The Road Cyclist's Guide to Training by

POWER

Part I: An Introduction

by Charles Howe

with contributions from Andrew Coggan, Ph.D.

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Foreword and acknowledgements

Since its first internet posting over four-and-a-half years ago, it has been heartening to witness the worldwide distribution of this guide, including citations on the Association of British Cycling Coaches web site, as well as others in New Zealand and France, and even a translation into Polish. In this third edition, the aim remains unchanged, albeit on an expanded scale: to provide basic concepts and methods of training in general, and with a power-measuring system in particular. It is written for road cyclists who are new to using this type of device, with perhaps no more than a rudimentary understanding of how their body works during exercise, so without being too deeply grounded in the underlying physiological mechanisms of human endurance performance, it is meant to stimulate riders to assess themselves, then develop and administer their own training regime. Now and then, I stray into areas with only tangential relation to power-based training (such as diet), since they can have a significant effect on power production, but such excursions are kept brief or else merely referential.

It all began with an attempt to gather, review, and set down the principles that have guided me, and the training habits I have tried to cultivate, in 20+ years as a serious 'performance' (and occasionally competitive) cyclist, and that initial purpose may have been somewhat selfish, but the larger motive was to fill a perceived need for a basic guide, made available free of charge. This effort grew in scale beyond what I could have anticipated, paralleling the increase in my knowledge of the power-based approach, as well as training in general. In the intervening time, at least one mass-market book on power-based training (available from Velogear and Amazon) has been published, but it seemed worthwhile to offer an updated and expanded edition of the original guide.

Initial proposal of this guide at an internet forum was met with reservations about the "cookie-cutter nature of these books and manuals. Each person needs different training." As should become apparent rather quickly, the purpose here is not to prescribe any sort of pre-fab, one-size-fits-all plan. A sample plan is included for a portion of the training year, but is meant only to illustrate one possible alternative for a particular application. Further, a generalized model is also presented, but its purpose is to help stimulate you, the rider, in creating a customized program that fits your capabilities, goals, and schedule, using the training principles, guidelines, and functional tests presented here, as well as through experimentation as to what works best for you.

Another objection expressed was that "a coach is the best way for an athlete to improve, and . . . a well-educated coach knows how to make adjustments when life intervenes." This is fine for some, but the vast majority of riders are self-coached, and I believe it is important to educate them *too*, rather than just tell them to 'get a coach' (and if they *do* get one, the better informed they are, the better they will understand and carry out any training program). You are capable of coaching yourself, in fact, *you may just be your own best coach.*

That said, I emphasize that no intent exists here to undercut any of the various fine and highly capable individuals who pursue coaching as a profession, only a recognition that most riders are self-coached, since they either cannot afford, or simply do not choose to hire anyone. On the contrary, a basic understanding of power-based training will likely help riders see that the experience, knowledge, and objective viewpoint offered by a coach could benefit them, and a brief directory of coaches who are versed in power-based training is included. Educating riders will allow them to have greater confidence in whatever advice they receive, thus making them more receptive and coachable, and may even spawn new coaches from the more technically inclined.

Admittedly, the self-sufficient approach has its limitations and is not for everyone, as some riders – perhaps many or most of the best – prefer to save time and leave the mental task of their training plan, diagnosis, and prescription to a coach. Indeed, the author's recent request for training information from one of this country's most distinguished competitors brought the response 'I don't know, ask my coach.' For the true professional athlete, who must balance media obligations, demands of travel, and much higher training volume, not to mention competitive pressures, a professional coach may be a necessity. Still, numerous elite athletes are deeply and involved in their training; Greg LeMond once remarked that he didn't do as well in school as he could have because he was often thinking about his training plan. It is for the rider whose interest in race preparation is beginning to dawn that this guide is written, in the hope of nurturing that nascent fascination.

I am deeply in the debt of Andrew Coggan, Ph.D., for his review of this manuscript, his generous contributions throughout the text, and his unfailing willingness to freely share his profound knowledge of exercise science.

Charles Howe
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Introduction

Perhaps unique among all endurance athletes, cyclists have the capability of accurately measuring their external work rate, or mechanical power output, while "in the field," i.e., on the road, trail, or track, using commercially available power-measuring systems from Ergomo, iBike, Polar, Saris/CycleOps Power-Tap, Quarq, and SRM (Schoberer Rad Messtechnik). These hold great potential as training aids, since power is the true measure of imposed stress load, i.e., exercise intensity, and as such, directly determines physiological and perceptual responses to exercise. They are particularly appropriate for road cycling, where resistive forces to forward motion vary greatly from one moment to the next in relation to terrain, wind velocity and direction, changes in speed, and road conditions. Indeed, many react with disbelief at how "jumpy" the current power display is when using any of these devices for the first time, and question the readout's reliability. This is often a result of having become accustomed to heart rate and being fooled by its delayed response to changes in intensity into thinking that the energy requirements of cycling are relatively steady, however, the wide and rapid variability of power output on-the-road is easily verified by comparing power data collected outdoors to that obtained from any indoor trainer.

In their initial attempts to quantify exercise intensity, cyclists somewhat naturally took their cue from distance runners by adopting pace guidelines for time and distance. The concept of goal and date pace was borrowed from perhaps its most widely known advocate, University of Oregon track coach Bill Bowerman. This approach can be reliable at a given velodrome, so long as temperatures do not vary significantly and the air is calm, but it loses precision under the ever-varying grade and wind conditions present on the road, with the possible exception of a standard (and sufficiently steep) uphill course. The 'paradigm' for measuring exercise intensity in-training was changed in 1977, when Polar introduced the first wireless heart rate monitors (HRMs). Accurate, reliable, and about the size of a wristwatch, they became progressively more ubiquitous as the price inevitably came down over time. As becomes apparent when correlated with power, however, HR is limited not only by its slow response to changes in intensity, but also since it can vary considerably for a given wattage (much moreso during outdoor cycling, as compared to indoors on a constant-load ergometer) due to physiological and environmental factors. Indeed, had powermeters preceded HRMs, the latter might have never been marketed and sold as a separate device. Finally, it has always been possible to gauge intensity by "feel," or perceived exertion (PE), preferably with the revised 10-point category-ratio scale proposed by Gunnar Borg, or else his original 6-20 point linear scale. PE is subjective in nature, with its precision limited accordingly, and yet, perceptual responses to exercise are an extremely important source of feedback during exercise, since they actually incorporate more physiological information than HR. As we will see, the integration of PE and power information serves to modulate effort in training and even some race situations.

Power-based training has long been possible, of course, with a calibrated bicycle ergometer, but the first power-measuring device for use "on the road" did not appear until 1988, when the SRM system was introduced. It was followed by the Power Pacer (Balboa Instruments) and Look Max One hubs in the early '90s, neither of which was a commercial success. SRM received a significant boost when it was embraced by several national cycling federations, as well as numerous professional and elite riders including Greg LeMond, but it took the Power Tap (1998, Tune Corp., purchased by Graber Products in late 2000, now branded as CycleOps), and the Polar S-710 (2001) to bring accurate and reliable power measurement within reach of most any rider. (Ciclosport models are not considered here, since they make only a crude estimate of power, based on weight, speed, and gradient.)

BENEFITS OF POWER-BASED TRAINING

1. *It eliminates guesswork from gauging exercise intensity.* As the true and objective measure of how hard you are working, power output directly determines physiological and perceptual responses to exercise, and even those with exceptional "feel" are unlikely to judge their wattage any better than to within perhaps 10%, whereas a powermeter is accurate to ±2% or less, allowing workouts (the training "dose") to be more closely controlled.

2. *Similarly, power-measuring systems allow the demands of racing to be quantified*, using interpretive tools such as Normalized Power and Quadrant Analysis, which are covered in Part II of this guide. Once these demands are known, training programs can be more appropriately and more realistically constituted.

3. *It allows fitness to be precisely quantified (including identification of strengths and weaknesses) and training regimes to be objectively evaluated.* This requires that a training log of relevant workout data be faithfully maintained, so that performance can be tracked from month-to-month and year-to-year.

4. It allows training load to be more realistically assessed and effectively managed, again, with the analytical tools Training Stress Score (TSS) and Training Stress Balance (TSB) discussed in the second part of this guide. Training programs become less haphazard and the training progression can be carried out precisely, making peak performances easier to predict, while helping prevent overtraining and injury.

5. Powermeters have other uses, such as pacing during time trials and even breakaways in mass start races; aerodynamic testing; stationary trainer calibration; and possibly as an aid to dieting and weight control. Previously, aerodynamic drag could be accurately measured only in a wind tunnel, but under carefully controlled conditions, it may be possible to do this via field testing and analysis of power data.

Leave it to a layperson from the [Wattage Forum](#) to offer a *précis* . . .

"Imagine training in a gym where you can't see how much weight you're lifting. You can't see numbers, or even how many plates you have on the bar. I think it would be a rare lifter who could maximize gains in that environment.

Riding outdoors without a powermeter is like training in a numberless gym. Yes, there are other metrics of intensity, but they are distorted and skewed by numerous environmental, physiological, and dynamic factors. So, for me, the powermeter has 'put numbers on the plates,' with all that entails in feedback and inspiration, from 'Man, I'm having a bad day' to 'Wow, I'm getting stronger.'" – Jens Kurt Heycke

and another . . .

*"It is true that power data will not tell you **why** your performance was sub-par, but it is the only way to tell **if** it truly is sub-par. For example: I recently got shelled at a bi-weekly race I can usually finish. HR was not out of the ordinary. The power data showed that, no, I wasn't having a bad day at all, rather, the race was much harder than usual. On the other hand, I've had some surprisingly high power outputs on days where I felt bad, but after a long warm-up (40 minutes) and an easy start, things went great. I've also had days where I felt similarly bad but 5 minutes into a 20 minute interval, I called it quits because I simply couldn't hang on."* –Andy Birko

DRAWBACKS TO TRAINING BY POWER

Still, any advocate of power-based training should have an appreciation of its limitations:

1. It appeals to the more analytical and technically-oriented. Not everyone is inclined, whether by background or temperament, to take a quantitative approach to training, furthermore, feedback during a ride or race may only serve as an unwelcome distraction, rather than provide valued information.

2. It lends itself to a structured program, while demanding discipline and patience. Use of a powermeter and a periodized training plan go hand-in-hand; for many, the planning, structure, analysis, and record-keeping required by such a system are an added hassle in a sport that is time-intensive enough already, and exactly what they seek to escape through cycling, while its "training by the numbers" aspect seems mechanical, unimaginative, constraining, and slow to yield progress. Practical considerations, like job and family, may make it difficult or impossible to closely follow any plan, however well-conceived.

3. It is conducive to solitary training. As Andrew Coggan points out below, the levels in his power-based training schema are referenced to "the athlete's own unique (and current) ability," which may mean training alone, at least during more intense and structured workouts. Again, this is directly contrary to one of the primary reasons why many riders are attracted cycling in the first place, namely, the shared effort and companionship of training together.

4. Even the most affordable models are expensive. Cycling is a costly enough sport as it is, and many will simply not be able to justify the added expense of yet another "gadget." Powermeters will probably never be priced comparably to HRMs, and like any electronic device, they can malfunction and be unreliable. Still, they are less expensive than many of the latest exotic frames and crazy-light components which seem so ubiquitous, while arguably of much greater benefit.

Energetics of road cycling

Mechanical power output *P*, expressed as Watts in the international system (SI) of units, is the rate of external work *W* in Joules, such that $P = W/\Delta t$, where elapsed time Δt is in seconds. Since work is the product of the net sum of forces ΣF, in Newtons, resisting the forward motion of the bicycle/rider system through a distance Δx in meters, the previous equation becomes $P = (\Sigma F \times \Delta x)/\Delta t$, or simply the product of force and the road speed *s* of the system in meters per second, i.e., $P = \Sigma F \times s$. This is perhaps the best way to think of power: *how fast you can travel against a given resistive load.* Rearranging to solve for speed gives $s = P/\Sigma F$. Thus, to maximize speed, the two fundamental tasks of the competitive cyclist are to increase power output through optimal training, proper diet, and adequate rest, while reducing the forces that resist forward motion, first of all, by minimizing aerodynamic drag, and to a much lesser extent, by reducing weight.

Using an expanded motion equation for cycling (see the section on aerodynamic testing in Part II of this guide), the power requirements of cycling (Figs. 1-4) are plotted to show how widely and rapidly they can vary, moreso, perhaps, than any other endurance sport, furthermore, this model assumes constant wind speed and direction. Even a rolling 30-second average for a relatively well-paced, flat time trial is surprisingly variable (Fig. 5), let alone 5-second average power for the same race (Fig. 5a), or even more still, for a road race or criterium. It follows that several different metabolic pathways, or energy systems, are called upon to meet these demands, with the extent to which each is taxed depending on rider and course characteristics, wind, race type, and pace.

ENERGY SYSTEMS OVERVIEW

Muscular contraction represents the conversion of chemical energy to mechanical work, which results solely and directly from the breaking of a high-energy phosphate bond within a molecule of adenosine triphosphate (ATP), producing ADP (adenosine diphosphate) and inorganic phosphorous (P_i): $ATP \rightarrow ADP + P_i + energy$. There are three sources of ATP supply to the working muscles (Table 1):

1. *The phosphagen system.* A very limited supply of ATP – enough for ~5 seconds of all-out effort – is stored directly in the working muscles, while re-phosphorylation of the ADP byproduct from phosphocreatine (PCr) stores provides enough to continue (albeit at a declining rate) for 12-15 seconds in total before glycolysis begins to come "on line." This process achieves the highest power output levels of the three systems, so it is recruited most heavily during the early portion of any maximal acceleration, such as the initial "jump" of a sprint or hard attack. Since this system does not produce lactic acid, it is sometimes (and rather confusingly) referred to as "anaerobic alactic."

2. *Non-aerobic glycolysis.* So called because it does not use, but will proceed in the presence of oxygen, this energy pathway is stressed most heavily (though not exclusively) when strong but submaximal demands are made, such as high-intensity efforts of 30-120 seconds. Type IIb, or fast-twitch muscle fibers, are the locus for glycolysis, with muscle glycogen (stored glucose) the substrate (fuel source). Also called the Emden-Meyerhof Cycle, or the lactic acid system, it is capable of producing large quantities of ATP at a high rate for a very short time, but much less efficiently than aerobic metabolism, since it does not utilize oxygen and cannot fully metabolize the glucose molecule. The byproduct of this is pyruvic acid, which at moderate intensities is used to make ATP by the aerobic system, but at higher intensities is produced more quickly than it can be metabolized or removed from working muscles (think of a funnel backing up). The excess is converted into lactic acid, which is eventually carried away in the bloodstream. This is accompanied by fatigue, i.e., a rapid drop-off in power-generating capability (colloquially known as "blowing up"), as the proton (hydrogen ion, or H+) associated with the lactate molecule causes muscle acidity (pH) to exceed an optimal range.

3. *The aerobic system.* Much (19 times!) more efficient than glycolysis at producing ATP, this pathway, also known as the Krebs Cycle or tricarboxylic acid (TCA) cycle, provides the majority of energy required for events longer than 75 seconds. It occurs primarily in Type I, or slow-twitch muscle fibers (although there is a continuum within Type II fibers, some of which display characteristics of the former), and for fuel, relies on fat (which contains more energy than carbohydrate – 9 kcal/gram vs. 4.1 – but is less readily metabolized) at lower intensities, progressing to carbohydrate (CHO) as intensity increases. As exercise duration wears on, there is a gradual shift in CHO fuel source from glycogen stored in the muscles to blood-borne glucose acquired exogenously via ingested CHO.

The capacity of each system can be assessed individually by the following four functional tests, and interpreted collectively as described in the chapter on Power Profiling. Of course, how much training emphasis to place on each system depends on such factors as rider characteristics and training status, as well as the demands of the event being prepared for, as discussed in the section on formulating a training plan.

1. *Maximal neuromuscular power* is obtained from average power in a 5-second all-out effort from a near-standing start, so data should be collected every 5 seconds, preferably less. Large, fast-twitch muscles that can "fire" (contract) rapidly determine performance in this test.

2. *Maximal anaerobic power* can be represented by average power for a 1 minute, all-out effort. While the result is largely reflective of energy production via non-aerobic glycolysis, the systems which "precede" and "follow" (neuromuscular and aerobic in this case, respectively) will play a lesser role as well, just as they do in testing for . . .

3. *Maximal aerobic power.* The upper limit or "ceiling" for steady-state (aerobic) power output, this associates with its physiological determinant, maximal oxygen uptake, or VO_{2max}. No protocol is presented here for a functional equivalent of the familiar incremental ("ramped"), laboratory-administered test (see Ric Stern's article for that), but the quintessential event suited to a high VO_{2max} (though still with a significant contribution from anaerobic capacity) is the individual pursuit, or a prologue time trial of similar duration, hence the 5 minute test suggested as a proxy here. Often considered to have a genetic basis almost entirely, this system is now seen to be more trainable than previously thought (training-induced increases of 15-25% are typical, and up to 60% may be possible), such as through workouts of 5-6 intense efforts lasting 4-7 minutes.

4. *Functional threshold power (FTP).* Although there are alternative tests for it (see Part II of this guide), as presented here, this is determined simply as average power for a 40-60 minute, flat-terrain time trial, which serves as an excellent practical alternative to a ramped lab test, since it correlates very closely with VO_2 at lactate threshold (LT) and gives a "bottom line," *functional* measure of endurance performance that integrates all three of its physiological determinants: 1) VO_{2max}; 2) VO_2 at LT; and 3) efficiency, or the ratio of energy output to energy consumed.

VO_2 at LT is determined in the lab during a VO_{2max} test as an increase in blood lactate concentration of 1 millimole/liter over low-intensity baseline (although power output at LT, as determined in the lab, will be 10-20% lower than average 60 minute TT power), and largely forms the basis for determining endurance cycling performance, as well as training levels in the schema presented below. The respective relationship between VO_{2max} and VO_2 at LT may be likened roughly to that of an engine's maximum horsepower to its governor, in that the latter controls what portion of the former can be used:

a. VO_{2max} sets the upper limit of ATP production via aerobic metabolism, and is determined primarily by cardiac output (Q), the ability of the heart to pump oxygen-carrying blood to the working muscles, rather than the ability of the muscles to extract O_2 from the blood; Q in turn depends on cardiac stroke volume (SV) and maximum heart rate: $Q = SV \times HR$ (the Fick equation)

b. VO_2 at LT determines the percentage of VO_{2max} that can be utilized for an extended (>3 minutes) time, and is correlated with several morphological components within the working muscles: the proportion of Type I fibers, the density of mitochondria (locus of aerobic ATP production), as well as the extent of capillarization (by which metabolic waste is removed), adaptations that increase to varying degrees in relation to years of sufficiently intense, specific endurance training (Table 2).

