the constant power to the maximum finishable power—was tested, and the configuration yielding the shortest time was selected. As the change point moved closer to the end of the course, the optimal power levels for both segments gradually decreased (Fig. 4). The best overall time was achieved when the power change occurred at 600 m (Fig. 5). This indicates that a short-duration start sprint may not be effective in improving total time.

These findings suggest that, for windless and flat short time trials, increasing power during the early part of the course generally leads to better finish times—even if it results in a reduced power output later. This supports the conclusion of Wilberg and Pratt (1988).[9] If using two distinct power levels, the transition point can be set near or slightly after the course midpoint. A gradual tapering of power may yield even better performance, a possibility that will be explored further in Section 4.4.

4.2 Flat windy course

Consider the case where the rider encounters a headwind for the first half and a tailwind for the second half of the flat course, with a wind speed set at 10 m/s. The constant power in this case is reduced to 329.1 W (1HTC in Table 9) compared to the windless scenario (1C) due to the increased time in the latter portion of the course. The maximum power for the first half was determined to be 370.4 W, while for the latter half, it was found to be 252.0 W (1HTIDmax). This strategy results in a time improvement of 2.2 seconds compared to the constant power scenario (1HTC). On the other hand, when the power for the first half is decreased by the same 41.3 W, the maximum power for the second half increases to 396.9 W (1HTDI), and the time becomes 3.9 seconds slower than the constant power case (1HTC).

In the opposite scenario, where the rider faces a tailwind in the first half and a headwind in the second half (Table 10), the constant power is slightly higher, at 337.3 W (1THC), due to the acceleration gained from the tailwind during the start. In the case where the power for the first tailwind section is decreased by 10% and the power for the latter headwind section is increased (1THDI−10%), the time is 0.5 seconds slower than the constant power case (1THC). This happens because the lack of start acceleration negates the advantage of increased power during the headwind portion. When the power for the first tailwind section is increased by 10% and the power for the second headwind section is decreased by 10% (1THID+10%), the time is only 0.02 seconds slower than the constant power scenario (1THC). This outcome occurs because the reduced power in the latter part of the course is nearly canceled out by the assistance from the start acceleration, due to the increased power in the first section.

4.3 Windless hilly course

In the scenario where the rider faces a 10% uphill for the first half and a 10% downhill for the second half of the 1 km course without wind, the total time worsens significantly under a constant power pacing strategy (1UDC in Table 12). This is due to the increased resistance from gravity on the uphill and the limited effect of power output on speed during the downhill, where air drag dominates. The constant power is reduced to 304.4 W to reflect the extended finish time. When the power for the uphill section is increased by 12.5 W, the allowable power for the downhill section must be reduced by 52.4 W (1UDIDmax). This trade-off results in a 4.2-second improvement in finish time. Conversely, reducing the uphill power by the same amount leads to a 47.7 W increase in downhill power (1UDDI), but the finish time worsens by 5.2 seconds.

In the opposite scenario, where the rider descends first and climbs in the second half (1DUC in Table 13), the constant power is higher and the overall time is significantly faster than in the uphill-first case. This is because the downhill start allows the rider to accelerate early and carry speed into the initial uphill section. Reducing the downhill power by 10% increases the available uphill power by 13.5 W and improves the finish time by 2.2 seconds (1DUDI−10%). At the critical downhill power level (1DUDImin), the uphill power increases by 28.7 W, and the finish time improves by 3.4 seconds compared to the constant power case. In contrast, increasing the downhill power by 10% (1DUID+10%) reduces the uphill power by 13.9 W, leading to a 2.5-second worsening in finish time.

From these results, it can be concluded that on a short hilly course, allocating more power to the uphill segment and less to the downhill segment leads to improved performance. However, it should be noted that the increase in uphill power tends to be much smaller than the corresponding decrease in downhill power, indicating diminishing returns for downhill effort and the importance of conserving energy for climbs.

4.4 Linear decrease in power for the windless flat course

Finally, a strategy was tested where the rider's power output decreases linearly from a high starting power to the critical power of 252 W over the entire 1 km distance. The optimal starting power was found to be 425.8 W, resulting in a finish time of 85.704 seconds. This is 1.4 seconds faster than the constant power pacing strategy (1C) and 0.3 seconds faster than the best time achieved by the stepwise increase–decrease pacing strategy (1IDmax).

