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Conference Abstract

Thrifty Reservoir: A Phenomenological Concept Model for Cycling

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Abstract

Thrifty Reservoir (TR) is a phenomenological model of field behavior of a rider, both in training and racing. The main component of TR is an energy reservoir; a stream of energy enters the reservoir, and an output stream propels the bike at the will of the rider. A control is exerted on the reservoir level. It is a PID (Proportional, Integral, Derivative) control, as it is usual in process engineering. Generally speaking, the control effect is to reduce the power available to the rider as much as the reservoir content is depleted. This property is a sort of thrift and therefore the model is named thrifty reservoir. This feature of TR, as far as the author knows, is a real novelty in cycling modelling as it imports concepts from process engineering into the cycling field. The model is mathematically described by a couple of equations: a differential equation for the dynamics of the reservoir and an algebraic equation for the control. TR is easily applied to training session with intermittent exercise or race conditions where intensity of effort is very variable in time as in a race or in a road training session. In this capacity TR differs from models based on explicit formulas, which work only on average values and have difficulties with intermittency. TR differs also from W'bal models which have no control mechanisms on reservoir content, and therefore have difficulties in identifying maximal effort points, while with TR they are easily identified. TR predictive capacity may be applied day by day to road training sessions and races without any need to run specific tests to determine its parameters. TR development may lead to a valuable tool available to trainers in their work, for instance in monitoring training progress, in designing more effective training sessions, and race strategy as well.

Keywords: Energy, Energy Control, Energy Balance, Gain of Control, Cycling, Road Training, Fatigue, Time-Power Relationship, Stylised Facts

1. Description

Thrifty Reservoir (TR) is a phenomenological model of field behavior of a rider, both in training and racing. As phenomenological the model works without any need to identify physiological correlates to its constituting parameters and working variables. The main component of TR is an energy reservoir; a stream of energy enters the reservoir, and an output stream propels the bike at the will of the rider.

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In particular control is PID (Proportional, Integral, Derivative) as: i) it decreases output in proportion to the reservoir level; ii) additionally it decreases output in proportion to the total amount of energy drawn in time from the reservoir; iii) increases for a short time, on the contrary, output in proportion to a sudden increase of energy request by the rider.

TR applies energy balance principle as W'bal does, but with two important differences: TR is a reservoir of energy without specifying the kind of energy, while in W'bal the content is intended to be anaerobic energy and in W'bal there is no control on the level. As a consequence, exhaustion condition of the biker is not clearly identified in W'bal. while TR identifies it easily. This is the main point in favor of TR: it identifies maximal effort of a biker and its predictions are in terms of maximal reachable performance rather than average performance.

TR differs also from data fitting models as CP model and PL mode because they work only with average data during an exercise, while TR is applicable to the instant power, even in race conditions, when power fluctuates very much and average power is somehow meaningless. Those models incur on severe limitations, while TR does not: for instance, they are not applicable to an intermittent training, because they cannot make allowance for recovery between two high intensity bouts.

TR model depends on six parameters, describing capacity of TR reservoir, maximum power output allowed when the reservoir is full, power feed to TR and characteristics of control. They can be determined from the power records of a single training day, provided in some part of it the rider reaches exhaustion, that is to say the rider at least in one point employs all the power allowed by the control. It has to be pointed out that TR parameters are not only determined by that point, but also by the whole power profile of the training day. This makes TR capable of predicting a maximal effort better than the measure of maximality in a single bout. Experimental data will confirm this special characteristic.

With six parameters TR is able to simulate effectively a number of well known "stylized facts": i) fatigue in extreme and severe exercise; ii) fatigue in intense and moderate exercise, which cannot be sustained indefinitely; iii) reduced performance between fresh conditions and after previous exercise, both intense and moderate; iv) recovery between severe and moderate phases of an intermittent exercise; v) reduction of sprint time at maximum power between fresh and fatigued conditions; vi) changes in the power-duration relationship due to previous prolonged exercise.

2. The aim

As the present study is the first phase of experimental verification, the aim is focused to verify the main TR feature: the capacity to extract from data collected on the road the maximal power a rider may reach at various durations of the exercise. Comparison with a specific test and with the results of other models will show that TR gives a better approximation to the maximality, while other models may give only an approximation to the average power. In simple words TR does not go "through" the data, as other model does, but it goes "over" the data, as a maximal effort is expected to do. This is a first step towards the validation of a model allowing the prediction of performance for any given duration, just starting from training and race data, without requiring any dedicated test.