The drawback to functional field testing is that it is self-administered, rather than carried out under the watchful eye of a coach or an exercise physiologist in a controlled lab setting, and can therefore be affected by environmental conditions, the motivation and concentration of the test subject, as well as (to a lesser extent) his or her judgment and skill in pacing correctly. For consistent and reliable test results, make sure you are rested, with no illness or infection present, and avoid extremes of temperature (especially heat) and wind. Flat terrain is recommended, but a steady, continuous uphill grade is fine, and even a rolling-to-hilly course will do if the same one is used each time (average power on a rolling/hilly course, or in variably windy conditions, will be somewhat less than for a windless, constant-grade test of similar duration).

It may take a few attempts to get the pacing just right and the wattage "dialed in" (Fig. 6), but once it is, average power achieved in any carefully executed threshold test should be highly repeatable from day-to-day. In your first test, just as in the initial, transitional period of powermeter use, you will likely need to use PE and HR guidelines to gauge intensity, while monitoring power, but by the second test, power can be used to guide pace.

Finally, although there is no functional test for it, *gross mechanical efficiency* rates mention as the ratio of mechanical work actually accomplished to energy expended metabolically to produce it. Since movement in cycling is mechanically constrained almost entirely within the sagittal plane, cycling efficiency is not related to smoothness of the pedal stroke – elite riders simply exert greater 'downstroke force' (Fig. 7) – but rather is determined by muscle fiber composition, being directly proportional to the percentage of Type I fibers present (Table 3), and typically falls within a range of 20-24%, trending upward very slightly as intensity increases, but declining as exercise duration wears on (most of the other 76-80% is lost as heat). Efficiency improves slightly over years of training, as there is a gradual conversion wherein some Type II fibers begin to function as Type I; of the three endurance performance variables, efficiency changes the least (and most slowly) with training, VO_{2max} is intermediately affected, and LT responds the most, or is the most "elastic."

ENERGY SYSTEMS IN PERSPECTIVE: AEROBIC/ANAEROBIC INTERACTION

Unfortunately, there is often a lack of context when descriptions of each energy system are presented separately, and along with illustrations such as Fig. 8 (which is widely used in exercise physiology courses), this can lead to misinterpretation of road cycling energetics. Indeed, wide and rapid variation in the energy demands of road cycling has led none other than Dr. Arnie Baker, M.D. to call road racing an "anaerobic sport" in his otherwise fine book *Smart Cycling*, but this is contradicted by what is already known:

1. Again from Fig. 8, most energy for any single, maximal effort *over 70 seconds*, starting from a rested state, comes from *aerobic* sources

2. In four *30 second* bouts of exercise, each separated by *complete* recovery, most of the energy utilized by the third bout comes from *aerobic* sources (Fig. 9), and the predominance of aerobic metabolism becomes even more pronounced during longer exercise bouts (Fig. 10), not to mention *continuous* exercise, such as any road race, where intensity is lower, and recovery is not nearly as complete.

3. The extent to which limited anaerobic energy sources are taxed (and blood lactate is produced) for a given set of race demands will be determined by how much and often threshold power is exceeded, therefore, the higher it is, the less they will be called upon, while the more often it is exceeded, the more quickly they will be depleted. Furthermore, within the context of any road (i.e., endurance) event, recovery from short "jumps" is actually more reflective of aerobic, not anaerobic fitness, since 1) fatigue during intense exercise is related to changes in high-energy phosphate (ATP) levels; 2) 100% of ATP resynthesis within working muscle occurs via aerobic metabolism; and 3) the rate of ATP resynthesis is correlated with mitochondrial respiratory (i.e., aerobic) capacity.

4. Racing categories and time trial performance both correlate much more highly with sustainable threshold power than with anaerobic capacity or sprinting power.

Thus, it often goes unrecognized the ability to sprint or attack in most all race situations rests on adequate aerobic capacity, since short-term power production is reduced when the effort is initiated from prior exercise (as opposed to starting from a rested state), and this reduction is in direct proportion to high-energy phosphate levels within the muscle. In other words, the really "strong" riders seem to be able to attack repeatedly, or when the pace is already very high, and then recover more quickly than others, largely because their muscles are more *aerobically* fit, rather than having markedly greater "lactate tolerance;" despite the seeming importance of sprinting ability in determining race outcome, it is more the case that the sprinter with the highest threshold power wins. Adam Myerson, a pro/elite-level field sprinter, summed it up nicely by noting that sprinting ability may be what helps you win the game (race), but having a high threshold power is what allows you to play the game in the first place, and influences how well you can play at the end, while Andy Birko offered yet another astute comment:

"When rested, I've got a pretty decent sprint (for a Cat. 4) at around 1100 Watts or so. When I hide, suck wheel etc., in a long race, I can produce about 800 Watts or so in the final sprint. When I'm pulling, chasing etc., I'm lucky if I can hit 650 Watts by the end. There's another guy in my club whose sprint speed is about the same as mine (I don't know his power), and when we do sprint drills, the results are split about 50/50. When we do our monthly time trial, he goes about 10 seconds faster on his road bike than I do on my TT bike. Guess who beats whom more often when we do our training races.

Anaerobic capacity is like a bank – every time you go over LT, you're drawing from the bank, and again, the further and longer you go above LT, the quicker you're withdrawing. You can only replenish the bank when below LT, so recovery from anaerobic efforts is directly related to how much you go above LT and long you stay there, and the higher your LT, the stronger your anaerobic efforts can be without draining the bank as much."

This interpretation is spot-on, and is essentially what appeared as a recent study published in the *Journal of Applied Physiology*. It explains why "genetic sprinters" need to be careful to "conserve their sprint" throughout most any road race; as Jim Martin (masters national match sprint champion, but only a Cat. 3 on the road) describes it: "I often to spend the whole race sitting in and suffering, waiting for the 1 km to go sign." Further, world and Olympic match sprint champion Marty Nothstein was generally unable to contest for the win once the 'smack' really started to go down in national-level points races and Madisons on the track, as well as road criteriums; despite his world-class sprint ability, and although he greatly improved his aerobic ability (threshold power), as evidenced by his win at the 2003 New York City Championship (a 100 km criterium), it was still not enough to handle the repeated surges thrown at him by riders such as Colby Pearce, Jame Carney, etc. Even for a points racer, the great bulk of training time still needs to be spent working on threshold power, although the rule change awarding 20 points – but no other benefit – for lapping the field tends to tip the balance a bit more towards those who can sprint well.

Or in other words, "It's an **aerobic** sport, damn it!" ☺

Special thanks to Andrew Coggan, Ph.D. for his contributions to this section.

Power Profiling™

By Andrew Coggan, Ph.D. (originally posted <u>May 19, 2003</u>)

THE ISSUE

It is simply human nature to wonder how one compares with others for any measurement, and cycling power output is certainly no exception to this rule. Consequently, there have been numerous calls for, and some attempts at, generating guidelines or benchmarks for power output based on rider category (i.e., Cat. 1, 2, etc.) Aside from satisfying people's natural curiosity, though, such category-based values would seem to have limited practical use; after all, the best measure of a rider's competitive ability relative to that of others is their actual race performance, not their power output. If, however, valid standards were available for power across different durations that represented different physiological characteristics or abilities, then it would be possible to identify a particular individual's relative strengths and weaknesses based on their "power profile." In such an analysis, the primary comparison would therefore be the rider against themselves, and not (directly) against others. Such information could be then used to help plan an appropriate training program, evaluate the effectiveness thereof, and to possibly identify events where an individual might be expected to achieve the greatest success. The goal of this effort was therefore to develop rational guidelines that could be used for this purpose.

THE APPROACH

In theory, tables of standards for power output for different durations could be generated by simply collecting data on a large number of cyclists of widely varying ability, however, very few (if any) coaches or other individuals are likely to have access to a sufficiently large database for this approach to be very accurate. As an alternative, estimates of power output for riders of differing abilities could be derived from actual performance, e.g., in time trials, but this approach requires making somewhat tenuous assumptions regarding body mass, effective frontal area (C_DA), etc., and is particularly complex when applied to shorter duration, non-steady-state events (e.g., the kilometer). The present tables were therefore instead generated using a third approach, which was to "anchor" the upper and lower ends of each range based on the known performance abilities of world champion athletes and untrained persons, respectively. The advantage of this approach is that it enhances the validity of comparisons across event durations, e.g., a "world class" power output should be equivalent regardless of whether the duration over which it is measured is 5 seconds or 60 minutes. The resultant values for intermediate performances were then cross-checked against available data to assure that this approach resulted in valid guidelines.

Since records are not kept for times, only distances, except for the fabled hour, any estimate of what the "world record" holder could maintain must be just that, an estimate. There is also the issue of obtaining accurate data with respect to both power and weight (more to follow). For the 60-minute record, I relied on Chris Boardman's 56.6 km World Hour Record in September 1996. Specifically, based on careful measurement of his power-speed relationship in training, Boardman's coach Peter Keen estimated his power to have been 442 W. The question is, how much did he weigh? Keen himself has stated that Boardman must have maintained a VO_2 of 5.6 liters/minute, or 81 milliliters/minute/kilogram during the attempt, which means he must have weighed 69 kg. That makes his power 6.40 W/kg, however, I should mention that Ric Stern has been told by Keen that Boardman was closer to 67 kg at the time of the record, thus contradicting himself.

So what could Boardman have maintained for 5 minutes? Well, using a C_DA value consistent with his 56.6 km/h, 442 W effort, and accounting for stored kinetic energy carried across the finish line, it is estimated he averaged 543 W (7.86 W/kg) during his 4 minute 11 second world record pursuit. (Note that the steady-state power estimated this way – i.e., 501 W – agrees almost exactly with the power just eliciting 100% of his 6.22 L/min VO_{2max} at his stated efficiency of 22.6%. This is as expected, given that anaerobic capacity is fully utilized during roughly the first 2 minutes of a pursuit, meaning that it is entirely "pay as you go" the rest of the way.) If these values of 6.40 W/kg for 3600 seconds and 7.86 W/kg for 251 seconds are then plugged into a critical power analysis, it is possible to estimate that Boardman could have maintained 7.60 W/kg for 5 minutes, and 6.62 W/kg for 20 minutes. (The same critical power analysis also demonstrates what an unusual talent Boardman was, combining an extremely high aerobic power with a very high anaerobic capacity.)

Based on both wind-tunnel measurements of his aerodynamic drag and lab/trackside measurements of blood lactate, Spanish sports scientists estimate that Miguel Indurain averaged 510 W during his hour record. His stated body mass was 81 kg, or 6.3 W/kg. I bring this up not to directly compare him to Boardman, but simply to point out the consistency of the power estimates from the two best-documented hour records.

Performance in flat-terrain time-trialing is best predicted by W/m^2 of C_DA, and since body mass has minimal effect in such a context, it might seem that absolute power in Watts alone would be preferable in such situations, but in fact, since C_DA correlates with body mass, W/kg should still be a better predictor across a wide range of sizes and abilities, even though mass per se has little effect on flat-terrain. Further, few people know their C_DA, so the choice is either W or W/kg, possibly with the latter scaled allometrically, e.g., $W/kg^{0.67}$.

The argument for using W/kg or $W/kg^{0.67}$ in the Power Profiling tables is stronger because the idea here is to be able to evaluate someone's relative performance ability over a broad time range (i.e., 5 seconds to 60 minutes) which reflects various physiological characteristics. This requires that the normative scales be equivalent, e.g., the 75th percentile on one is equal to 75th percentile on another. This would not be possible if you used only Watts for this purpose, since having additional lean body mass contributes more to short-term power output (when O_2 delivery is not limiting) than to long-term power output. As it stands, road riders already often come off looking as if they lack neuromuscular power, which in fact they do, at least when compared to bigger, more powerful athletes, who typically compete on the track. Most important of all is to remember that the tables are meant to determine relative strengths/weaknesses, not to predict performance or racing category.

Across a range of body masses, there are good theoretical reasons why power should scale with body mass to the ⅔ power, i.e., as $W/kg^{0.67}$, but in the field of allometric scaling, theory and reality don't always coincide, and the actual exponent that best describes the relationship is probably closer to unity.

The other issue is what one is attempting to ascertain by expressing the data in this manner. Clearly, when riding uphill, it is W/kg^1 that matters, not $W/kg^{0.67}$. On the other hand, effective frontal area determines the power required to overcome air resistance, and is more closely related to height than to mass. Taken in conjunction with the fact that the actual exponent is probably higher than 0.67, I therefore see no benefit to using $W/kg^{0.67}$. Finally, I think that such allometric scaling might be beyond the average person's grasp, at least without extensive explanation.

CHOICE OF TARGET DURATIONS

Index efforts of 5 seconds, 1 minute, 5 minutes, and 60 minutes were chosen as those best reflecting neuromuscular power, anaerobic capacity, maximal oxygen uptake (VO_{2max}), and lactate threshold (LT), respectively. This should NOT be taken to imply that, for instance, a 1 minute all-out effort is completely anaerobic (in fact, roughly 40-45% of the energy during such exercise is derived aerobically) or fully utilizes anaerobic capacity (which generally requires 1.5-2.5 minutes to deplete), or that a 5 minute all-out effort entails exercising at precisely 100% of VO_{2max} (most athletes can sustain a power that would elicit 105-110% of their VO_{2max} for this duration). Rather, power output over these target durations would simply be expected to correlate well with more direct measurements of these different physiological abilities. Secondarily, the index efforts were chosen in an attempt to increase reproducibility (e.g., use of 5 vs. 1 second power as an indicator of neuromuscular power), and for convenience (e.g., selection of 60 minute power as an indicator of power at LT).

Power Profiling is a registered trademark of TrainingPeaks, LLC. Originally presented in tabular form, it is now available in a graphical version is as well. Here are blank scales for men (left) and women:
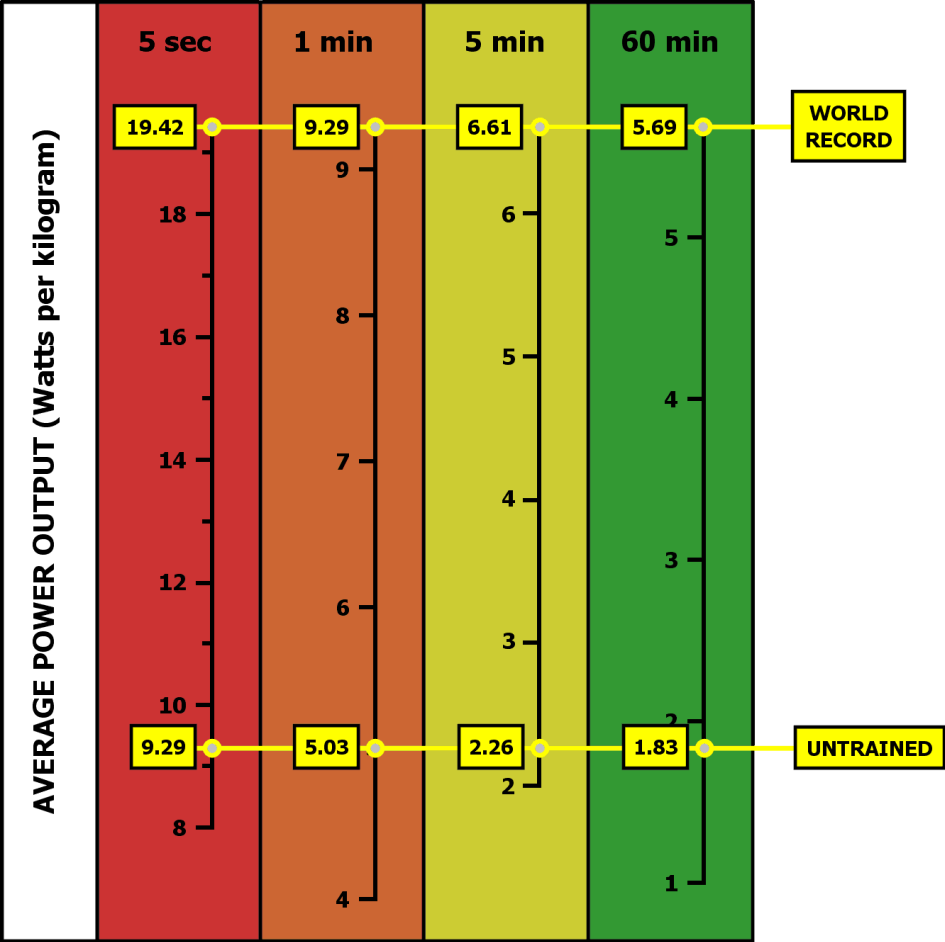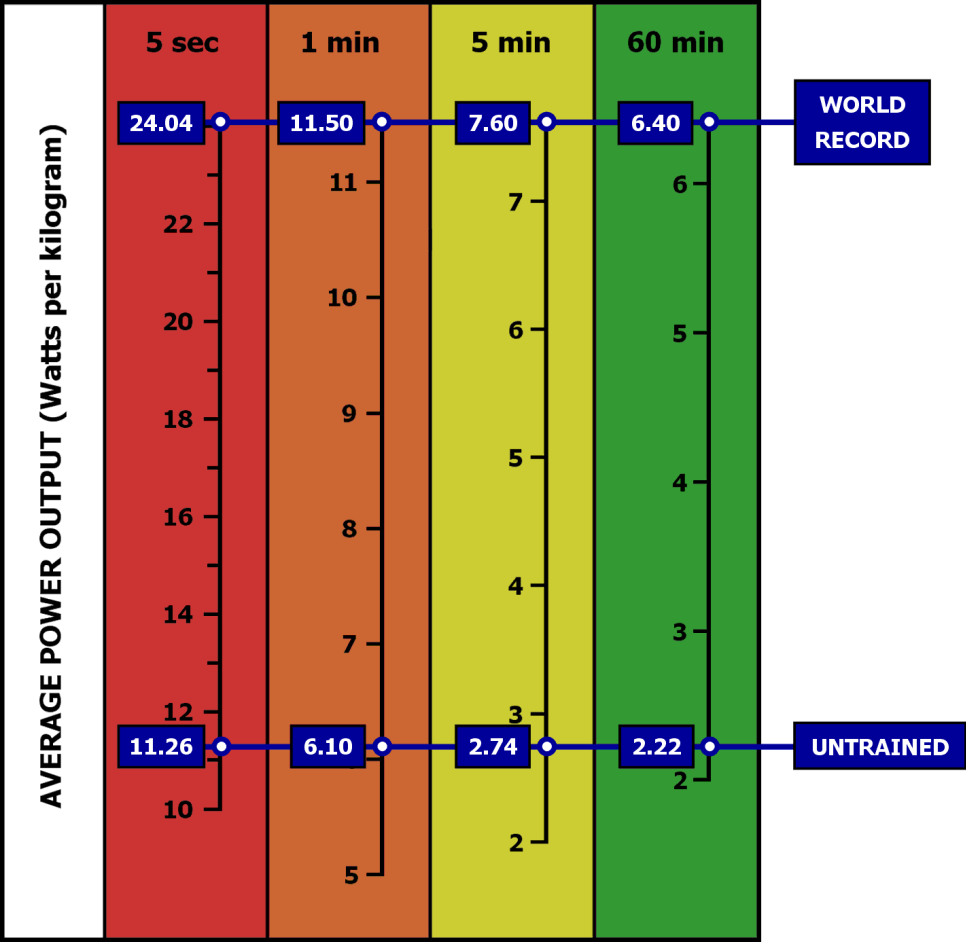
APPLICATION AND INTERPRETATION

To create a rider's Power Profile, simply locate and highlight (or circle, if using a printed copy) the peak or maximum power they can generate for 5 seconds, 1 minute, 5 minutes, and 60 minutes, then connect the values horizontally. If his or her performance falls between tabled values, which will often be the case, assign them to the nearest ranking. It is critical that the values used in this analysis be truly reflective of the athlete's very best effort over that duration – otherwise, the resultant profile may be distorted, leading to flawed conclusions and inappropriate actions. For instance, even though many people have the motivation to go really, really, really hard for many minutes in a row only when racing, it is somewhat unusual to match 1 or 5 minute bests during mass start races, because you don't get to start such efforts from complete rest (necessary to be able to utilize all of anaerobic capacity), and you generally can't afford to go all-out for such periods, because if you did, you'd blow up completely and get dropped.