Figure 6 shows the exertion profiles for each strategy. In the constant power case, exertion rises linearly, indicating that the rider's maximum ability is not fully exploited. The step-decrease pacing strategy causes exertion to peak very early, inducing significant fatigue. In contrast, the linear decreasing pacing strategy results in a gradual increase in exertion. Although fatigue is higher than with constant power, it is less than with the stepwise pacing strategy, leading to the best finish time.

While there may be faster power-decreasing patterns to explore in future studies, the 1.4-second improvement in a 1 km time trial is meaningful. This suggests that dynamically reducing power over distance can enhance performance more effectively than maintaining constant power.

5. Conclusions

The effects of variable power pacing strategies were investigated through numerical simulations that considered the peak power–time relationship and acceleration. The main findings for 10 km time trials are summarized as follows:

(1) For flat and windless courses, varying power caused a 0.5–0.7 second delay compared to a constant power pacing strategy. However, a fast-starting strategy with a moderate start sprint shortened the finishing time by about 1 second.

(2) Increasing power during uphill or headwind sections and decreasing power during downhill or tailwind

sections improved finishing times by 0.5–3.0 seconds in most cases. However, this strategy was ineffective for downhill-then-uphill courses. Applying the opposite strategy in uphill-then-downhill scenarios worsened finishing times significantly, by about 30 seconds.

The accuracy of commercial power meters is within 1–2%, and cycling computers display power in 1-watt increments. Numerous factors such as minor course unevenness, temperature, humidity, and changes in wind direction and speed can all affect finish time. Even small differences in clothing or body position on the day can alter aerodynamic drag. Therefore, for the 10 km time trials, a constant power pacing strategy with a moderately fast start is recommended. If there is one thing to avoid, it is reducing power on uphill sections.

For 1 km time trials, the findings are as follows:

(1) A linearly decreasing power pacing strategy yielded the best performance, improving finish times by 1.4 seconds on windless, flat courses.
(2) Variable power pacing strategies shortened finishing times by 2.2–4.2 seconds on windy or hilly courses, except for the case of a tailwind followed by a headwind, where times worsened by 0.5–1.7 seconds.
(3) Power adjustments exceeding 10 W were possible and had a particularly large effect for courses with an initial downhill followed by an uphill section.

Considering the above results, a variable power pacing strategy is recommended for a 1 km time trial. On a flat, windless course, the linear tapering pacing strategy yields the best performance. If this is difficult to implement, a two-step power pacing strategy can be adopted as an alternative. On a hilly course, power should be increased on uphills and reduced on downhills. Unfortunately, the wind conditions investigated in this study are not fully realistic. To achieve more realistic simulations, deceleration at corners should also be taken into account.

While considering exertion and acceleration in cycling time trial simulations is not novel, extending this approach to more complex courses with multiple hills and corners will help develop practical pacing guidelines. Furthermore, a device that displays current exertion and predicts exertion until the finish line could greatly assist cyclists in optimizing their pacing if developed.

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Conflict of interest

The authors report there are no competing interests to declare.

CRediT authorship contribution statement

YF was responsible for conceptualization, data curation, methodology, supervision, validation, and writing – review & editing. BA was responsible for data curation, formal analysis, investigation, software, visualization, and writing – original draft. All authors have read and approved the final version of the manuscript and agreed with the order of authorship.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT3.5 in order to improve their English writing. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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Statement of ethics

This study does not involve human participants and therefore does not require IRB approval.

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Table 1 Parameters for calculation.

M	70 kg
m	8.0 kg
m'	1.4 kg
ρ	1.20 kg/m^3 (1 atm., 293K, dry)
$C_D A$	0.22 m^2
C_R	0.005
L	0.17 m
r_w	0.334 m (2.10 m circumference)
R_G	53 t/15 t

Table 2 Windless flat 10 km time trial course (% change: percentage change in finishing time compared to the constant power pacing strategy. *Italics indicate slower cases*, and **bold indicates faster case**s. This notation is used consistently below.)