3. Experimental data on field

Data from 19 athletes were taken from training sessions performed 4 days before a CP test. They were all males (age 23±4 yr., weight 65.7±3.8 kg, height 176 ± 4.5 cm), Cyclists were instructed to perform three all-out tests of 15", 3' and 12' respectively. TR parameters were determined day by day in the 4 days training session and then, averaged on the 4 days, used to predict tests. All data were tested for normality using the Shapiro-Wilk test. For each of the time points (15", 3', and 12') analysis of variance (ANOVA) repeated measures tests were used to: i) compare MMP for 4 days to CP test; ii) to test the quality of fitting CP test data by models (CP, PL, TR); iii) to compare prediction of the three models to the CP test. In all cases post-hoc tests to investigate differences were performed using the

Bonferroni correction. Statistical significance was set at $p < 0.050$.

First a maximality test has been performed between CP test and MMP of the four days of training at 15 s, 3 m and 12 m. When comparing for the 15 s timepoint, MMP was found larger than CP test ($p = 0.003$), while for the 3 m and 12 m timepoints MMP was significantly lesser than CP (p < 0,001). This means that neither CP test, nor MMP guarantee maximality all the time span long. Even when one of the two prevails, there is no reason to think that its value is the real maximum. For details of differences see Table 1.

In the second place fitting of CP test data was done. Parameters of CP model (2PHM) and PL model (Power Law) were obtained by linear regression, and then differences of real data and regression line were computed. TR parameters were calculated from the power record of the whole exercise of about 4 hours, which included the three bouts of 15 s, 3 m and 12 m of the test. Then with the so calculated parameters three theoretical values at 15 s, 3 m and 12 m were calculated. ANOVA showed that all the fittings were different (p<0,001) from CP test data. In particular data fitting of CP test with CP model is poor: indeed, only at 12 m timepoint regression, value is acceptably close to the real value, while at 15 s timepoint is largely overestimated and at 3 m timepoint is underestimated. Fitting with PL is better than CP model at all timepoints, but still some values are underestimated, showing that even PL does not yields maximal values. TR fitting, being maximal as expected, slightly overestimates all timepoints. More details on differences in Table 2.

A clearer perception of how fitting goes is given in Figure 1a. The large ineffectiveness of CP model is immediately evident. TR model is slightly over PL model and runs almost parallel to the straight line of it, leaving the CP test data all below. This is precisely what is expected to happen if TR is maximal. How can TR model find out values larger than the same data which originated its parameters? This is because TR works on all 4 hours exercise and not only on the three values of CP test. CP model and PL model regressions identify average trends, while TR identifies maximal trends.

In the third place data from training were used to provide a real prediction. MMP at 15 s, 3 m and 12 m along the four days of training were taken to determine parameters of CP and PL models. TR parameters were determined by integration the power record for each of the four days, and then the average over the four days taken to predict 15 s, 3 m and 12 m performance. The parameters of the 3 models were obtained from training session data and were completely independent from CP test data.

ANOVA showed that all the models give significantly different results (p < 0,001) all over the timepoints. Also CP model has a performance even worse than fitting, so showing that it has no predictive capacity. TR line has again a similar trend to PL model at a little higher level, because PL predicts average and TR predicts maximal performance. More details in Table 3.

Figure 1b elucidates the situation better than many words. A close comparison between Figure 1a and 1b shows that passing from fitting to prediction worsens results of CP and PL models, probably due to the lack of maximality of MMP at 3 m and 12 m time points. TR, on the contrary, overcomes well this limitation of the starting data, maintaining its maximal character.

Table 1. How maximality is distributed between CP test and MMP

Timepoint	CP test	MMP of 4 days training	Comments on maximality
15 s	918±102	960±112	MMP maximal
3 m	475±34	445±33	CP test maximal
12 m	393±28	339±29	CP test maximal

Table 2. Fitting of CP test data with various models

Timepoint	CP test	CP model fitting	PL model fitting	TR model fitting
15 s	918±102	1206±197	895±98	1000±99
3 m	475±34	444±30	510±35	538±32
12m	390±32	392±32	373±29	408±34

Table 3. Prediction of CP test with various models from training data

Timepoint	CP test	CP model prediction	PL model prediction	TR model prediction
15 s	918±102	1334±179	938±103	989±129
3 m	475±34	405±27	474±31	512±29
12m	390±32	341±28	325±27	379±19