While each individual is likely to have a somewhat unique pattern that may change slightly over time, some typical patterns and general guidelines for interpretation are given below. In considering the following, however, keep in mind that performance at each duration is being evaluated in comparison to the world best – thus, in comparison to match sprinters, road cyclists will tend to appear relatively weak in 5 seconds and, to a somewhat lesser extent, 1 minute power, whereas non-endurance track racers will likely have relatively low 5 and 60 minute power relative to their abilities at the shorter durations. (The possibility of developing road and track-specific tables was considered but rejected, in part because many riders compete in both disciplines.) Also consider that, based on physiological considerations, an inverse relationship might be expected between the anaerobic (i.e., 5 second and 1 minute) and aerobic (5 and 60 minute) efforts, whereas a positive association might be expected between each pair. (The scientific literature is in fact split on whether there actually is an inverse relationship between short-term and long-term power, however, there is clearly a positive association within each category.)

The shape, or profile of the resulting plot, will fall in to one of several categories:

(–) Generally horizontal plot, i.e., all four values falling at about the same point on their respective range: this pattern is characteristic of the typical "all rounder," i.e., a rider who doesn't necessarily excel at any one thing, but is likely competitive in their category across a broad range of events. Given the fact that only specialists will likely truly excel at the extreme durations (i.e., 5 seconds and 60 minutes), very few individuals will show this pattern and still fall at the upper end of each range. On the other hand, the vast majority of non-elite athletes will likely show a generally horizontal power profile.

(\ ) Distinctly down-sloping plot (especially between 1 minute and 5 minutes): this pattern would be characteristic of an excellent sprinter/"fast twitcher," i.e., an athlete whose naturally abilities are skewed towards success in short duration, high power events. Since aerobic ability is quite trainable, such an individual may be able to turn themselves into more of an "all-rounder" by appropriately-focused training – however, if they have already been training hard for many years, they may always still be better at anaerobic vs. aerobic efforts. If so, focusing on events that favor these abilities (e.g., track racing, criteriums) may result in the most success.

(^) Sharply inverted-V pattern: an athlete characterized by both relatively high anaerobic capacity and aerobic ability, and thus well-suited for events such as the pursuit. Alternatively, a potential "all-rounder" who simply hasn't focused on raising their lactate threshold to its highest possible level.

(/) Distinctly upsloping plot (again, especially between 1 and 5 minutes, but also from 5 to 60 minutes): the classical time-trialist pattern, i.e., weak in neuromuscular power and anaerobic capacity, but with a relatively high aerobic power, and especially a high lactate threshold. While such riders may improve their performance by working on their weaknesses, this may not necessarily be true if it results in a decline in their strength, which is sustainable power.

(V) Sharp V-pattern: an unlikely combination, given the expected inverse relationship between neuromuscular power and lactate threshold, and the positive relationship expected between VO_{2max} and lactate threshold. Should such a pattern be observed, care should be taken to assure that the values being used are truly representative of the athlete's abilities, and to be sure that the pattern isn't simply being misinterpreted (i.e., considering a generally horizontal or "w" pattern to be a "V").
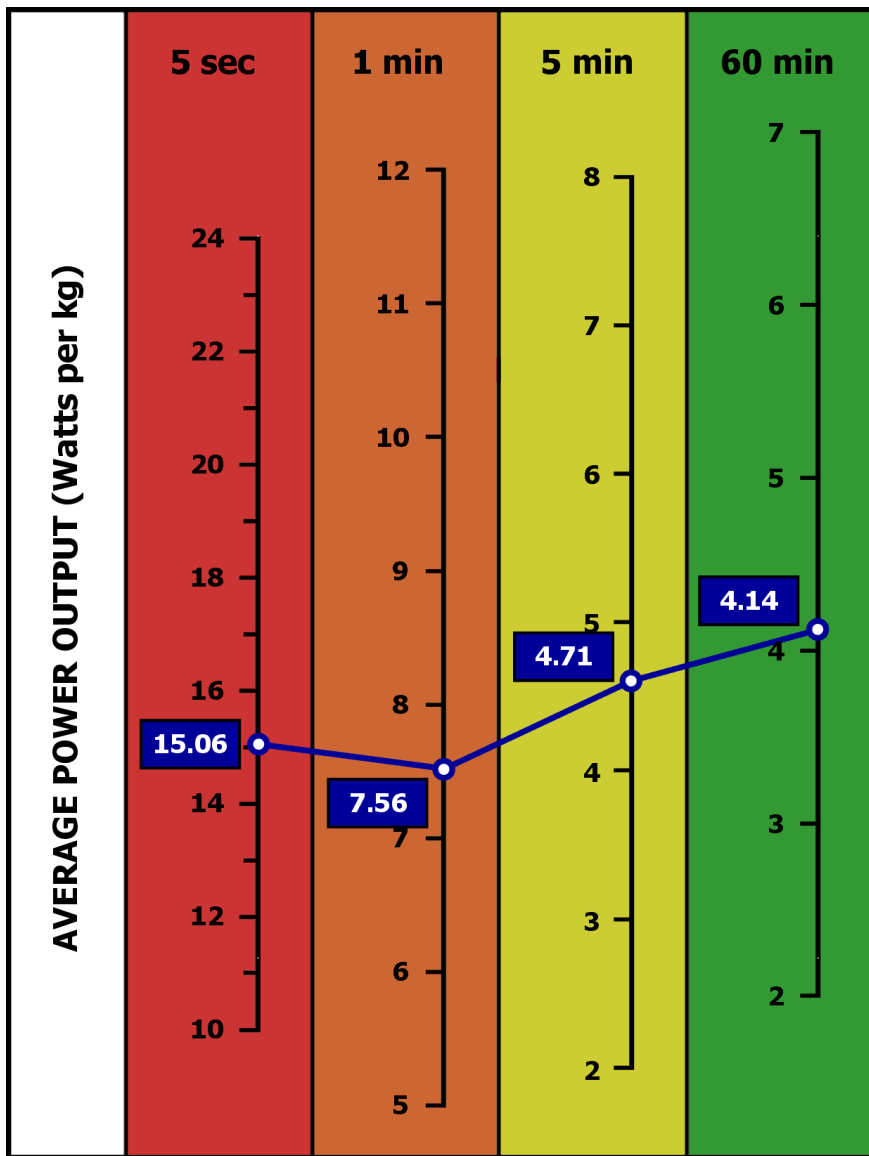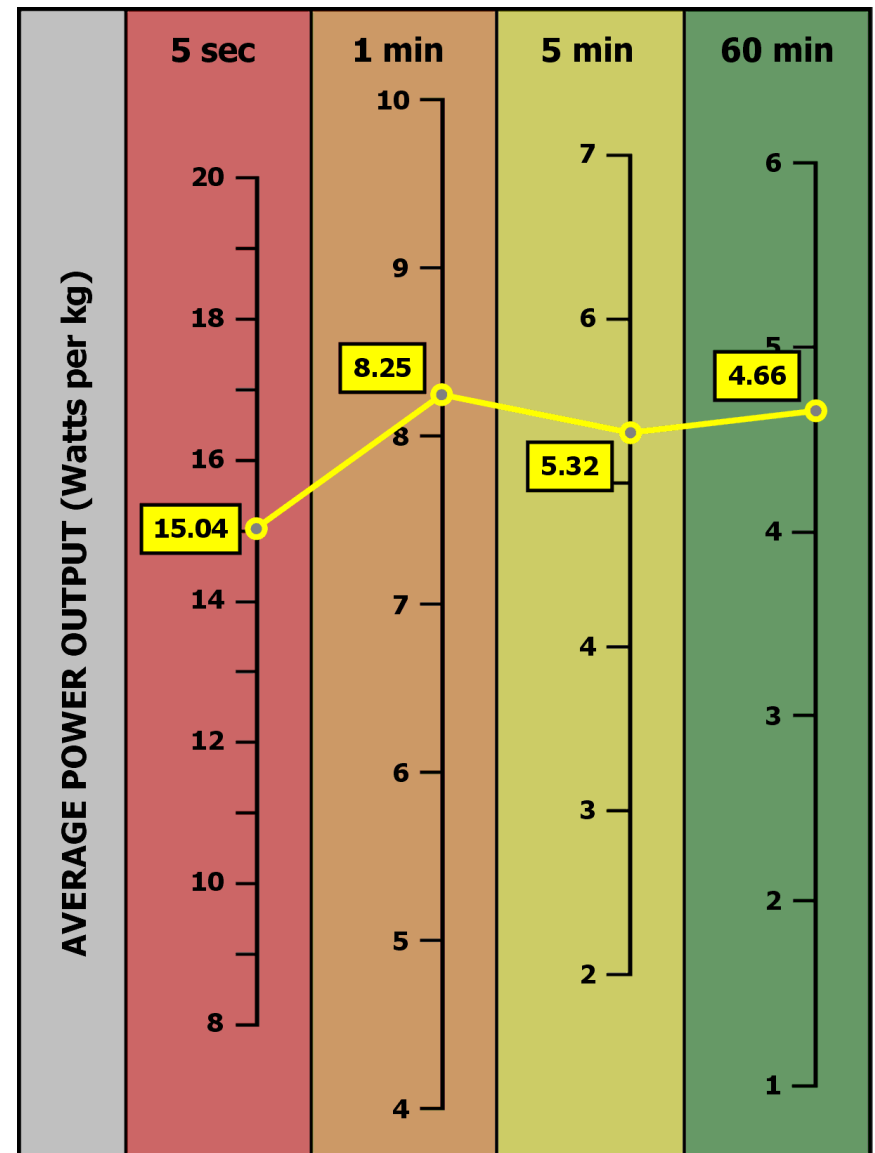
ALL ROUNDER: Masters 45+ criterium/points racer (male)
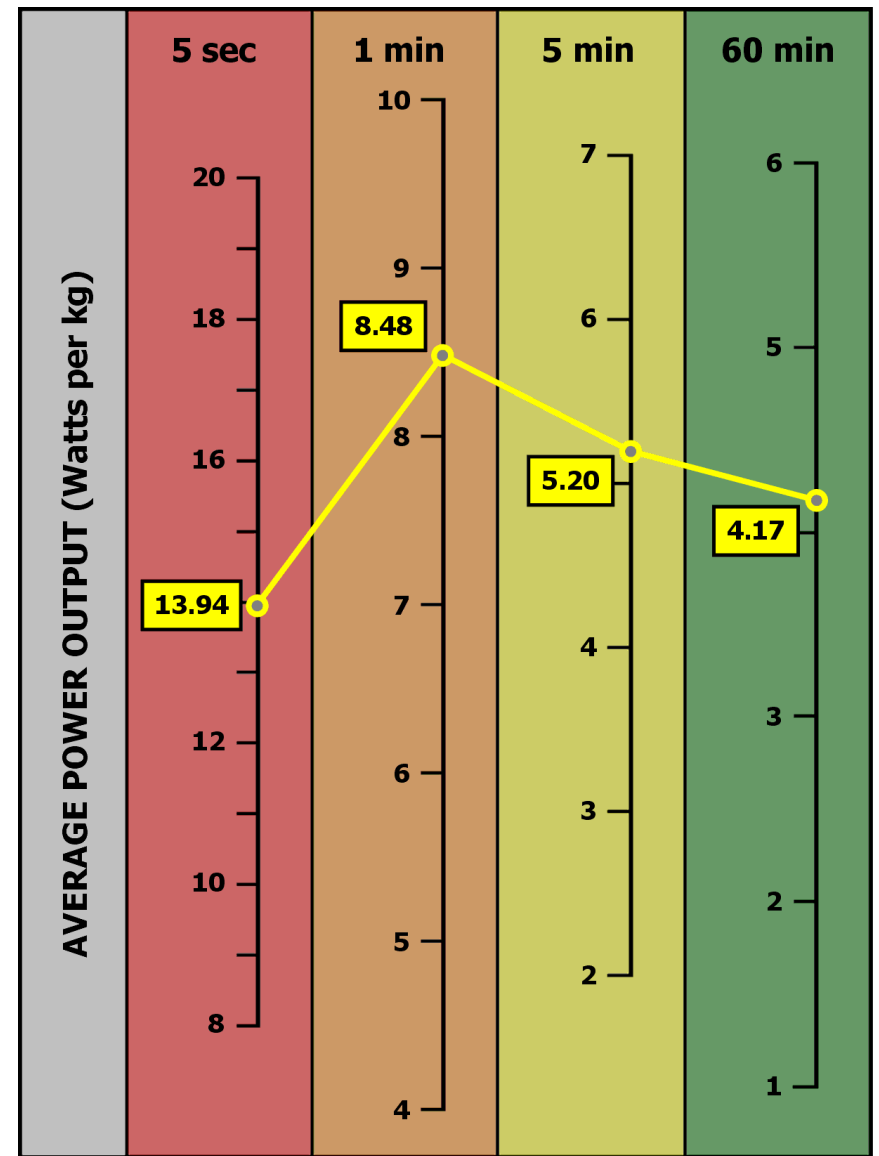
PURSUITER: U.S. national champion (female)
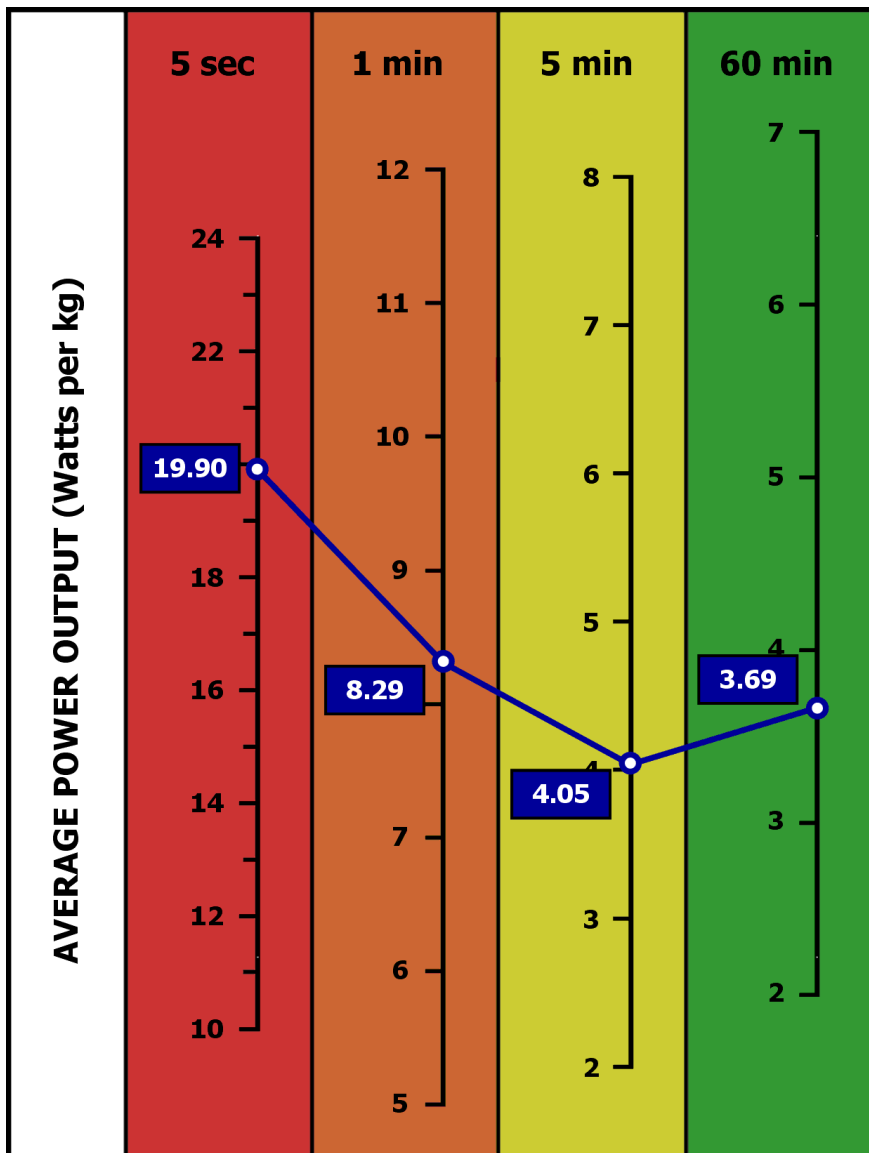
SPRINTER: Cat. 3 roadie with "amazing sprint" (male)

TIME TRIALIST: Elite Australian Road Racer (female)

HOW THE ABILITY LEVELS WERE CHOSEN

The upper and lower bounds of each range, of course, were fixed based on known power outputs of world champions/record holders and untrained individuals, respectively, while the values in between were spread equally (i.e., linear relationship assumed), simply because at present there is not enough data to justify doing otherwise. Remember, the purpose of the tables is to compare relative ability across different exercise durations reflecting different physiological characteristics, not to assign categories or describe riders at each level; strip the ability levels away, and the tables would be just as useful. This is why a normal distribution was not assumed and the values were not spread that way; that might better reflect reality (or might not – no one has the data to say for sure), but it has the disadvantage of squeezing everything together toward the middle, making anyone who isn't well above or well below average appear to be an "all rounder."