Case	Power (W)/lap time (s) for the first half	Power (W)/lap time (s) for the latter half	Time (s)/% change
10DI	*252.2/441.80*	*273.4/416.89*	*858.69/0.09*
10C	262.6/434.85	262.6/423.14	857.99
10IDmax	*273.0/428.69*	*252.0/429.74*	*858.43/0.06*

Table 3 Effects of a start sprint on a windless, flat 10 km time trial course

Case	Power for the start sprint (W)	Cruising power (W)	Time (s)/% change
10S−062.6	200	262.7	858.76/*0.10*
10S+037.4	**300**	**262.4**	**857.56/−0.04**
10S+137.4	**400**	**261.8**	**856.98/−0.11**
10S+237.4	**500**	**261.0**	**857.64/−0.03**

Table 4 Effects of headwind and tailwind for a flat 10 km course

Case	Power (W)/lap time (s) for headwind	Power (W)/lap time (s) for tailwind	Time (s)/% change
10HTDI	*257.5/775/21*	*269.1/283.71*	*1058.92/0.34*
10HTC	260.7/769.56	260.7/285.73	1055.29
10HTIDmax	**263.9/763.90**	**252.1/288.39**	**1052.32/−0.28**

Table 5 Effects of tailwind and headwind on a flat 10 km course

Case	Power (W)/lap time (s) for tailwind	Power (W)/lap time (s) for headwind	Time (s)/% change
10THDImin	**252.0/293.65**	**264.2/743.85**	**1037.50/−0.05**
10THC	260.8/290.79	260.8/747.00	1037.97
10THID	*269.6/288.40*	*257.4/754.40*	*1042.80/0.47*

Table 6 Effects of uphill and downhill on a windless 10 km course

Case	Power (W)/lap time (s) for uphill	Power (W)/lap time (s) for downhill	Time (s)/% change
10UDDImin	*252.0/1619.29*	*294.0/208.95*	*1828.24/1.68*
10UDC	257.1/1587.20	257.1/210.79	1797.99
10UDID	**257.8/1584.96**	**252.0/211.23**	**1796.19/–0.10**

Table 7 Effects of downhill and uphill on a windless 10 km course

Case	Power (W)/lap time (s) for downhill	Power (W)/lap time (s) for uphill	Time (s)/% change
10DUDImin	*252.0/212.23*	*258.0/1522.93*	*1735.16/0.01*
10DUC	257.2/212.00	257.2/1522.92	1734.92
10DUID	*262.4/211.64*	*256.5/1537.05*	*1748.69/0.79*

Table 8 Windless, flat 1 km course

Case	Average power (W) /lap time (s) of first half	Average power (W) /laptime (s) of latter half	Time (s) /% change
1DI	*276.8/52.587*	*419.7/37.645*	*90.232/3.6*
1C	346.9/48.586	346.9/38.489	87.075
1IDmax	**417.0/45.601**	**252.0/40.392**	**85.993/–1.2**
425.8→252 (W)	**382.4/46.243**	**295.5/39.461**	**85.704/–1.6**

Table 9 Effects of headwind and tailwind on a flat 1 km course

Case	Power (W)/lap time (s) for headwind	Power (W)/lap time (s) for tailwind	Time (s)/% change
1HTDI	*287.8/77.131*	*396.9/36.357*	*113.488/3.5*
1HTC	329.1/71.915	329.1/37.690	109.605
1HTIDmax	**370.4/67.725**	**252.0/39.718**	**107.443/–2.0**

Table 10 Effects of tailwind and headwind on a flat 1 km course

Case	Power (W)/lap time (s) for tailwind	Power (W)/lap time (s) for headwind	Time (s)/% change
1THDImin	*252.0/46.695*	*395.4/53.329*	*100.024/2.2*
1THDI–10%	*303.6/43.926*	*361.7/54.386*	*98.312/0.5*
1THC	337.3/42.452	337.3/55.395	97.847
1THID+10%	*371.0/41.173*	*311.2/56.697*	*97.870/0.02*

Table 12 Effects of uphill and downhill on a windless 1 km course

Case	Power (W)/lap time (s) for uphill	Power (W)/lap time (s) for downhill	Time (s)/% change
1UDDI	*291.9/142.472*	*352.1/29.206*	*171.678/3.1*
1UDC	304.4/136.485	304.4/29.621	166.485
1UDIDmax	**316.9/132.202**	**252.0/30.119**	**162.321/–2.5**