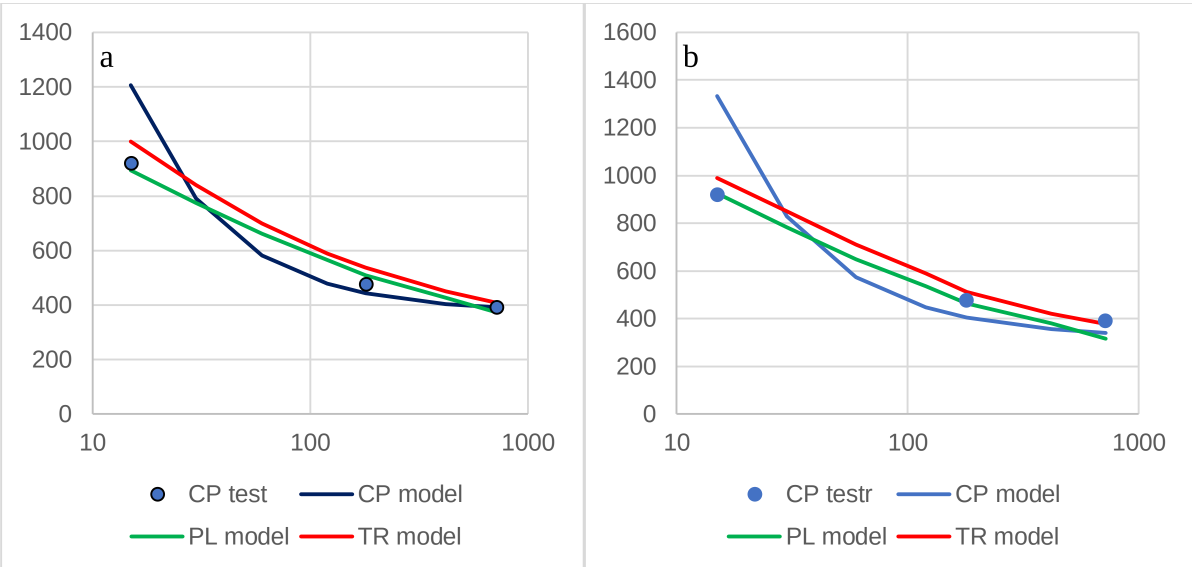

Figure 1. Comparison among different models. a – capacity of fitting: b – predictive power. In abscissa time in seconds, in ordinate power in Watt.

4. TR capabilities

The statistical analysis reported above demonstrates the basic statement: TR predicts maximal performance of a rider just starting from data obtained in a training session. In the previous analysis the role of the CP test was only to validate that statement. This is the very behavior expected for a model: to predict performance and not simply to fit the data. TR has no need to run specific tests to be successfully employed for practical purposes, while other models (CP, PL) not only need a specific test (CP and PL models need a CP test to determine their own parameters), they also have little or null predictive power on maximal efforts. Moreover, they have not the flexibility to be applied to cases where the effort is intermittent or affected by large power fluctuations as in races.

The features of TR open the way to a number of applications impossible with other models. They are: i) day by day follow-up of the evolution of the shape of a rider; ii) calculate the drop in performance after a long exercise both in the severe and moderate range iii) calculate the mechanical efficiency of a rider; iv) optimize the gear ratio and cadence in any part of a time trial; v) foresee the effectiveness of a strategy for the day after race.

For the last point let us consider an example of strategy: half an hour of severe and extreme exercise to breakaway, 4 hours of intense exercise to sustain the breakaway, at the end 60 s of extreme exercise to prepare the sprint. Using TR it is possible to calculate the maximum level acceptable for the rider in all the three parts of the strategy, in order to instruct the rider to spend the maximum energy, without going beyond the limit to keep enough energy to win the sprint.

5. Future work

To exploit al the TR potentialities more experimental work is necessary. First of all, to verify the predictive capacity of maximal efforts for time points well beyond 12 m. Then it would be very useful to extend the panel of athletes and test them more extensively both in training sessions and in races. Laboratory tests would be welcome to finely tune TR parameters and test the stability of parameter determination over a wide range of exercise intensity and duration.

6. Conclusions

The comparison among different models shows TR as the most capable to predict maximal effort of a rider. The present study is a very promising step in predicting a cyclist performance without running on purpose tests, with the advantage of making predictive capacity available day by day, irrespectively they are training or race days. TR opens the way to a number of applications impossible with other models as day by day follow-up of the shape of a rider, the calculation of performance drop after fatigue, the calculation of mechanical efficiency of a rider. Moreover, TR helps in race management as identifying optimal gear ratio and cadence in a time trial and the stating an effective strategy for a single- day race.

Of course more work has to be performed by extending the panel of athletes to be observed and increasing the time span of application. TR may become a valuable tool available to trainers in their work not only in optimizing race strategy, but also in designing more effective training sessions as well.

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