The scales tend to be skewed from a road racer's perspective, as they are based on the performance of specialists (match sprinters for 5 second power, kilo riders for 1 minute, etc.) To state it another way: compared to a true sprinter, most people racing on the road *do* have relatively low neuromuscular power, however, I don't think one really can or should try to develop discipline-specific tables. First of all, too many people cross over to different disciplines, thus making it difficult to develop valid standards, especially since the only point of proposing discipline-specific tables would be to improve the category guidelines, which is not the point of the tables. Secondly, discipline-specific tables would deviate from the logic that was used to develop the tables in the first place, namely to help assist riders in evaluating their ability over a range or durations.

If you assume there is a big enough population base fighting it out to be "top dog" in each specialty, it seems to me that ensures the scales will align properly (the most important part). Logically one would expect each scale should *not* be linear (thus addressing the point about the extremes), but instead be normally distributed. I could, for example, have assumed that world champion/world record performance is, say, 5 standard deviations above the mean, and the lowest level of the untrained 5 SDs below, or something like that, however, that doesn't alter the comparison across scales, and has the disadvantage of crowding together all values in the middle.

To reiterate: the ability levels, as specified in the tabular version, are just rough approximations, i.e., most riders of a certain category can generate the specified power for the specified duration, but that doesn't mean that all can, nor does it mean that you should be a certain category (although it does indicate you have the potential). Another factor to keep in mind is that no matter what duration you choose to look at, it will never be an absolutely "pure" reflection of a single physiological trait. For example, somebody could have a high 5 minute power relative to their sustainable power as a result of having an unusually high anaerobic capacity (in which case you'd also expect their 1 minute power to be pretty good as well).

LIMITATIONS AND CAVEATS

There is a paucity of direct data on the power outputs of female cyclists. Thus, as a first approximation the standards for women were simply fixed at 85% of the corresponding standards for men. This correction factor was based on typical male-female differences in VO_{2max}, anaerobic capacity, etc., as reported in the scientific literature (differences that are largely, but not entirely, due to differences in body composition). While relatively crude, the accuracy of values generated using this approach appears to be sufficient, as verified by comparison to available data, e.g., known power outputs of elite Australian road cyclists.

The standards are based on the performance capacities of young adults, and thus do not account for the effects of aging (or development). The possibility of developing age-specific standards was considered, but rejected due to the lack of sufficient direct data as well as the complexity of attempting any corrections based on known physiological changes. For example, while VO_{2max} declines by ~0.5 milliliters/minute/kilogram per year (or ~0.35 ml/min/kg per year in women) starting at around age 30, muscle strength and power are generally well-maintained until around age 50, then begin to decline somewhat more rapidly thereafter. Such observations imply that, for maximum accuracy, different age-based correction factors might need to be applied to the aerobic (i.e., 5 and 60 minutes) and the anaerobic (i.e., 5 seconds and 1 minute) standards. It is unlikely, however, that these differential changes with age are sufficient to significantly alter a rider's "profile," and it is suggested that the tables simply be applied "as is" regardless of a rider's age.

ACKNOWLEDGEMENTS

Power-based training levels

By Andrew Coggan, Ph.D. (originally posted <u>October 15, 2001</u>)

In developing the following schema, I have drawn from a number of sources, including Peter Janssen's *Lactate Threshold Training*, *The Cyclist's Training Bible*, by Joe Friel, and the British Cycling Federation's training guidelines (developed by Peter Keen), in addition to my own background in exercise physiology and experience of training and racing with a Power Tap hub since 1999. I would also like to recognize all the people who responded to my initial request for power data, as that has helped me to verify and refine the system. I'll begin by describing the various 'levels' in the system first, followed by a table of the adaptations induced by each, then move to a discussion of some of the details.

INTENSITY	AVG. POWER*	AVG. HR*	PE	DESCRIPTION	TYPICAL WORKOUT
Level 1 *Active recovery*	≤55%	≤68%	<2	"Easy spinning" or "light pedal pressure," i.e., very low-level exercise, so as to minimize muscular force requirements; too low in and of itself to induce significant physiological adaptations. Minimal sensation of leg effort/ fatigue. Requires no concentration to maintain pace, and continuous conversation possible. Typically used for "active recovery" after strenuous training days (or races), between interval efforts, or for socializing.	30-75 minutes
Level 2 *Endurance*	56-75%	69-83%	2-3	"All day" pace, or classic "long slow distance" (LSD) training (note that "slow" is in relation to the very high intensity, interval-centered training programs that were popular when the term was coined in the 1970s). Sensation of leg effort/ fatigue generally low, but may periodically rise to higher levels (e.g., when climbing). Concentration generally required to maintain effort only at highest end of range and/or during very long rides. Breathing more regular than at Level 1, but continuous conversation still possible. Frequent (daily) training sessions of moderate duration (i.e., 2 hours) at Level 2 possible (provided dietary carbohydrate intake is adequate), but complete recuperation from longer workouts may take more than 24 hours.	2-5 hours
Level 3 *Tempo*	76-90%	84-94%	3-4	Typical intensity of fartlek workout, 'spirited' group ride, or briskly-moving paceline. More frequent/greater sensation of leg effort/fatigue than at Level 2. Requires concentration to maintain alone, especially at upper end of range, to prevent effort from falling back to Level 2. Breathing deeper and more rhythmic than Level 2, such that any conversation must be somewhat or very halting, but not as difficult as at Level 4. Recuperation from Level 3 training sessions more difficult than after Level 2 workouts, but consecutive days of Level 3 training still possible if duration is not excessive and dietary carbohydrate intake is sufficient.	1.5-3 hours

INTENSITY	AVG. POWER*	AVG. HR*	PE	DESCRIPTION	TYPICAL WORKOUT
Level 4 *Lactate threshold*	90-105%	95-105%	4-5	Just below to just above FTP, taking into account duration, current fitness, environmental conditions, etc. Essentially continuous sensation of moderate or even greater leg effort/fatigue. Continuous conversation difficult at best, due to depth and frequency of breathing. Effort high enough that continuous cycling at this level is mentally taxing – therefore typically performed in training as multiple 'repeats,' 'modules,' or 'blocks' of 15-30 minutes duration (totaling 30-60 minutes). Recovery between efforts need be no longer than required for a mental break or to turn around. While consecutive days of training at Level 4 may be possible, such workouts should, in general, be performed only when sufficiently rested/recovered from prior training, so as to be able to maintain intensity.	2 × 20 minutes @ 95-100% FTP
Level 5 *Maximal aerobic power*	106-120%	>106%	6-7	Longer intervals (3-8 minute, with 2:30-5:00 recovery) meant to raise VO_{2max}. Strong to severe sensations of leg effort/fatigue, such that completion of more than 30-40 minutes total training time is difficult at best. Conversation not possible due to often 'ragged' breathing. Should be attempted only when adequately recovered from prior training – consecutive days of Level 5 work generally not desirable even if possible.	5-6 × 5 minutes @ 110-115% FTP
Level 6 *Anaerobic capacity*	≥121%	n/a	>7	Short (30 seconds – 3 minutes), high-intensity intervals designed to increase anaerobic capacity. Nearly complete recovery in between. Heart rate not useful as guide to intensity due to non-steady-state nature of effort. Severe sensation of leg effort/fatigue, and conversation impossible. Consecutive days of Level 6 training rarely attempted.	8-15 × 1 minute @ ~150% FTP
Level 7 *Neuromuscular power*	n/a	n/a	**	Very short (<25 seconds), very high intensity efforts (e.g., jumps, standing starts, short sprints) that generally place greater stress on the musculoskeletal rather than metabolic systems. Complete recovery in between efforts. Power useful as guide, but only in reference to prior similar efforts, not FTP.	5 × 15 seconds (2-3 sets)

*As % of average in a 40-60 minute time trial. **Maximal

10 point perceived exertion scale	
LEVEL	**SENSATION**
0	Nothing at all
½	Extremely weak (just noticeable)
1	Very weak
2	Weak (light)
3	Moderate
4	Somewhat strong
5	Strong (heavy)
6	
7	Very strong
8	
9	
10	Extremely strong
**	Maximal

Magnitude of adaptations of by training level.

EXPECTED PHYSIOLOGICAL/ PERFORMANCE ADAPTATIONS	TRAINING LEVEL					
	2	**3**	**4**	**5**	**6**	**7**
Increased plasma volume	✓	✓✓	✓✓✓	✓✓✓✓	✓	
Increased muscle mitochondrial enzymes	✓✓	✓✓✓	✓✓✓✓	✓✓	✓	
Increased lactate threshold	✓✓	✓✓✓	✓✓✓✓	✓✓	✓	
Increased muscle glycogen storage	✓✓	✓✓✓✓	✓✓✓	✓✓	✓	
Hypertrophy of slow twitch muscle fibers	✓	✓✓	✓✓	✓✓✓	✓	
Increased muscle capillarization	✓	✓✓	✓✓	✓✓✓	✓	
Interconversion of fast twitch muscle fibers (type IIb → type IIa)	✓✓	✓✓✓	✓✓✓	✓✓	✓	
Increased stroke volume/maximal cardiac output	✓	✓✓	✓✓✓	✓✓✓✓	✓	
Increased VO_{2max}	✓	✓✓	✓✓✓	✓✓✓✓	✓	
Increased muscle high energy phosphate (ATP/PCr) stores					✓	✓✓
Increased anaerobic capacity ("lactate tolerance")				✓	✓✓✓	✓
Hypertrophy of fast twitch fibers					✓	✓✓
Increased neuromuscular power					✓	✓✓✓

Note: this table is meant to indicate the relative 'potency' of each training level, i.e., the extent to which training at a particular intensity *for a given period of time* is expected to induce the listed adaptations, however, there will always be a trade-off between training intensity and training volume, which is unaccounted for here. With respect to increasing resting glycogen stores, for instance, this means that a whole lot (whatever that is) of training at Level 2 might be just as, if not more effective than much less training at, say, Level 3.

DISCUSSION

Average power during a ~60 minute time trial, or functional threshold power (FTP), provides a logical basis for training levels since it correlates very highly with power at lactate threshold, the most important physiological determinant of endurance cycling performance, integrating VO_{2max}, the percentage of it that can be sustained, and cycling efficiency (although, if you define LT as a 1 mmol/L increase in blood lactate over the baseline observed during low-intensity exercise, the corresponding wattage will be some 10-20% lower than FTP). Indeed, beyond the first few seconds of exercise, the entire power-duration performance curve can be described quite closely using just two mathematical parameters, representing anaerobic capacity and power at lactate threshold, respectively. While shorter efforts might be more convenient, 60 minutes was chosen because it corresponds roughly to the former standard TT distance of 40 km, and because it is only slightly less than that generated during shorter TTs. In theory, one could derive specific correction factors to be used with data during shorter TTs (e.g., power during a ~20 minute TT will be ~1.05 times that of 60 minutes) in order to fit such data into the system, but given individual variation in the exact shape of the power-duration curve, day-to-day variability in performance, and the breadth of the specified power levels, this may only convey a false sense of precision. Along somewhat the same lines, one could base a system on laboratory-derived measures, such as lactate threshold itself, but relatively few people have access to such measurements, as opposed to simply going out and measuring their own power during a TT. Conversely, one could dispense with using one single 'anchor' measurement, and simply reference all workouts back to the maximum power that can be generated for that duration (i.e., Friel's 'critical power paradigm'), however, such an approach requires much more testing than simply using average TT power, while providing little if any practical advantage, in my opinion.

There is about a 3-5% tolerance to each training level, e.g., if your Level 1 recovery rides are up to 58-60% instead of <55% of your "true" threshold (60 minute) power, because you have estimated the latter from a shorter test, it really will not make any difference. Any more than 3-5%, though, and things do begin to change significantly, meaning that the percentages used to set the training levels would have to be adjusted, from which arises the question, "what is the shortest TT during which your power will be no more than 3-5% greater than what you could sustain for 60 minutes?" The answer will vary somewhat between individuals. For instance, my own power for a ~20 minute TT is only about 4% higher than over 60 minutes, so it would work pretty well for me personally, however, my power-duration curve is "flatter" than the vast majority of people out there; one study, for example, found that average power during a 20 km (not 20 minute) TT was 107% of that during a 60 minute TT. Consequently, I am leery of basing training levels (using my system, without any adjustments) on the results from anything shorter than a 30 minute effort.

Determining the appropriate number of levels is somewhat arbitrary, since the physiological responses to exercise really fall on a continuum, with one intensity domain blending into the next. In other words, there really is no clear distinction between high Level 3 and low Level 4, it is all just shades of grey. A compromise was therefore struck between defining more levels, to better reflect this fact, and fewer, for simplicity's sake. The seven levels specified were considered the minimum needed to adequately describe the different types of training required to meet the demands of competitive cycling, so the range within each is somewhat broad, but this should not be a major disadvantage, for several reasons. First, there is obviously an inverse relationship between a given power output and how long it can be sustained, thus, it is axiomatic that shorter training sessions or efforts will be conducted at the higher end of a given range, whereas longer sessions or efforts will fall towards the middle or lower end of a given range. Second, since power is a more precise indicator of exercise intensity than, for instance, heart rate, workouts should still be adequately controlled despite the seemingly large range in power within each level. Finally, as with all training systems, exercise prescriptions should be individualized, in this case taking into account the power the athlete has generated in previous similar or identical workouts . . . the primary reference, therefore, is not to the system itself, but to the athlete's own unique (and current) ability. In this regard, the present classification scheme should be viewed primarily as an overall framework, not a detailed plan.

The suggested heart rate ranges must be considered as imprecise, because of individual differences in the positive y-intercept of the power-heart rate relationship. That is, even when power is zero, heart rate is not, with differences between individual in this 'zero power' (not resting) heart rate significantly influencing the percentage of average 60 minute TT heart rate corresponding to any given power output. Because of this, I do not believe it is really useful to try to derive power ranges from heart rate ranges (as Friel's initial attempt to do so readily shows). Expressing heart rate as a percentage of the range from that at zero power (derived by back-extrapolation of the linear power-heart rate relationship) to that at FTP – akin to the Karvonen formula for heart rate reserve – corrects for this individual effect and allows you to more precisely specify the levels based on heart rate, however, I rejected this approach as simply being too complex, especially given that this is a power-based system. Nonetheless, I have derived guidelines for heart rate (as well as perceived exertion) from power data, which can be used along with power to help guide training.

Guideline values given below for perceived exertion are from Borg's 10 point category-ratio scale, instead of the original 20-point scale that is probably more familiar to most people, since the category-ratio scale explicitly recognizes the non-linear response of many physiological variables (e.g., blood and muscle lactate), and thus provides a better indicator of overall effort. Since perceived exertion increases over time, even at a constant exercise intensity (power), the suggested values or ranges are for relatively early in a training session or series of intervals.

While this system is based on the average power during a workout or interval effort, consideration must also be given to the distribution of power within a ride. For example, average power during mass start races typically falls within the range defined as Level 3 ('tempo'), but races are usually more stressful due to the greater variability (and therefore higher peaks) in power. Similarly, due to soft-pedaling/coasting down hills, the same average power achieved during a hilly (or even mountainous) ride will not reflect the same stress as an equal average power achieved during a completely flat workout. To some extent, this variability is taken into account in defining the various levels, especially Levels 2 and 3 (training at the higher levels is likely to be much more structured, thus tending to limit variations in power), and can be accounted for more precisely using the Normalized Power™ algorithm presented in Part II of this guide. Nonetheless, a workout consisting of, say, 30 minutes at Level 1 (as warm-up in transit from an urbanized area), 60 minutes at Level 3, and another 30 minutes at Level 1 (as warm down) would best be described as a tempo training session, even though overall average power might fall within Level 2 ('endurance').

A final caveat: defining various training 'levels' is only the first step in developing a training plan; what matters as well is the distribution of training time or effort devoted to each level. Discussion of such follows shortly, but two points I wish to emphasize are: 1) I believe that training should be highly individualized, to account for each athlete's unique abilities, goals, and state of development (e.g., age, training background), and 2) compared to some, I tend to place more value in training at Levels 2, 3, and 4 – indeed, what many consider to be 'junk training.' In that regard, my philosophy apparently parallels that of Peter Keen, or at least how his ideas are reflected in British Cycling Federation training guidelines.

Training principles

In any program, certain concepts underlie the training prescription, no matter for whom it is prepared. As you review the next chapter on formulating a training plan, some of the following trends will become apparent.

1. *Individualization.* Training prescriptions must be shaped by the fact that different individuals may respond in significantly varying degrees, and have varying recovery needs, for a given workout or training load. Other factors to be taken into account are age, training status/history, individual characteristics (e.g., strengths and weaknesses, as assessed with Power Profiling), weather, training opportunities (e.g., local availability of roads/trails, terrain, traffic), work schedule and other responsibilities, competitive priorities and preferences (which races you want to do well in, which you want to use for training, and which you *enjoy* the most, since motivation will determine how diligently you train), role within a team, etc.

2. *Periodization.* Training programs are organized by periods of time, each with a specific purpose and emphasis, the aim being to make performance consistent and predictable while preventing overtraining and injury, by applying the appropriate training stress, in the proper amount, at the proper time, thus avoiding excessive and rapid changes in training load and its three variables (frequency, duration, and intensity).