Table 13 Effects of downhill and uphill on a windless 1 km course

Case	Power (W)/lap time (s) for downhill	Power (W)/lap time (s) for uphill	Time (s)/% change
1DUDImin	**252.0/31.530**	**355.2/78.461**	**109.991/–3.0**
1DUDI-10%	**293.9/30.991**	**340.0/80.256**	**111.247/–1.9**
1DUC	326.5/30.608	326.5/82.826	113.434
1DUID+10%	*359.2/30.250*	*312.6/85.667*	*115.917/2.2*

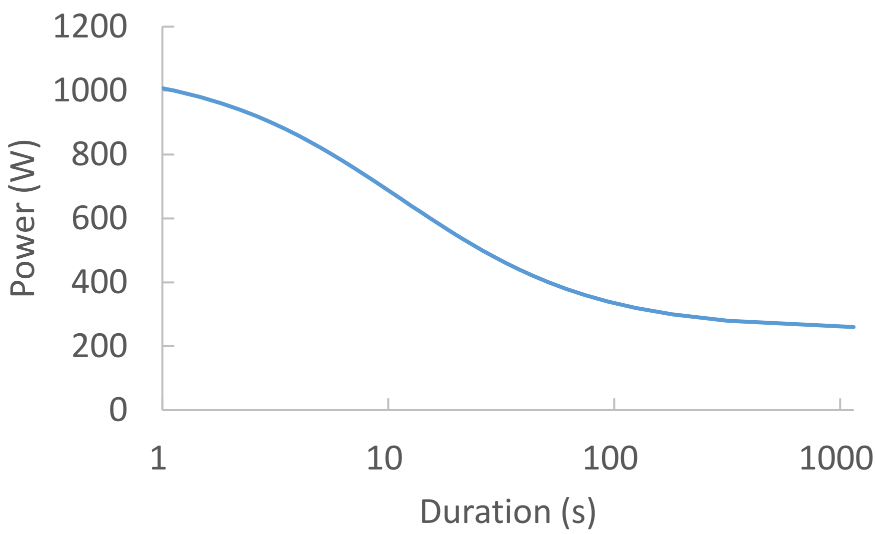
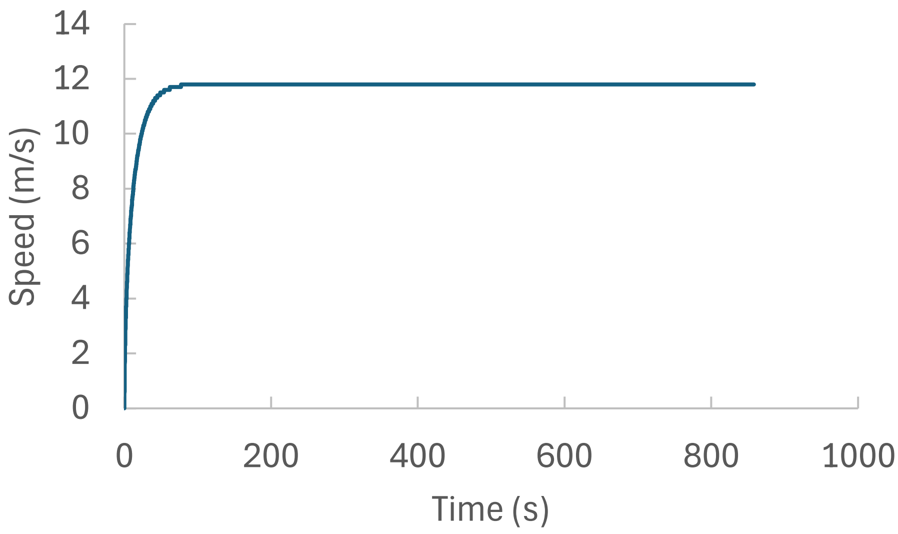
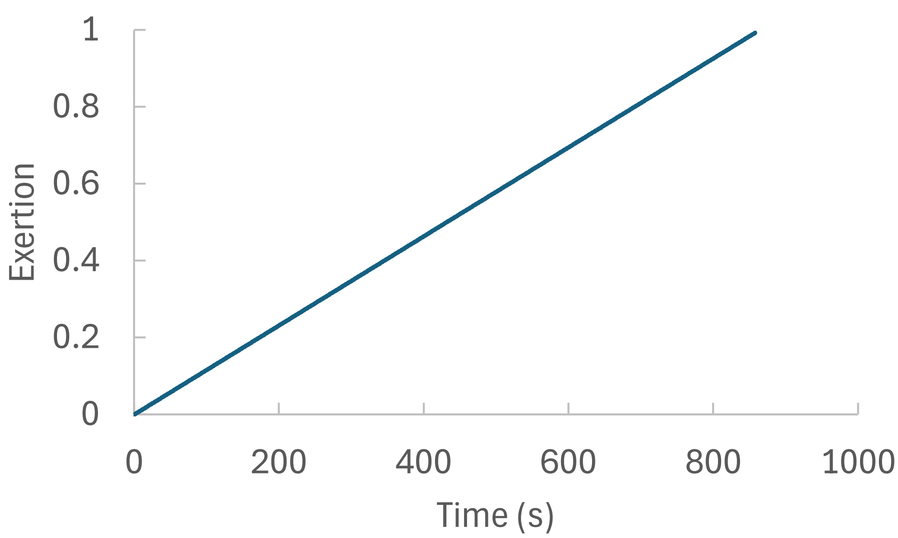