   This process is often likened to the structure of a pyramid, perhaps Aztec or Mayan rather than Egyptian, since the targeted event or period of competition is more accurately represented by a plateau rather than a classic peak. Another analogy might be to higher education, where introductory courses that are broad in scope provide the basis for advanced courses where knowledge is applied more narrowly, as related to a particular area.

   Similarly, physical training proceeds from general (i.e., aerobic) to specific conditioning, while overall training stress must be increased gradually, consistently, and incrementally (see "Progression" below). Typical designations for the pre-season preparation period are "Base" (or "Foundation"), "Build," and "Specialization," followed by periods of competition and recuperation/rebuilding, then finally off-season phases of "Stabilization" and "Maintenance."

3. *Progressive overload.* The story of Milo of Croton from the 6th century B.C. illustrates this principle perfectly. Every morning, according to legend, this greatest of ancient Greek athletes of would lift a young calf overhead and carry it across a pasture. As it grew, Milo lifted a little more each day, until he could carry the full-grown bull.

   Similarly, training adaptation, and hence improved performance, is induced by stress loads that "challenge" the body (exceed existing fitness levels) and fatigue it to an appropriate degree (see Seth Hosmer's fine summary of the workout/recovery cycle for more). As an old and fundamentally useful maxim runs, "Train where you are, or slightly beyond, not where you want to be." In response, and after adequate rest/recuperation, the body's plasticity allows it to "defend" itself, and "supercompensate" or rebound to reach a higher level of fitness. It is in quantifying the imposed stress load, especially at higher/variable intensities, that power-measuring devices and analysis software are most useful.

4. *Balance*. "Variety" is often cited as a training principle, but it is often desirable for training composition to vary little for weeks on end (such as a period of aerobic conditioning), and while it is important to avoid boredom and remain motivated, variety simply for its own sake can produce sub-optimal training.

   Instead, it is better to strive for optimal *balance* in a training program, which depends on the event being prepared for as well as rider characteristics. For instance, if preparing simply for a long, flat, relatively "isopower" time trial, an appropriate training balance will include little anaerobic capacity training, if any at all. At the other extreme, competitors in the 4,000 meter team pursuit must strive for the most nearly "perfect" combination, or comprehensive balance, of anaerobic, maximal aerobic, and threshold capacities, plus adequate neuromuscular power – after a period of rather unvarying aerobic conditioning which is identical to that needed by road competitors.

More generally, periods of competition must be balanced with structured training. Racing (especially criteriums) and group rides impose specific neuromuscular demands as well as wide, rapid variations of intensity that structured training does not normally replicate, leading some to place excessive emphasis on the notion that 'the best training is racing,' however, it is not as effective as 2-3 hour steady-state tempo rides or long (40-60 minute) intervals at lactate threshold in creating consistent aerobic demand and increasing muscle respiratory capacity. After a period of competition, aerobic endurance and lactate threshold need rebuilding through structured workouts.

5. *Specificity.* This exists in varying degrees; stated in the most general terms, to get better at a given activity, you must do that activity, e.g, riding the bike is more specific to cycling than running is, even though both have similar training effects. Thus, "supplemental" training activities (e.g., cross-country skiing, speed skating, running, etc.) should be limited to periods of injury and "active recuperation" during the off-season.

Aerobic conditioning (base training) consisting of prolonged (90 minutes-4 hours), moderately intense, fairly steady-state rides is specific to all road competition, but to optimize performance in a given event, you must train (stress) the systems that underlie it in a way that more closely mimics event demands. Thus, after a sufficient period of base conditioning, training becomes more specific, i.e., narrowly focused or specialized in reference to the task (event) being prepared for as it draws near: to get ready for a longer (30+ minute) time trial, do long (~20 minute) repeats at threshold intensity on a course like the race route (the actual course is best, if possible); to be able to bridge gaps or prepare for prologue TTs, shorter (1 minute) intervals at ~150% threshold power are indicated; to improve at climbing, climb hills of similar grade and length to those you will encounter, etc.

A broader concept may be *simulation*, which includes specificity but goes beyond it in attempting to duplicate race conditions, as well as physiological demands, as closely as possible. What is the general lay of the course, and what are the particular characteristics? Where does the road narrow? What are the road conditions? What is the weather forecast? Is it likely to be rainy, hot, cold, sunny, cloudy? What are the prevailing winds, and where are they most likely to be a factor? What is the elevation range of the race course? What time of day do you normally train, and when does the race take place? Have you prepared in these conditions?

6. *Reversiblility*. Just as fitness gains (adaptations) occur at a certain rate in response to training, so too does the loss of fitness follow a predictable time course in response to inactivity or a reduced training load. This must be accounted for upon a return to training after injury or illness, during the transition to the off-season, and when tapering/peaking, which is defined as strategic manipulation of training variables to enhance or accentuate supercompensation and produce peak performance for selected events.

7. *Evaluation.* Periodic testing, careful record keeping of relevant workout/race data, and meaningful analysis are essential to assessing progress and the effectiveness of any training program.

8. *Rest, recuperation, and diet.* Maximum fitness gains are realized when training stress and recuperation, as well as energy production and intake, are kept in approximate equilibrium, i.e., there is sufficient time and rest between long/intense workouts, plus adequate intake of proper nutrients both during and after each workout.

From a broader perspective, training and competition need to be balanced with some time off altogether (complete rest), as well as periods of "active recuperation" where fitness is stabilized and maintained. Just as large increases in training load are to be avoided, neither should you let yourself fall too far out of condition. A friend recently remarked to me, "but I thought the off-season was the time to drink beer and smoke cigars." **NOT!** Once again, consistency is truly the key.

Towards an annual training plan

"It seemed that all my past life was but a preparation for the hour and trial at hand."

– WINSTON CHURCHILL, 1940

Some may protest that proof is lacking from a scientific standpoint, but there is little dispute among those who practice the *art* of coaching that periodized training works, in that it helps to make performance predictable and helps prevent overtraining, even injury, by budgeting training volume (weekly stress load) and the distribution of time spent at each training level in a measured, gradually progressive fashion. A question more likely to provoke useful discussion might be whether a training program should prepare the rider to peak for one event, for several (and if so, how much time should separate the peaks), or should lead to a more prolonged period where form is maintained like a plateau, or "mesa," to extend the topographic analogy.

While nearly everyone has a race or two they would most like to win, the 'single peak' approach has its drawbacks, since everything points to just one or two events, thus creating too narrow a focus where the success or failure of the entire year may end up being judged on a single performance. Athletes invest untold amounts of time, effort, passion, and money to achieve their goals, making sacrifices in other areas of their lives and even risking health, all to take part in events where the outcome can turn on the smallest events and margins, and where pure chance can determine the difference between triumph and disaster, so it hardly needs be pointed out just how problematical athletic success can be. This is especially true for cycling, and even moreso in the races that count the most, since many other riders have trained to peak form as well, making wins hard to come by even for the most talented. The same passion that inspires hope and belief can turn to an even more profound disillusionment when a single event-goal is chosen, pointed toward throughout the training year, and then is not realized. Finally, and as discussed in more detail shortly, there will almost inevitably be disruptions to the training plan at some point, which may compromise preparation for the targeted event.

The first edition of this guide contained a customizable plan/log, which derived weekly training prescriptions by distributing time among each level of intensity according to percentages of total volume (hours) allotted for the week; from there, daily workouts were suggested, and some examples given. Weekly hours, in turn, were based on time budgeted for 3-6 week periods called "cycles," which in turn were a fraction of "phases" (4-16 week periods), which in turn were a percentage of total yearly hours.

Accounting for training time in this manner may be useful, particularly for riders who are new to quantitative training methods, as it can serve as a starting point for planning out the year, and give a sense of relative proportion, ebb and flow, etc., but the author (Howe) grew skeptical of its underlying approach, and it was for the most part scrapped, for several reasons:

1. for higher annual training volumes, such a 'proportional' method of planning produces unreasonable durations at Levels 4-6, and reducing the percentages allotted to higher intensities means you aren't really taking a proportional approach anyway

2. it may actually *retard* a sense of judgment and proportion; half the time I wouldn't know what the last workout was, or what the next one would be until I checked the plan, due to the constantly-varying nature of each cycle

3. especially among the more obsessive-compulsive, even with a healthy awareness that training must be customized, such a precisely-specified training plan can become an end-in-itself, rather than a means to an end; you become a slave of it, and training is made to fit the plan, rather than the plan being shaped in relation to the demands of the particular event being prepared for, and adjusted in response to personal responses of the rider

4. it is complicated, time-consuming, problematical, somewhat arbitrary, and of questionable value to break down races and longer mixed-intensity rides into time at each intensity level; Training Stress Score™ (TSS), presented in Part II of this guide, has largely obviated this practice, if it ever had much legitimacy at all

So the old log was given up for one that tracks only duration and power in its several varieties: average wattage with 0s (coasting time) and without (pedaling time only), 'normalized' power as defined later on, plus work in kiloJoules, TSS, and workout details.

			Pre-season preparation phase of a sample training plan (road racing emphasis, 8 hr./week limit).					
WEEK		**VOLUME**	**WORKOUTS (TYPE – DETAILS)**					
No.	End	(hr:min)	#1	#2	#3	#4	#5	#6
Period 1: Aerobic conditioning/lactate threshold (base)								
1	1/6	4:20	2 S – 1:00	2 S – 1:00	3 S – 1:00	2 S – 1:20		
2	1/13	4:40	4 S – 20 min @ ~90% FTP	2 S – 1:15	3 S – 1:20	2 S – 1:30		
3	1/20	5:00	4 S – 30 min @ ~90% FTP	2 S – 1:30	3 S – 1:15	3 S – 1:30		
4	1/27	5:20	4 S – 40 min @ ~92% FTP	2 S – 1:30	3 S – 1:15	3 S – 1:40		
5	2/3	5:40	4 S – 40 min @ ~92% FTP	2 S – 1:00	3 S – 1:15	3 S – 1:15	3 S – 1:15	
6	2/10	6:00	4 S – 40 min @ ~94% FTP	2 S – 1:15	3 S – 1:15	3 S – 1:15	2 S – 1:20	
7	2/17	6:20	4 F – 45 min @ ~94% FTP	2 S – 1:15	3 S – 1:15	3 S – 1:20	2 S – 1:30	
8	2/24	6:40	4 F – 40 min @ ~96% FTP	2 S – 1:15	3 S – 1:15	3 F – 1:30	3 F – 1:45	
9	3/1	7:00	4 F – 40 min @ ~96% FTP	3 F – 1:00	7 F – 4 × 15 s × 3; 3 S – 1:30	3 S – 1:30	3 F – 2:15	
Period 2: Lactate threshold/maximal aerobic power threshold (build)								
10	3/9	7:00	5 F – 5 × 5 min @ ~107% FTP	3 F – 1:15	7 F – 4 × 15 s × 3; 3 F – 1:30	3 F – 1:30	2/3 R – 2:20	
11	3/16	7:15	5 F – 5 × 5 min @ ~108% FTP	3 F – 1:20	7 F – 4 × 15 s × 3; 3 F – 1:30	3 F – 1:30	2/3 R/V – 2:30	
12	3/23	7:30	5 F – 5 × 5 min @ ~109% FTP	3 F – 1:15	7 F – 4 × 15 s × 3; 3 F – 1:30	3 R – 2:00	2/3 R/V – 2:30	
13	3/29	7:45	5 F/U – 5 × 5 min @ ~109% FTP	3 F – 1:25	7 F – 4 × 15 s × 3; 3 F – 1:30	3 R – 2:00	2/3 R/V – 2:30	
14	4/6	8:00	5 U – 5 × 5 min @ ~110% FTP	3 F – 1:25	7 F – 4 × 15 s × 3; 3 F – 1:30	3 R – 2:00	2/3 R/V – 2:45	
Period 3: Anaerobic capacity/aerobic maintenance								
15	4/13	8:00	6 F – 8 × 60 s @ ~150% FTP	2 F – 2:00	6 F – 8 × 60 s @ 150% FTP	2 F – 2:00	2/3 F – 2:00	
16	4/20	7:30	6 F/U – 8-10 × 60 s @ ~150% FTP	2 F – 1:30	6 F/U – 8-10 × 60 s @ ~150% FTP	2 F – 1:30	6 F/U – 8-10 × 60 s @ ~150% FTP	2 F – 1:30
17	4/27	7:30	6 F/U – 8-10 × 60 s @ ~150% FTP	2 F – 1:30	6 F/U – 8-10 × 60 s @ ~150% FTP	2 F – 1:30	6 F – 8-10 × 60 s @ ~150% FTP	2 F – 1:30
Period 4: Specificity/taper								
18	5/4	6:45	2 F – 1:30	4 F /U – 45 min @ 100% FTP	2/3 R – 2:00	3 H/V* – 2:15		
19	5/11	6:30	2 R – 1:30	7/6/5 F/H – 4 × 30 s; 3 × 3 min @ ~122% FTP	2/3 R – 2:00	3 H/V* – 2:00		
20	5/18	4:05	2 R – 1:15	3 H/V* – 1:30	6 F – 3 × 45 s; 2 F – 0:45	**3 H/V – <u>1:35 CR</u>**		

Workout type: training level is followed by F – flat; H – hilly; R – rolling; S – stationary trainer workout; U – uphill; V – variable pacing (e.g., a group ride).

Workout details (following workout type): for interval workouts, the number of repetitions is followed by interval duration in minutes and power-based intensity. FTP refers to average power in a 40-60 minute TT from the previous season.

Race types (in **bold**; "*" indicates a training race or 'spirited' group ride): CR – circuit race; CT – criterium; ITT – individual time trial; RR – road race; SR – stage race.

Workouts are sequential, i.e., #1 is done first, then #2, etc.; #3 and #4 are normally Saturday and Sunday rides, respectively. Since Monday is a day off, and there are normally 48 hours in between workouts #1 & #2, they will typically fall on Tuesday and Thursday, but may be done back-to-back, or "blocked" (on Wednesday and Thursday) in the latter portion of the period.

Recovery interval time, as well as ~10 minutes of warm-up/cool before interval workouts, is included in weekly totals above. Interval workouts may be followed by a 40-60 minute Level 1 recovery ride the next day; such rides are not noted above, nor are they are included in weekly totals.

Instead, a simplified approach (based on the Lydiard model) is proposed here, which identifies key weekly workouts and prescribes duration/intensity for each; even though TSS is the preferred means to assess training load, weekly volume in hours is used here, until TSS can be discussed in detail later on. Each phase is given a name intended to identify its purpose. The off-season ("Stabilization/maintenance"), though not detailed here, is for mental relaxation, fun, a break from competition, and perhaps even from riding itself. Cycling is not discontinued entirely; a weekly training load of perhaps half the previous season's peak is recommended, but this is supplemented with aerobic activities such as running, cross-country skiing, skating, etc., and perhaps strength training. Muscles, tendons, and joints are allowed to recover and rebuild from the racing season through this "active recuperation" process, rather than by total rest. Bicycle fit and medical issues should also be resolved at this time.

Controversy persists as to whether resistance training ultimately makes any difference in road cycling performance. Most likely, similar results can be achieved through 'strength training on the bike,' and Level 7 workouts can be done year 'round to maintain neuromuscular power, since the metabolic strain incurred is limited so long as duration remains under 15 seconds per repetition. Nonetheless, if a strength training program is undertaken, conventional wisdom generally holds that multi-joint movements, in sets of 8-12 repetitions, should be used to strengthen cycling-specific muscles without adding mass, with maintenance throughout the year. Weight training is generally not recommended for children under 16, or prior to the closing of the growth plates. For a complete discussion of an annual plan, see Joe Friel's *The Cyclist's Training Bible*.

As laid out above, the purpose of the Pre-Season Preparation Phase (17 weeks) is largely aerobic conditioning, with 3 weeks of anaerobic capacity training at the very end. In the sample plan above, written for a rider with limited training time and an emphasis on hilly road racing, functional threshold power (FTP) testing is carried out weekly throughout Period 1, and of course, each test counts as a Level 4 workout ("training is testing, and testing is training"). Depending on the type and level of activity maintained over the winter, a loss of ~10% in from the previous season's peak FTP value is fairly typical for a mature rider, depending on how the off-season went. In the very first test, just as in the initial, transitional period to power-based training, it may be necessary to use PE and/or HR guidelines to gauge intensity, while monitoring power, but by the second test, power can guide pace. The rest of each week's training time is spent at Levels 2 and 3, and is ridden mainly by PE, plus a couple short Level 1/2 rides (not shown) as needed for recovery.

Power in the weekly FTP test is increased incrementally every other week throughout Period 1, until a target value is reached at the end of the phase. For instance, if 300 W was your peak FTP the previous year, a value of 270 W might be initially assumed or determined by test, then be raised by ~2% (5 W) every other week, so that ~290 W is reached after 9 weeks. Hilly terrain is limited during this period, and each workout should leave you feeling "pleasantly tired," looking forward to the next day's training. Level 7 workouts are added once training moves outdoors in late February/early March, but as previously noted, these can be done most anytime, and are omitted during indoor training only because many stationary trainers do not allow all-out sprinting, due to slippage at the tire/roller interface. Group rides during this period should be controlled, with competitive tendencies firmly curbed. To invoke an old and fundamentally true bromide, "Too often people train as if it were racing, then race as if it were training."

The purpose of the weekly FTP testing is as a check of progress, to calculate TSS, and to provide a reference value that is used to calculate *suggested* interval intensities; as pointed out previously, however, "exercise prescriptions should be individualized, in this case taking into account the power the athlete has generated in previous similar or identical workouts . . . the primary reference, therefore, is not to the system itself, but to the athlete's own unique (and current) ability." A useful practice to help gauge interval intensity is to adopt a standard set of representative workouts for each training level, e.g., 1 × 40 minutes for threshold workouts, 5-6 × 5 minutes for Level 5, and 8-12 × 1 minute for Level 6.

By the end of Period 1, lactate threshold will have been raised sufficiently to allow more productive and sustainable Level 5 training, so a 5 × 5 minute interval workout is substituted for the weekly FTP test in Period 2, to bring aerobic fitness to a peak. While these sessions are meant to be challenging, it should always be possible to complete them without a life-and-death struggle, i.e., with a little bit to spare, and some challenge remaining for the next workout.

Once aerobic development is as complete as possible, 2-3 of weeks of anaerobic capacity (Level 6) training in Period 3 close out the Preparation phase. Since these workouts require at least 48 hours of recovery and impede further aerobic training, they are interspersed with short/easy Level 1 recovery rides, and a weekly ~2 hr. Level 2 ride is scheduled at the end of the training week to maintain aerobic fitness. Terrain for Level 6 intervals may be flat and/or uphill; as always, the exact composition depends on the demands of the event as well as the individual. An old maxim runs, 'Train your weaknesses, race your strengths,' and indeed, events you wish to peak for should be chosen to fit your abilities, but your strengths may become less so if you do not train them, too. Weaknesses should be trained simply to minimize them as much as possible, not with a goal of rapidly transforming yourself into a different kind of rider.

Finally comes a 1-2 week period of specific training, wherein the neuromuscular demands of racing are simulated, followed by a week of tapering off and 'sharpening.' Training races are included for just that purpose – to induce race-specific adaptations, including rapid accelerations, practice sprints, bike handling/pack riding skill, tactical preparation, etc. – not so they will take on a competitive priority in their own right.

The most specific way to prepare for any race is to train on the actual course to be used, but this is often impractical or not possible at all. The next best thing is a course map and profile, but if it is unavailable from the race organizer, the route can be "remote-viewed" with http://gmap-pedometer.com, the TopoFinder feature at Trails.com (fee required), or with Topo! interactive terrain-mapping software. Here is a profile of a local 36 mile circuit race held annually on the second or third Sunday of May, used by some as one of their "A" races for which they attempt to peak, and for which the above sample program is written:
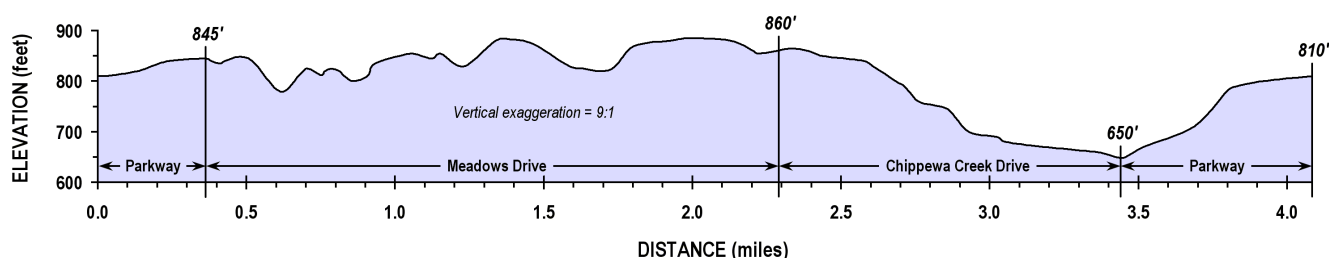
The entire course lies within a heavily wooded park. From the base of the climb to the start of the finishing straight, 120' in elevation is gained in 0.3 miles, a grade of 7.6%. The 'backstretch' is technical, with numerous curves and short but steep climbs, while the downhill has a few very gradual curves, allowing unbroken descent, and the finishing straight is a 200 meter false flat which heads southwest, into prevailing winds. The remainder of the course is largely sheltered from any wind. Training in the two weeks prior would ideally be structured so as to reflect these characteristics. Note that while duration during the week of the race is ~55% of the week before, frequency is only one day less, and intensity may actually be *increased* slightly.

Miscellaneous notes on training

SPRINT AND INTERVAL WORKOUT TIPS

A distinction can be drawn between "training" and "using" the phosphagen system. The former implies that training adaptations from very short (<12 seconds) duration exercise are somehow linked to the rate of energy *production*, and although some studies show increased levels of resting phosphocreatine (PCr) stores as a result of sprint training (in rats), the change is small, on the order of 10% at most. Moreover, the enzyme responsible for PCr breakdown/ATP synthesis, creatine kinase, does not alter its overall activity in response to training, so the inherent limited adaptability of the phosphagen system, rather than the short durations at which it is trained, makes it much less responsive to training than, for instance, VO_{2max} and lactate threshold.

On the other hand, the term "neuromuscular power" (as adopted from Dr. Jim Martin) places the emphasis on factors determining the rate of energy *utilization*, i.e., neural recruitment, muscle mass, speed of muscle contraction and hence rate of ATP hydrolysis, etc., and in fact, most (if not all) of the adaptations leading to improved performance in a rider's initial "jump" are related to increases in these factors, rather than in energy production. Thus, what is actually being accomplished is the training of neuromuscular power, even though you have to use the phosphagen system to do so.

Furthermore, it is difficult to pin down the precise moment at which depletion of phosphocreatine becomes an important factor contributing to muscle fatigue, as there are clearly other mechanisms that are likely just as, if not more, important in causing the early and rapid decline in muscle power, such as failure of excitation-contraction coupling (motor nerve fires, but muscle doesn't respond); again, regarding the *maximal* power that may be generated (versus the ability to sustain it), the issues are how big the working muscles are, how rapidly they can contract, and how well your motor system can activate them, not the availability of energy (assuming, of course, that we are discussing an effort which starts from rest). Combine this with the fact that the phosphagen system is at best minimally trainable, and it emerges why thinking in terms of "neuromuscular power" instead of "anaerobic (phosphagen/alactic) power" is desirable. Is this simply semantics? In a way, but recognizing the distinction can help put the pieces of the puzzle together.

So then, as the conventional wisdom goes, sprinters are born more than made, and indeed, *peak* sprinting power depends more on genetics, and less on training, than any other functional test, but just as it was important previously to evaluate each of the energy systems in the context of endurance exercise, so it may be useful here to distinguish between sprinting in road races vs. criteriums. For instance, Jeff Braumberger, a local elite rider and former professional who clocked 53:16 for a 40 km time trial without aerodynamic equipment in 1986, is sometimes let down by his sprint in criteriums, even against some Cat. 2 competitors, if he is unable to 'weaken' them sufficiently or break away. On the other hand, he recently won the Ohio District Road Race rather easily in a 3-up sprint, since he had the best 'kick' left over among the climbers that the course had selected for. Again, despite the traditional "train your weaknesses, race your strengths" advice, shortcomings should be trained just enough to minimize them in relation to principal opponents, so for example, a natural climber/time trialist should not aim to transform himself in to a field sprinter, at the neglect of his strong points.

If duration is kept under 15 seconds, sprint (Level 7) workouts can be done at any time during the year; since stored ATP is the primary fuel source, the metabolic stress is limited, as indicated by the fact that lactic acid is not produced in any significant amount. Recovery in between repetitions should be complete (at least 4 minutes), as the goal is to maximize the power generated, and such workouts are usually scheduled early in the training week, just prior to an endurance or tempo ride. As with other intense workouts, they should be tailored to the event being prepared for. Is the finish up or downhill? Does a tailwind or headwind prevail? (Be sure to note this during the race.) Is there a landmark that lies at the desired distance from the finish where you want start your sprint (especially important in a point-to-point race)? As [Adam Myerson](#) has pointed out, someone with a high maximum wattage should typically go later, i.e., follow wheels, save their burst, and come off a wheel at the last moment, whereas a rider with a lower maximum but a good average sprint wattage needs to go early and try to hold on until the finish. Additionally, positioning, teamwork, timing, and other factors will influence the result as much as peak and average power in the finishing meters, but further discussion of sprint tactics and technique is beyond our purposes here.

There are several component parts to a sprint: the initial "jump," when the resistive load is highest (from the change in kinetic energy, or so-called 'inertial' force, due to rapid acceleration); the wind-up, or middle portion, when acceleration continues, but slows, and speed is brought up nearly to maximum; and the final stage, when cadence and speed are at their highest, but power is declining (each of these phases is analogous to the start/drive, transition, and maintenance phases of 100 and 200 meter sprints in track and field, respectively.) Traditionally, advice for how to structure sprint workouts has been based on what type of sprinter you are, and which aspect you are trying to improve. Hard jumps from a low speed (walking pace), in a high gear or on an uphill grade (not too steep), lasting under 10 seconds, were recommended to improve initial acceleration and maximum power, while 'undergear' efforts (or in a normal gear with a tailwind or downhill), of ~25 seconds, might be prescribed to improve legspeed and pedaling technique (neuromuscular coordination) at high rpm for the final part. Another related drill is to 'jump' at high speed out of another rider's slipstream, in the latter stages of a 25 second effort. Over against this approach is the view which holds that a skill is best learned when it is practiced as a continuous whole, to be discussed further in a later edition of this guide.

<center>*   *   *   *   *   *   *</center>

Perhaps in no other aspect of quantifying exercise intensity will a powermeter have greater impact than on pacing, during both interval training and time trials, especially in the initial stages of each; the delayed response of PE and HR, coupled with the anticipation of intense effort, make it all too easy to start out too hard. Fig. 6 depicts pacing profiles of the author's initial and subsequent 30-minute time trial tests with a powermeter, and the difference is dramatic. Use the average wattage display in interval mode to ease into intervals and TTs; average power at 1 minute should be ~10% under the planned final average, and ~5% under after 5-minutes. By that time, PE will have caught up to the effort, with the risk of going too hard subsiding correspondingly. Don't worry about starting too easily – worry about being consistent in the final stages of the last interval.

(As previously noted, new powermeter users are almost invariably surprised at how "jumpy" the current power display is, with some even concluding it to be in error, and although this variability may be partly due to instrument artifact, the energy demands of road cycling do indeed fluctuate rapidly, frequently, and widely, even at relatively constant average power on flat terrain. Thus, a rolling average of 30-60 seconds is preferable to instantaneous wattage for pacing, but some models lack this capability, and an overall average is the goal for each interval, anyway. Keep in mind, though, that the interval feature gives a *cumulative* average, so as the interval proceeds, this value becomes more and more 'weighted,' i.e., based on an increasing number of samples, and is therefore progressively less reflective of change. For instance, if you average 300 W for 15 minutes, but drop to 299 W in 1 minute, your average for the 16th minute was just 284 W.)

Begin interval workouts with ~10 minutes at Level 1 progressing to Level 2, followed by ~5 minutes of Level 3/4, and then a brief period to pedal lightly and drink a bit. The week's first interval session should be the shortest and most intense, while "mixed intensity" interval workouts (e.g., Level 6/5/4), should progress from the shorter, more intense efforts to the longer ones, which helps keep intensity up throughout the workout (uphill efforts may be performed slightly higher than those of similar duration on flat terrain). At least 10 minutes of Level 1/2 cool-down time should follow each Level 4 or 5 workout, with perhaps 15 minutes allowed after Level 6 workouts. In addition to post-workout data download and analysis, interval duration/average power, PE, and other appropriate data should be recorded for future reference.

Traditionally, recovery time between work and rest intervals has been a function of heart rate, but it does little to indicate if you are ready to go again, and sometimes a complete recovery is not desired anyway. A better way of determining recovery is by muscle energetics. For both Level 4 and 5 intervals, all that really counts is what you do during the work interval; you are only trying to keep the intensity up, and not manipulating the work:recovery ratio to alter metabolism. No more than a brief mental break is really necessary for Level 4 intervals, and taking more than the minimal amount of rest really serves only to prolong the workout. Use whatever is convenient, such as how long it takes to turn around on an out-and-back course and take a brief drink. With Level 5 efforts, given that the half-life for phosphocreatine resynthesis is about 20-30 seconds, muscle energetics should be almost completely recovered in 2.5 minutes, or ~5-6 half-lives. Other factors, of course, contribute to fatigue, and it may eventually accumulate, such that stretching recovery to 5 minutes will allow power levels to be maintained in later efforts, but using longer rest periods throughout the entire workout is unlikely not allow overall intensity to be raised significantly.

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Level 6 sessions are more complex. If the purpose is to work on both musculoskeletal power and anaerobic metabolism simultaneously, or if you are in a peaking phase, then longer recovery periods may be useful, as they will allow you to maintain the highest overall power. What is long enough is a matter of feel, developed through experience, and will vary with the individual, as well as practical considerations such as route characteristics (e.g., how long it takes to get back down and turned around during hill repeats.) On the other hand, if you are trying train anaerobic capacity alone, then incomplete recovery may be the way to go, so as to "stack up" the metabolic stress, but with *too* short a recovery, the average power may be too low, and it ends up being a quasi-aerobic effort. So the test of whether recovery is sufficient is simple . . . if it is hard, but still possible, to complete the last repetition within ~10% of the third rep or so, then wattage was correct, and recovery was adequate. If average power falls significantly before the last effort, then either it was too high, or recovery was too short, or perhaps some of both. Lastly, if you can complete the workout too easily, then the wattage was probably too low. Thus, pacing is important *throughout* the full workout (just as *within* a single effort), so for instance, if you feel strong in the first interval of a workout, stay at the planned wattage and save a little for later on, trying to finish strongly, rather than fade in the last repetition. The exception is Level 6 intervals, when done only to increase anaerobic capacity, which suggests they be done "all out," so that power is very high initially, then is allowed to decline during the interval.

<p style="text-align:center">*   *   *   *   *   *   *</p>

Fig. 12 is an attempt to show the relationships of physiological strain (i.e., response to training stress), maximum tolerable or achievable training duration/volume, and the training effect (in terms of the increase in muscular metabolic fitness/functional threshold power) as a function the training intensity (expressed relative to FTP).

Obviously, as exercise intensity increases, so too does physiological strain, in a quasi-exponential fashion, whereas the maximum duration/total volume of training that can be performed decreases in essentially a mirror-image manner. The increase in metabolic fitness, however, approximates an inverse-parabolic function: at very low intensities there is no overload, and hence no training adaptation, while at very high intensities, the adaptations induced are either qualitatively different (e.g., true sprint training), or, due to the ever-increasing physiological strain, you simply cannot do enough total volume to achieve the same degree of overload and resultant physiological adaptation (increase in FTP). In between these extremes you are, to a large degree, simply trading volume for intensity and vice-versa, with little impact on the overall magnitude of the training effect (the colored zones are simply meant to describe the general nature of these relationships for purposes of illustration, and should not be held to hard and fast). Even so, there tends to a "sweet spot*," seemingly around the border between levels 3/4, where the combination of intensity and volume is maximized while avoiding an excessive increase in physiological strain, and it is interesting to note this is where many people like to train when they fall into the mode of banging out hard-ish rides day-after-day, yet this is precisely what is often considered the classic "no man's land" in terms of training intensity. At least one coach, however, having had great success with his athletes by training them at "sub-Level 4," has suggested that the preceding schema of training levels be modified to include this additional level, or that Level 4 be split such that the lower part results in the largest increase in threshold power, with the upper part to be avoided until you need to squeeze out the last per cent of improvement. While such a suggestion appears premature, it does seem that once you are above FTP, the increase in physiological strain/reduction in training that can be performed tends to outweigh any benefit from increasing the intensity, such that ~102-108% of FTP is something of a grey zone, and the relative efficacy of ~10 minute intervals seems questionable.

Two final cautions: the above referenced figure shows the *absolute* effectiveness of Level 3/4, in that you get more of an effect since the stress is lower than Level 4, and you can go longer (plus you get the added benefit of more glycogen storage). In fact, you must you MUST go longer to get the added effect, so if you only have an hour to ride (or if trying to wring out the last few tenths of a per cent in improvement just before an event such as a TT), a 2 × 20 interval workout would be a better choice since it gives you more "bang for the buck," i.e., is relatively more time-effective. Secondly, it is important to realize that stress, duration, and training effect are plotted as a function of percent of FTP, not Normalized Power (as explained in Part II of this guide). Although the two often get used interchangeably, when there is a large difference between them (i.e., when, power is highly variable), there will be less training effect.

Thanks to Frank Overton for suggesting the term 'sweet spot.'

OVERLOAD: AEROBIC AND NEUROMUSCULAR

"Racing is the best form of training," runs an old and oft-repeated maxim, and much was initially made of the wide and rapidly variable nature, not simply of road cycling (as contrasted with an indoor trainer or constant-load ergometer), but of road racing in particular, and criterium racing most outstandingly, as becomes apparent from analyzing power data collected during competition. Focusing excessively on this phenomenon, however, ignores what we already *do* know about the effect, if any, of variations in power on both acute and chronic adaptations to exercise.

The latter point is key. For example, one possible conclusion that might be reached after carefully analyzing power data files is that the variability of energy demands while racing is so important that it must be duplicated in training as closely as possible (e.g., by motorpacing), but we know already that conventional training works well as preparation for racing, especially road and stage racing. That in itself suggests that perhaps variability is not nearly so important, and/or that there is something else going on.

In fact, both are true. First, consider what happens when you start lifting weights: you get stronger very quickly, before any significant hypertrophy can occur. That is evidence of the extent to which performance can be improved through changes in motor control, and how rapidly such adaptations can occur, so it makes sense that just a few weeks of "sharpening," (either specific training, training races, or races used as training) is enough to prepare for racing, even if you have just been plugging away, putting in steady-state miles for weeks on end beforehand. Conversely, though, highly-variable training for months on end will not prepare you adequately, for the simple reason that such efforts entail using your muscles the way they "want" to be used, i.e., intermittently, relying on bursts of glycogenolysis for energy, even in Type I (aerobic) fibers. This creates much less of an overload condition in terms of metabolism, because you keep giving your muscles a break, during which time they resynthesize some creatine phosphate, refresh O_2 stored locally within the myoglobin, etc. Logically, if you want to induce an increased capacity for aerobic energy production (i.e., higher mitochondrial density), you need to make the muscle fibers work *continuously* for a longer period of time than they are used to, or "want" to, thus forcing them to adapt. This is especially true of the fast-twitch fibers that have a lower inherent aerobic capacity to begin with.

As affects training, this indicates much time spent right around lactate threshold, since that is the point at which fast-twitch fibers are brought into play, plus many long, relatively steady miles which fatigue the most aerobic, most easily recruited muscle fibers, requiring use of those further "up the spectrum;" and perhaps manipulations that further enhance fast-twitch fiber recruitment, such as extended low-cadence/high-force ("overgear") intervals, or the classic approach of going hard at the end of a long (3½+ hour) Level 2 endurance ride. What it *doesn't* mean is a lot of short intervals, motorpacing, or racing, since, while they can be highly effective at increasing muscle power and even VO_{2max}, each is likely to be less effective at increasing the respiratory capacity of the recruited fibers, simply because the "energy crisis" that is the signal to enhance mitochondrial formation is just not sustained long enough, and indeed, this is borne out by several studies in the scientific literature.

Thus, despite the great importance of specificity, racing is not **primarily** or **exclusively** the best training. The 'race twice a week and everything else easy' dictum followed by many riders throughout the year results in a gradual decline in aerobic fitness, and inserting a 'recover and rebuild' period of tempo rides plus Level 5 interval workouts at the appropriate time in the training year, or even in place of the regular mid-week training criterium, can be very beneficial.