Fig. 1 Assumed peak power-time curve.



(a)



(b)

Fig. 2 Speed (a) and exertion (b) for the 10 km course (10C in Table 2).

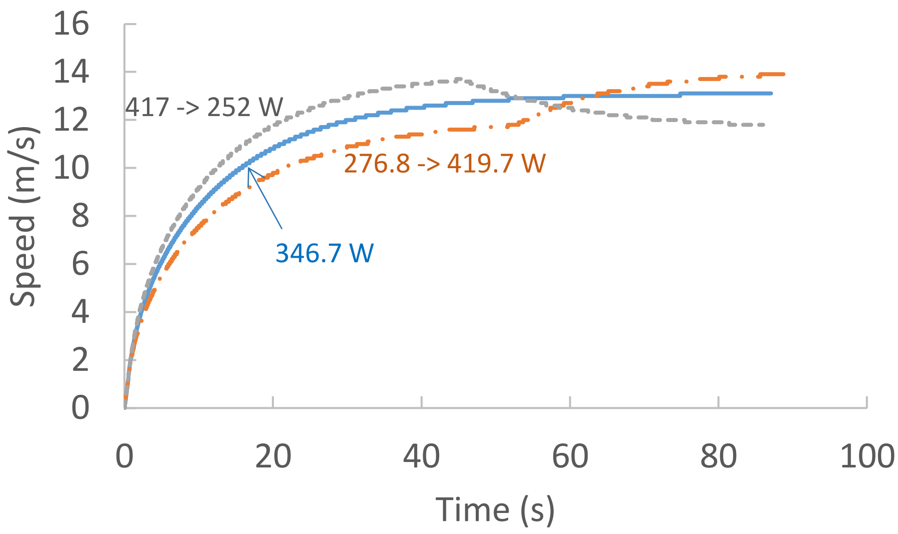


Fig. 3 Effect of power change on the windless flat 1 km course.