HI-INTENSITY CONFUSION: THE MISUSE OF HEART RATE

It is highly unfortunate that HRMs preceded powermeters to market, since heart rate seems to have become deeply entrenched in the popular mind as the supreme measure of how hard the body is working, indicative of an often undefined, near-mystical "whole body stress." In fact, the response to exercise stress, or physiological strain, is best assessed, first, by the stimulus (work load) itself, especially through the normalizing algorithm presented in Part II of this guide, while being continuously correlated with perceived exertion, which reflects more physiological responses than HR, and does so more reliably. HR tracks well enough with power at lower intensities, where it provides apparently more "stable" feedback than power, due to the cardiovascular system's slow response to the rapid changes in intensity so characteristic of road cycling (the half-life for an increase in

heart rate following a step-change in power is 20-25 seconds, and the effect is accentuated slightly by the smoothing algorithms programmed in to the HRM), so it can be useful for relatively steady-state Level 1/2 training, but as wattage increases, say, beyond ~75% of FTP, the correlation between HR and power becomes weaker, and HR becomes less and less reliable an indicator of physiological strain.

Factors documented to elevate HR include decreased barometric pressure at higher altitudes, environmental heat, dehydration/cardiovascular drift, lack of sleep, time of day, medication and diet (e.g., caffeine), recent illness/infection, variability of intensity and terrain, psychogenic factors (e.g., nervousness), increased cadence, and possibly even position on the bicycle, such as when time trialing. On the other hand, it is normal for HR to be depressed by recent heavy training, and by accumulated fatigue/lack of recovery (overtraining). Finally, mere day-to-day variability in HR can be up to 4%, whereas power is normally reproducible to ±2% or even less. Thus, training by HR, while merely monitoring power, largely robs any power-measuring system of its most important benefit, namely, to guide training by precisely quantifying and administering the exercise load. The choice of title here is deliberate: we should not simply train *with* power, as though it were a mere adjunct metric, one supplemental gauge of intensity among several others; rather, it is advocated to train *by* power, i.e., with the appropriate interpretative tools, it is the *arbiter supreme* of training prescription, execution, and evaluation.

One prominent coach even goes so far as to advocate using power information purely in a postscriptive manner:

> *"Watching your wattage during the course of a ride is not very useful. Wattage fluctuates quickly and often; heart rate is a much better gauge of workload during a workout. Power becomes useful when you are sitting in your living room after the workout. I recommend purchasing a powermeter that can be downloaded to your home computer. Downloadable powermeters help you see how your power output changes with your heart rate, speed, and cadence during the course of a single ride, a few weeks, or several months."*

On he blathers about a world-class triathlete of his who made "astronomical" gains of over 9% in his 20-minute repeats at a given HR. In fact, a 10% increase from off-season lows is not extraordinary, even for elite athletes.

This approach is even worse than a 'train by HR, monitor power' method, since it defeats the pacing function of an on-bike power-measuring system entirely, effectively relegating it to a mere testing device that does nothing to guide training. You might as well just get tested periodically in a lab, and save the cost of the power measuring system and PC, since they will do nothing more than give a nice feeling that your power is better for a given HR, which is of questionable benefit, due to the variability of HR at a given power output (indeed, this is likely why the "astronomical" 9% gains were observed.) It is true that power on the road varies rapidly and widely, and because of this, it is more useful to view a cumulative or 30 second rolling average during workouts, rather than the current power display (as is apparently referred to above), but whichever approach is used, both are more precise and more useful than HR as measures of the stress load being imposed. Finally, "see[ing] how your power output changes with your heart rate, speed, and cadence" makes the classic, fundamental error of confusing a dependent variable (HR) with an independent variable (power), i.e., the response with the stimulus. It's the other way 'round: heart rate, speed, and cadence should be interpreted in the light of changes in power.

It is indeed extremely important to have feedback from the body to gauge its response to a given work load, but the point that die-hard HR advocates seem to miss is that our brains are already equipped to integrate information from a variety of sources, not just that provided by instruments which measure power and heart rate. These other sensors have been developed by eons of evolution, and do a pretty good job all by themselves, especially if frequently "calibrated" by reference to an external standard (i.e., a powermeter). In fact, that was the whole premise behind Gunnar Borg's original 6-20 point rating scale for PE: the values are simply the HR expected for the average young untrained person exercising at that intensity, minus the trailing zero. Although useful, this is not quite the best description of how physiology works, since it does not track well with non-linear responses (e.g., blood lactate, a marker of muscle metabolic stress), only linear ones such as heart rate (Fig. 11), so Borg eventually issued a revised 0-10 point category-ratio scale.

Thus, ignoring HR altogether will likely help develop and refine a sense of PE in relation to power. What matters, though, is the practical difference that it makes in training, and how you respond to "how it feels" for any wattage should be determined mainly from a functional standpoint, that is, whether you can complete the workout as planned (a careful, gradually progressive, periodized program is assumed here). If PE is higher than

normal or expected for a given wattage, some say pack it in right there, but the recommendation here is to try to complete the workout, if possible. Whether you "bag it" based on how you feel (even if able to finish) depends on any number of things: how early it is in the workout, your level of motivation, whether you will be able to rest adequately following or have a particularly hard day ahead, where you are in your present training cycle/year, what you have planned for the weekend, etc. Even cutting back slightly (2-4%) on the wattage and making it through the planned duration, if not at the planned intensity, is generally better than just going home, since each workout is (or should be) built on the gains of the last, and you don't get better by not training. Knowing when to quit early is something of an art, but the decision is informed little, if at all, by HR, which will likely just provide comforting confirmation or else confound what power and PE levels have already told you. The proof of whether it was wise to continue or not will come in subsequent workouts.

For instance, in a well-paced, 2×20 minute interval workout at perhaps 100% FTP, the first repetition is usually strenuous, but not a major challenge to complete. Just as HR drifts upward for a given power output as duration wears on, so too does PE increase, and the effort should start 'getting to you' with ~3 minutes to go in the second rep, as you wonder a bit if you can make it to the end, think about how good it will feel to be finished, start counting down the time left and telling yourself "2 minutes . . . get through the next minute and the last one will take care of itself," etc. Watch average wattage closely and try not to fade; mentally, it's important to finish strong.

On the other hand, if you do the best you can, but lose a few Watts, as happens occasionally, it likely means you was just a bit below par, but if you fade in the first rep, then either the wattage was too high, or else there is something wrong physically, especially if it was a workout I have recently been able to complete. Using the preceding perceived exertion scale, referenced to functional responses in the latter stages of tempo and interval workouts, may be helpful in evaluating workout duration and intensity:

4 – Workout easily completed. Chosen intensity or duration either too low (easy) or too short, respectively, such that average power rose (or could have been raised) substantially throughout the workout, or else power/duration were intentionally set low due to training status, recent layoff, illness, etc.

5-6 – Workout finished with some difficulty towards end of session; completion somewhat, but not seriously in doubt. Intensity/duration about right, as power remained steady or increased gradually throughout, and could not have been sustained much or at all beyond end of workout.

8 – Extreme difficulty and serious doubts about ability to finish encountered during middle and latter stages of session. Intensity/duration too high/long, or else recovery inadequate, since power either faded during last interval, or workout not was quite completed.

10 – Workout terminated well short of goal (early or middle of session) due to illness or accumulated fatigue, or intensity/duration not being sustainable (unrealistically high/long).

Taking this idea further, here is an attempt to differentiate the physical sensation(s) of several causes of fatigue (reduced power-generating capacity), with the means of prevention in parenthesis:

1. low muscle glycogen/blood glucose ("bonking") during longer rides/races – localized sensation of stress/fatigue in quadriceps area (knowledge, judgment of adequate quantity/correct timing of carbohydrate feeding)

2. high blood lactate ("blowing up") during TTs, intervals, breaks, chases, and when bridging – discomfort ("burning") sensation localized in chest and legs, plus increased breathing rate (knowledge/judgment of proper pacing, aided by feedback from powermeter)

3. environmental heat stress/elevated core temperature – overall perception of heat, as well as visual signs of excessive sweating (awareness of heat index, plus knowledge/judgment of adequate fluid replacement – the "drink before you're thirsty" rule – plus external cooling, i.e., "drenching" as possible/available).

Again, the ultimate test of how accurately training has been structured is whether workouts can be consistently completed throughout a gradually progressive, periodized plan. Occasionally failing to finish a workout due to the chosen wattage and duration being too high is not a disaster; after all, in order to find your limits, it is sometimes necessary to exceed them. Still, integrating PE with power data is essential to optimal energy distribution and consistent, productive steady-state workouts which allow aerobic development to proceed almost indefinitely.

So then, to gauge and guide training intensity, the choice here is power, in partnership with perceived exertion; heart rate may have some uses, but does not merit the cult status to which it has been elevated. Justifications usually run something like "Power is important, but you need heart rate too," (i.e., the "data is good, and more data is better" argument), and "Heart rate tells you how hot your aerobic engine is running for a given power output; training by power alone is like the rev-head who always runs his engine at 800 horsepower and pays no attention to rpm." If HR is substantially different from one workout to another, it is unlikely that total energy expenditure would ever be more than perhaps 5%, and there may not any difference at all (e.g., lack of sleep will elevate submaximal heart rate, but has little if any effect on efficiency.) Old habits die hard, though, and onward it marches still, a beast that goes on fighting after having its head cut off, to the extent that its more persistent advocates seem obsessed with it, true believers clinging to a security blanket on to which they project fears ("I've overtrained!" or "I've peaked too early!") and hopes ("I'm on form!") beyond anything remotely reasonable, like a kind of Rorschach Test.

MANAGING FATIGUE

Fatigue and overreaching are often confused with overtraining, the distinction being that the latter is a *long-term* decrement in performance which requires weeks or even months to recover from, whereas the former is a simply a part of the workout/recovery cycle. Irritability, disrupted sleep, lack of enthusiasm, and significant changes in HR (whether waking/resting or at a given intensity) are all frequently identified as symptoms of overtraining, but it is common for one or several of these factors to appear acutely in the course of a season after races and interval sessions, or towards the end of a period of high stress (high volume/intensity); it is the point at which such signs persist and are accompanied by diminished performance (as determined by decreased power-generating capacity), that is critical to determining when added rest is needed.

Overtraining is most effectively prevented by avoiding large, sudden changes in training volume, as well as excessive competition, both of which go without saying in following a periodized, progressive plan. "Non-training stresses," e.g., of the environmental/emotional variety enter in to the equation too, as overall stress is balanced against "recovery factors" which include diet and the amount and quality of sleep/rest; the focus of this article is on the latter two, and fundamentally, minimizing fatigue is a matter of knowledge, attention to detail, planning/thinking ahead, time management, and decision-making.

► Interval workouts should generally be at least 36 hours apart, and 48-72 hours before competition, with an intervening Level 1 'recuperation ride' of 40-70 minutes, preferably in the early morning if during periods of high heat and humidity. Cue yet another concise summary quote from the Wattage Forum:

"Over the course of an intense or long workout, damage occurs in the area under the greatest stress, i.e., the working muscles, causing fluids to 'leak out' of the muscles and accumulate within and between cells. Afterwards, by necessity, the body must be 'particular' about where it directs blood, since there are far more blood vessel routes than the heart can manage with all of them dilated, so blood flow to the working muscles is greatly reduced once the workout is over, and oxygen demand returns to normal levels. A recovery ride causes vasodilation in the area of damage, along with an influx of blood that carries repair substances. It also creates a gradient to remove waste products through diffusion.

The key to recovery rides is to keep intensity at a level that doesn't stress the system enough to cause additional damage, and since a system not stressed is a system not being trained, recovery rides are not considered to cause any training adaptation. The point isn't to generate minimal watts – that can be achieved by not riding at all – but to demand just enough work (~50-60% of FTP) at the muscle site to elicit increased blood flow response to elevated oxygen demands." –Terry Ritter

Just as with interval workouts, where one rider's specific training objectives may not match another's, so too do easy days lend themselves to riding alone unless a cooperative partner can be found, but all too often, competitive instincts take over, and a hammerfest ensues. Put another way, it's common to train as if it's a race – and then race as if it's training. Have the discipline to go easy enough on your easy days, so that you can go hard enough on your intense days, and realize the maximum benefit (adaptation) from them. As a rule of thumb, you should feel fresh and rested two or three times a week, preferably before each intense workout or race. Interval intensity may be reduced during high-volume weeks, but increased in a taper week. **Always** include 1-2 days per week of rest or recovery rides.

► Hydrate and feed adequately before, during, and after all workouts; "Drink before you're thirsty, and eat before you're hungry" is not a cliché, but a sound practice that accurately reflects the body's delayed hormonal stimulus to cravings. Weight loss should be limited to no more than 2% for any ride, and every 1 lb lost should be replaced with 15 oz. (450 ml) of fluid afterward. ~0.6-1.0 grams carbohydrate (CHO) per kilogram of lean body mass (LBM) should be ingested in a 6-8% solution for every hour of intense exercise, or about 24 oz (710 ml) for a 70 kg rider, in 3-4 episodes each hour, commencing at ~45 minutes in to the ride (on long rides in locations where only water is available, powdered Gatorade carries well in a 2 oz container, such as a travel size bottle of shampoo, which holds just enough for a 24 oz bottle.) Keeping to such a schedule may be more problematical in competition than training, and although it is possible to reverse fatigue resulting from lowered blood glucose ("bonking"), this condition should be avoided at all costs, since it 1) forces the body to use more protein, 2) compromises the immune status; and 3) reduces the effectiveness of any workout during which it occurs. Further, repeated bouts of exercise-induced hypoglycemia within a certain timespan increases susceptibility to it happening again, setting up a vicious cycle and causing even more disruption to training.

► Proof may be lacking that solid foods prolong endurance vs. CHO beverages alone, however, if they are desired, a useful practice on longer (4+ hour) rides/races may be to consume low-glycemic foods early in the ride, perhaps even a sandwich with some thinly sliced meat, then progress to higher-glycemic snacks later on, as well as post-exercise. For an explanation of the Glycemic Index (GI), Glycemic Load (GL), and a listing of these for numerous foods, see http://www.mendosa.com/gi.htm.

► An important time for CHO intake is immediately after intense or long workouts and races. No more than 20 minutes post-exercise, ingest ~1-1.5 g of CHO per kg lean body mass plus 0.25-0.4 g/kg protein, perhaps followed by a light massage, shower (if on the road, take a washcloth and cold water for rinsing), and a nap if possible, then a meal with CHO-protein in the same amount the next hour, with vitamin B, C, and E supplements afterward. Pamper yourself after and in between hard/long workouts!

► Depending on daily training volume, total food intake each day should be 30-64 kcal per kg of lean body mass (LBM), or equivalently, 14-29 kcal/lb. There are 4 kcal per gram of CHO and protein, and 9 kcal/g of fat; so for a diet in the recommended caloric balance of 65%-20%-15% CHO-fat-protein, these percentages translate to 5-10.4 g/kg CHO, 0.7-1.4 g/kg fat, and 1.1-2.4 g/kg protein. Thus, a rider with an LBM of 60 kg would require 300-432 g CHO, 42-84 g fat, and 66-144 g protein. Caloric balance may be altered slightly (+5%) in favor of CHO during the 2-3 days prior to competition, further, in actual practice, individuals with higher training volume should cap daily fat consumption at ~1 g/kg, and protein at ~2 g/kg so up to 12 g/kg CHO may be needed to meet remaining requirements.

On-line diet and fitness journals are available at http://www.lifestylestech.com/page2.html (small fee required), http://dietpower.com, and http://www.fitday.com (free). For a complete food calorie database, try http://www.calorieking.com or http://calorie-count.com.

► The value for external work performed (in kilojoules) provided by a powermeter can be used to approximate energy consumption in kcal, however, this requires that gross mechanical efficiency (GME) be determined by a lab-administered VO_{2max} test; for 1 kJ of work performed at a GME of 19%, 1.26 kcal are burned; 21% – 1.14 kcal; 23% – 1.04 kcal; 25% – 0.96 kcal; 27% – 0.89 kcal. This result can be used to adjust diet according to the caloric requirements of a workout, in addition to basal energy expenditure (BMR), in kcal/day, as estimated from the Harris-Benedict Equation:

$$BMR_{\male} = 66.473 + 13.752m + 5.003h - 6.755a; \quad BMR_{\female} = 665.096 + 9.563m + 1.85h - 6.755a$$

where m = body mass in kg, h = height in cm, and a = age in yr.

Even if weight losses are kept within a reasonable range (<4% a month) and protein intake is maintained or increased, it is still likely at least some lean body mass will be lost, causing a decline in absolute VO_{2max}. Thus, it is overly simplistic to believe that performance can be easily enhanced by losing a few pounds. Without question, losing what is truly excess weight very gradually may improve performance, particularly on extended climbs, but you must titrate things very carefully. Energy balance is a very important determinant of nitrogen balance, and losing only fat is a difficult thing to do.

TRAINING INDOORS

Nearly everyone ends up training indoors only as a dreaded last resort, when weather or schedule preclude an outdoor ride. Working out inside, however, produces some subtle differences and benefits, and may even be a preferable alternative (or supplement) to training on the road.

The most basic (and obvious) difference lies in the nature of the resistive load imposed. Although most stationary resistance trainers have a flywheel, few are heavy enough to faithfully simulate the kinetic energy changes so typical of road cycling (or most any form of "free range" activity), nor do most load simulators replicate the almost constant changes in grade and terrain experienced outdoors (a flat road and no wind being practically non-existent in the real world). Each factor contributes to the wide and rapid variation of power output outdoors, even during relatively steady-state efforts. Stationary trainers, on the other hand, even when not in "erg" mode, impose a much more even load for a given speed, as becomes quickly apparent if a powermeter is used to verify resistance.

(Some trainers have an ergometer, or "erg" setting, which maintains a constant workload. That is, when cadence drops, resistive torque increases, and vice-versa, such that the product of the two – power output – remains constant. This feature allows the rider to "set and forget" a specific power level, and ensures that an unvarying intensity is maintained. What can make the "erg" more difficult for some is that the load is relentless. You either ride at the set load or you stop; you can't ease off for more than a moment or so. Contrary to occasional claims, neither the Computrainer, nor any type of erg, keeps power constant *within* a pedal cycle, rather, it keeps power constant *across* a number of pedal cycles, which is what people are not used to, since, when riding outdoors, we get to go hard for a bit, using fast-twitch motor units for a few seconds, go easy, go hard again, etc. This is precisely how neuromuscular systems are designed to function, i.e., episodically, and why training this way to excess may not create the best aerobic overload.)