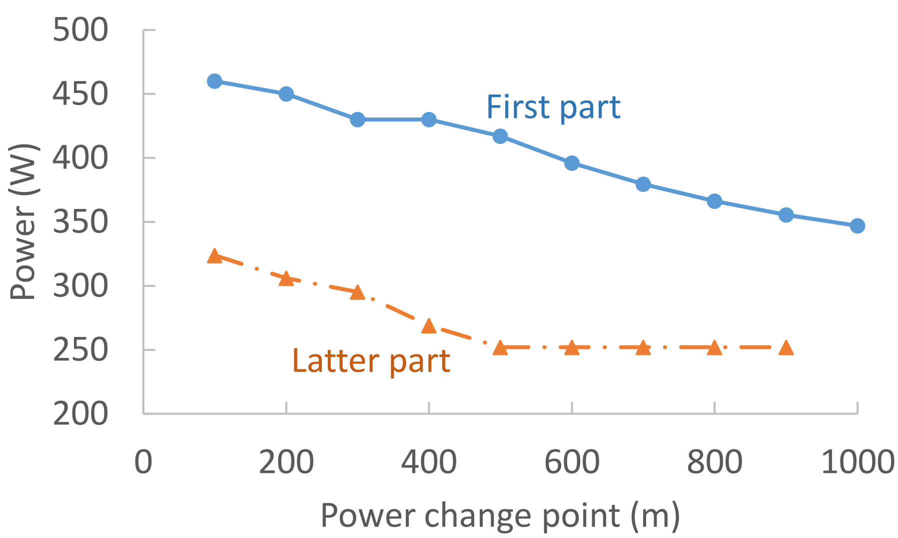


Fig. 4 Best combination of power levels for the windless and flat 1 km course.

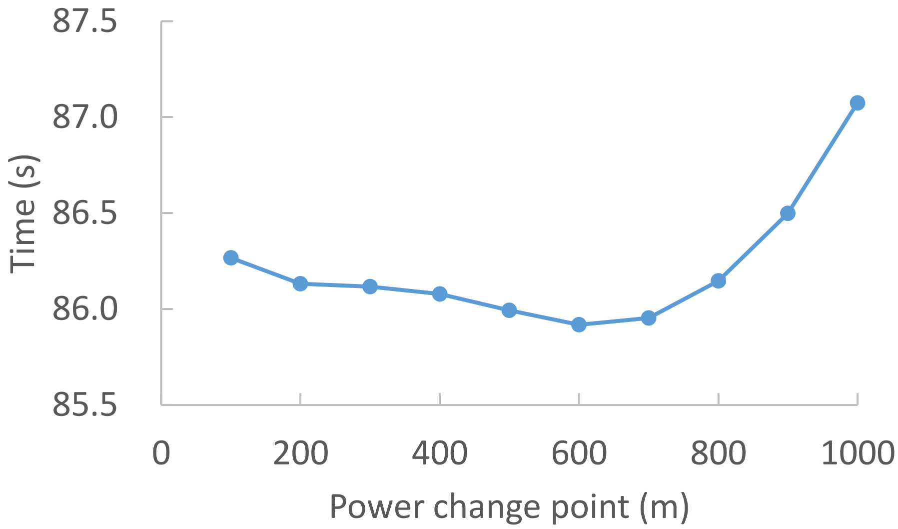


Fig. 5 Effect of power change point on the finish time for the windless, flat 1000 m time trial.

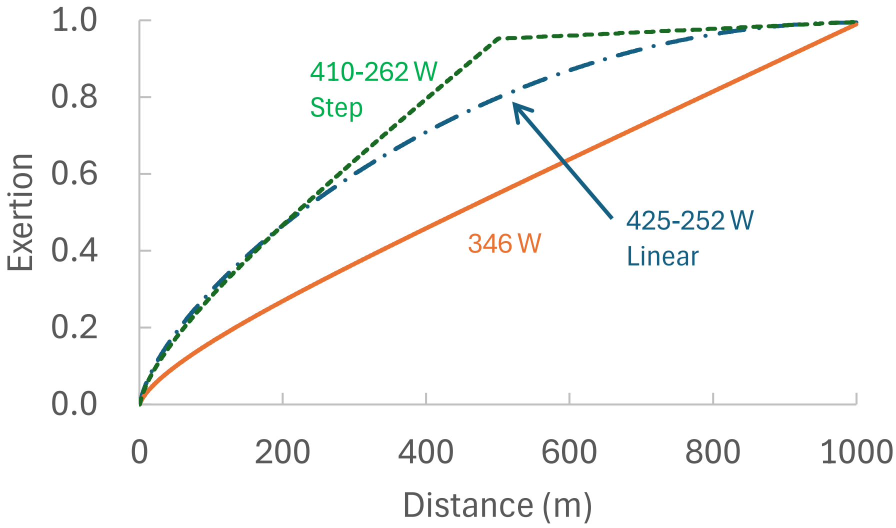


Fig. 6 Exertion for constant power, step and linearly decreasing power cases.