Another difference is the lack of a cooling headwind in the neighborhood of 20-30 mph, causing some to blame any performance deficit indoors entirely on thermoregulatory issues, but this is overly simplistic; power production and perceived exertion may be either higher or lower indoors, depending on the individual, the trainer they use, how adapted they are to it, the terrain/environment they have available for outdoor training, etc. Thus, two steps are toward raising one's indoor power output are to

1. use a trainer that has enough "inertia" (stores a lot of kinetic energy), i.e., one with an adequately massive flywheel, to better simulate outdoor cycling. The Velodyne, among a few others, meets this criteria, and as a result, power output on it is usually as high as, if not slightly higher than, what can be done outdoors (especially if variations in power are accounted for with the normalization algorithm presented later on). On something with a light flywheel, however, it can be disconcertingly difficult to generate the same power indoors as outdoors.

2. keep cool enough, making every attempt possible to minimize thermal stress, so that you can maximize the absolute training load, unless you are specifically attempting to prepare for exercise in the heat (which is analogous to the effects of altitude: since it compromises absolute intensity, there is no advantage, and probably significant *dis*advantage, to training at higher elevations, unless preparing specifically for competition there.) This means using a powerful fan, keeping the room cool (at least under 70° F, and ideally below 65°), and staying hydrated. Look for high-velocity "air circulator" models that move at least 2000 cubic feet per minute, such as from Holmes, Honeywell, Lakewood, Patton, Air King, and Vornado (see http://www.dmartstores.com/fans.html to order, and http://www.vornado.com for the manufacturer's site). Direct the air flow at your head and upper body, but position the fan to the side, so it does not blow directly in to your eyes.

How you constitute indoor workouts will depend on your particular characteristics and abilities, the sort of racing you do, what your outdoor rides are like, and so forth, but it makes sense to balance indoor training with outdoor workouts that are as variable as possible. Alternatively, one could attempt to deliberately structure indoor workouts to stress muscle power more, by doing short, high-power intervals, with either complete or

incomplete recovery (microintervals), the idea being in both cases to induce more neuromuscular than metabolic stress, and having recognized the limitation to monotonic indoor training, some like to throw in frequent out-of-the-saddle "surges" to up the intensity. To best replicate outdoor cycling, however, the variations in power wouldn't be completely random, since you would want them to occur within a certain frequency range. That is, varying power on even a minute-by-minute basis doesn't really mimic what happens outdoors . . . the changes would have to be more often than that. On the other hand, a sudden doubling of the power requirement in middle of a pedal stroke wouldn't be ideal either, since, unlike cycling outdoors, you don't have as much stored kinetic energy to help carry you through the "dead spot."

To summarize, training on the road is more specific, whereas indoor workouts are more controllable and create a better aerobic overload, so optimal results may be obtained using an appropriate combination of the two approaches, or by manipulating force and cadence during indoor training sessions.

<p align="center">*   *   *   *   *   *   *</p>

The relatively constant workload of indoor training makes HR a more robust indicator of exercise intensity than it is outdoors, so long as cooling is adequate. In particular, being a cardiovascular variable, HR tracks fairly well with cardiovascular fitness, not metabolic fitness, i.e., with VO_{2max} rather than LT (the classic Astrand-Rhyming method for predicting VO_{2max} is based on this very fact), so lower a higher HR at a given submaximal power output might indicate lower VO_{2max}, even with plenty of LT intervals and equivalent sustainable power output. Such changes are not specific to LT power, but essentially occur across all submaximal power outputs. Interpreting any HR/power* value, however, is complicated by the fact that this ratio decreases with increasing power output, independent of changes in fitness, furthermore, it increases as power becomes more variable. A final noteworthy point: the magnitude of the change in submaximal HR is generally greater than the change in VO_{2max}, and may change even if VO_{2max} does not.

For instance, the author's (Coggan's) heart rate during bi-weekly, pre-season 2×20 minute LT intervals was averaging 149 beats/minute in 2003, vs. 143 the year prior, this despite the fact that power was the same, and I didn't even really feel like I had started to push myself all that hard either year. My approach was basically the same both years: 3 months of weight training 3 days/week, plus 3-4 days/week of steady riding through the end of December, after which I dropped the weights and started riding 6-7 days/week, with 2×20 minute intervals twice per week. The difference was that I was more fit at the beginning of the 3 month "maintenance" phase in Fall 2001 than in Fall 2002 (the result of racing a full calendar in '01, vs. viewing '02 as a write-off), and with different early season goals, I was doing more specific training, namely VO_{2max} type intervals (6×5 minutes on/2.5 off) once per week during my build-up in early 2002, something I neglected in '03. In other words, and exactly as predicted by the known physiology and training specificity, my HR response seemed to be tracking my (relative lack of) cardiovascular fitness (lower VO_{2max}), and not my metabolic fitness (LT power).

*Technically, HR/power is the correct stating of the relationship, not the more commonly used power/HR, since HR is the dependent variable.

Special thanks to Andrew Coggan, Ph.D. for his contributions throughout this chapter.

Tables and illustrations

Table 1. Overview of energy systems.			
SYSTEM	**PROPERTIES**	**LOCUS**	**SUBSTRATE**
Phosphagen (ATP-PCr)	1. Highest contractile force 2. Fastest contraction 3. Quickest to fatigue 4. Recruited last	Fast-twitch (Type IIb) muscle fibers	ATP, ADP
Non-aerobic glycolysis (substrate phosphorylation)	1. Higher contractile force 2. Fastest contraction 3. Quick to fatigue 4. Recruited second	Fast-twitch (Type II) muscle fibers	1. Glycogen (muscle, hepatic) 2. Plasma glucose
Aerobic metabolism (oxidative phosphorylation)	1. Lowest contractile force 2. Slowest contraction 3. Slow to fatigue 4. Recruited first	Mitochondria of slow-twitch (Type I & IIa) muscle fibers	1. Intramuscular triglycerides 2. Plasma free fatty acids 3. Glycogen (muscle, hepatic) 4. Plasma glucose

Table 3. Effect of muscle fiber composition on efficiency for groups with high (H) and normal (N) % type I fibers.						
SUBJECT PAIR (H, N)	**MUSCLE FIBER COMPOSITION (% type I)**		**VO_2max (l/min)**		**POWER at VO_2max (W)**	
	H	**N**	**H**	**N**	**H**	**N**
1, 8	83	46	4.62	4.67	357	335
2, 9	77	54	4.39	4.38	336	293
3, 10	76	49	4.59	4.54	363	336
4, 11	76	55	4.12	4.06	325	287
5, 12	70	38	4.61	4.66	324	314
6, 13	64	45	4.00	4.01	313	287
7, 14	62	52	5.00	4.91	376	359
MEANS ±SE	**73 ±3***	**48 ±2**	**4.48 ±0.13**	**4.46 ±0.13**	**342 ±9***	**315 ±11**

*Significantly greater than Normal % Type I Group ($p<0.002$; by design, the groups differed in % Type I muscle fibers).

Group H (subjects 1-7) possessed >56% Type I fibers, whereas Group N had 38-55% Type I. Subjects were paired according to criteria described in the methods section.

In: Horowitz, J.F., et al. High efficiency of type I muscle fibers improves performance. *International Journal of Sports Medicine* 15(3):152-7, April 1994.

Table 2. Correlation matrix of key physiological responses to exercise (factors 1-4), muscle morphology (5-10), and training variables (11 and 12).

FACTOR	1	2	3	4	5	6	7	8	9	10	11	12
1. Time to fatigue at 88% of VO_2max		0.90	-0.84	-0.79	0.62	-0.58	0.70	0.65	0.74	-0.29	0.62	0.16
2. %VO_2 at LT	0.90		-0.91	-0.87	0.55	-0.42	0.48	0.36	0.49	0.08	0.75	0.07
3. Glycogen used*	-0.84	-0.91		0.90	-0.49	0.48	-0.54	-0.49	-0.63	-0.12	-0.74	-0.04
4. RER*	-0.79	-0.87	0.90		-0.54	0.44	-0.30	-0.21	-0.42	-0.13	-0.56	0.09
5. %Type I	0.62	0.55	-0.49	-0.54		-0.43	0.46	0.38	0.52	0.06	0.38	0.27
6. Mean fiber area	-0.58	-0.42	0.48	0.44	-0.43		-0.30	-0.47	-0.86	0.34	-0.02	-0.13
7. Capillaries per fiber	0.70	0.48	-0.54	-0.30	0.46	-0.30		0.92	0.72	-0.46	0.44	0.26
8. Capillaries around	0.65	0.36	-0.49	-0.21	0.38	-0.47	0.92		0.81	-0.51	0.20	0.27
9. Capillaries per mm^2	0.74	0.49	-0.63	-0.42	0.52	-0.86	0.72	0.81		0.18	0.18	0.25
10. Citrate synthase activity	-0.29	0.08	-0.12	-0.13	0.06	0.34	-0.46	-0.51	-0.53		0.09	-0.12
11. Years cycling	0.62	0.75	-0.74	-0.56	0.38	-0.02	0.44	0.20	0.18	0.09		0.72
12. Total years of endurance training	0.16	0.07	-0.04	0.09	0.27	-0.13	0.26	0.27	0.25	-0.12	0.72	

P < 0.05 when *r* ≥ 0.514; *P* < 0.01 when *r* > 0.641; and *P* < 0.001 when *r* < 0.771.

*During 30 minute exercise bout at 79% of VO_2max.

In: Coyle, E.F. et al. Determinants of endurance in well-trained cyclists. *Journal of Applied Physiology* 64(56):2622-30, June 1988.

Back to referring page
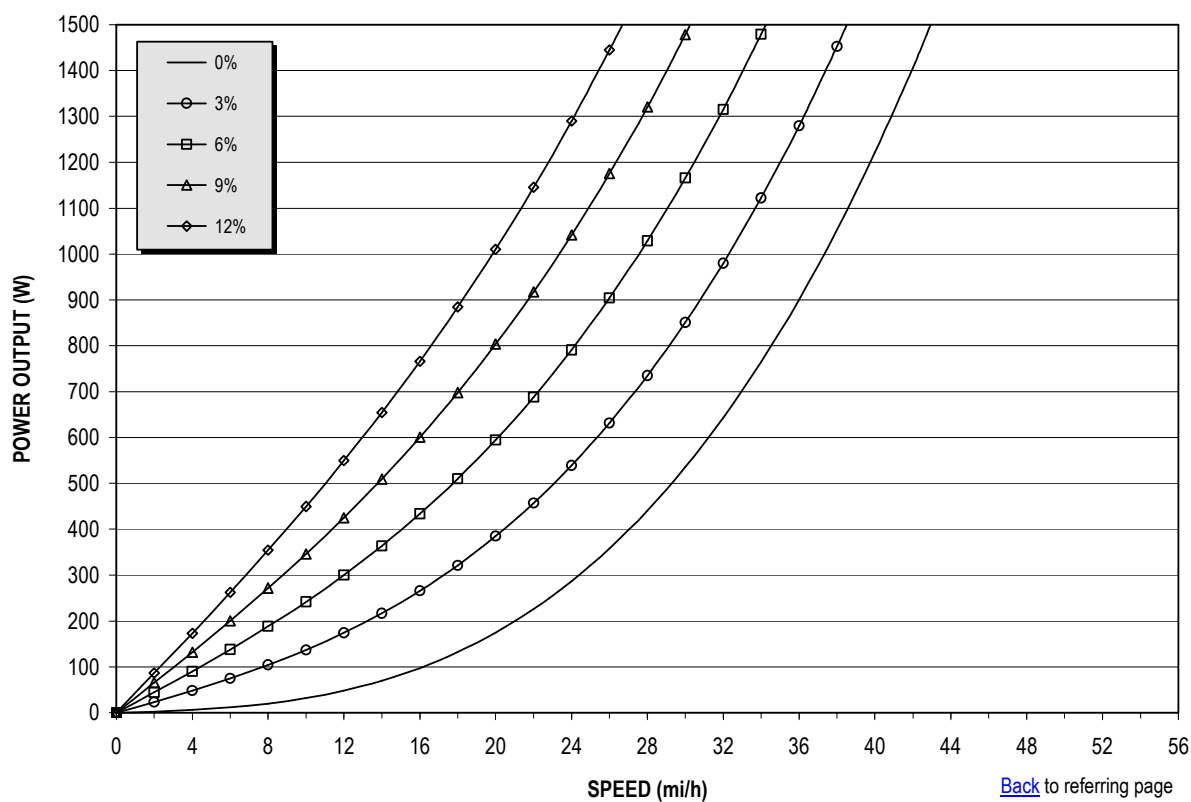
Fig. 1. Power requirements as a function of speed for an 80 kg bicycle/rider over selected grades 0-12%.
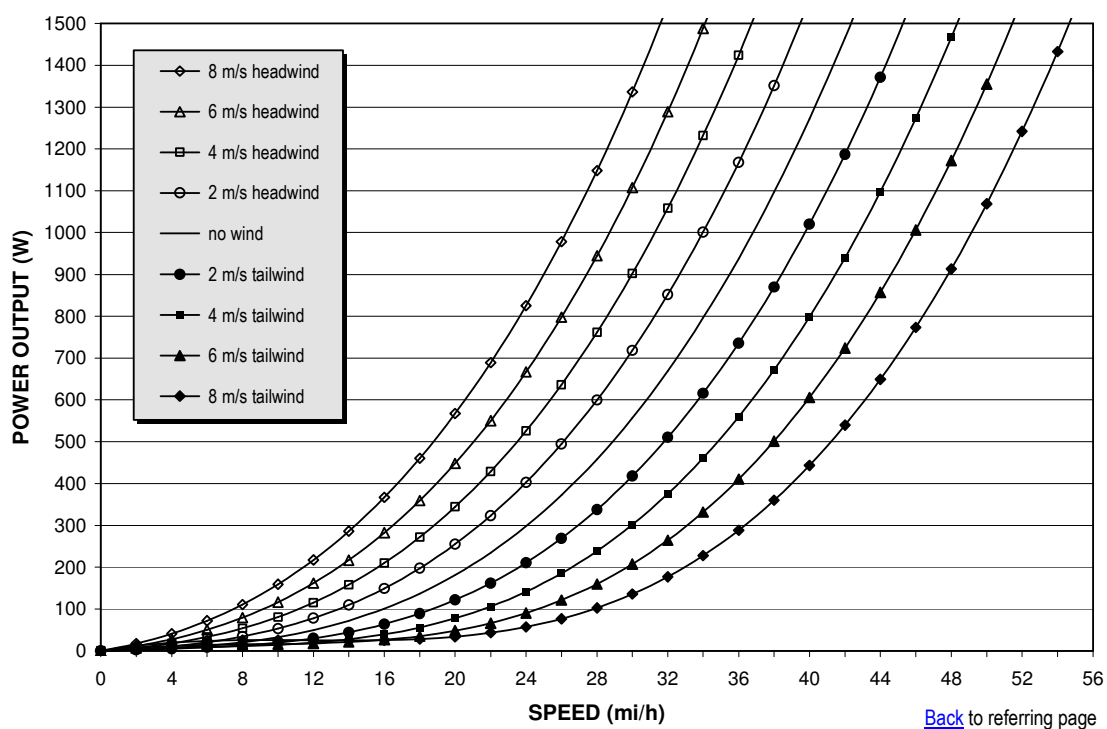
Fig. 2. Effect of wind on power as a function of speed for an 80 kg bicycle/rider over flat terrain.
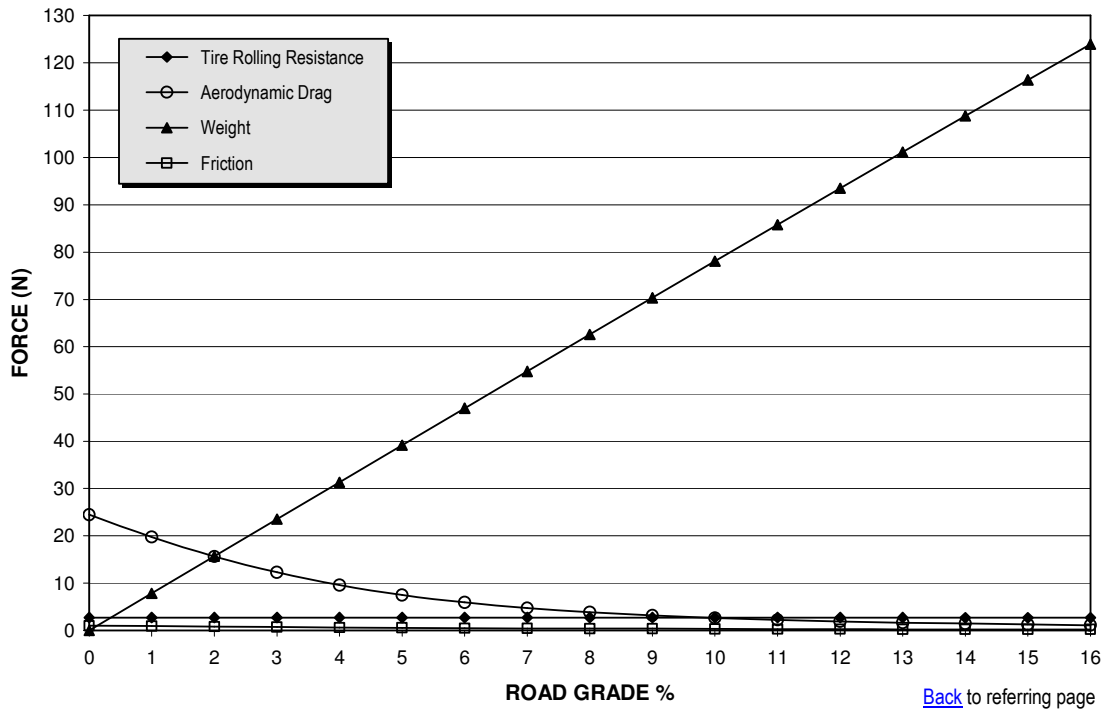
Fig. 3. Magnitude of resistive forces on an 80 kg bicycle/rider at 300 W over varied terrain.
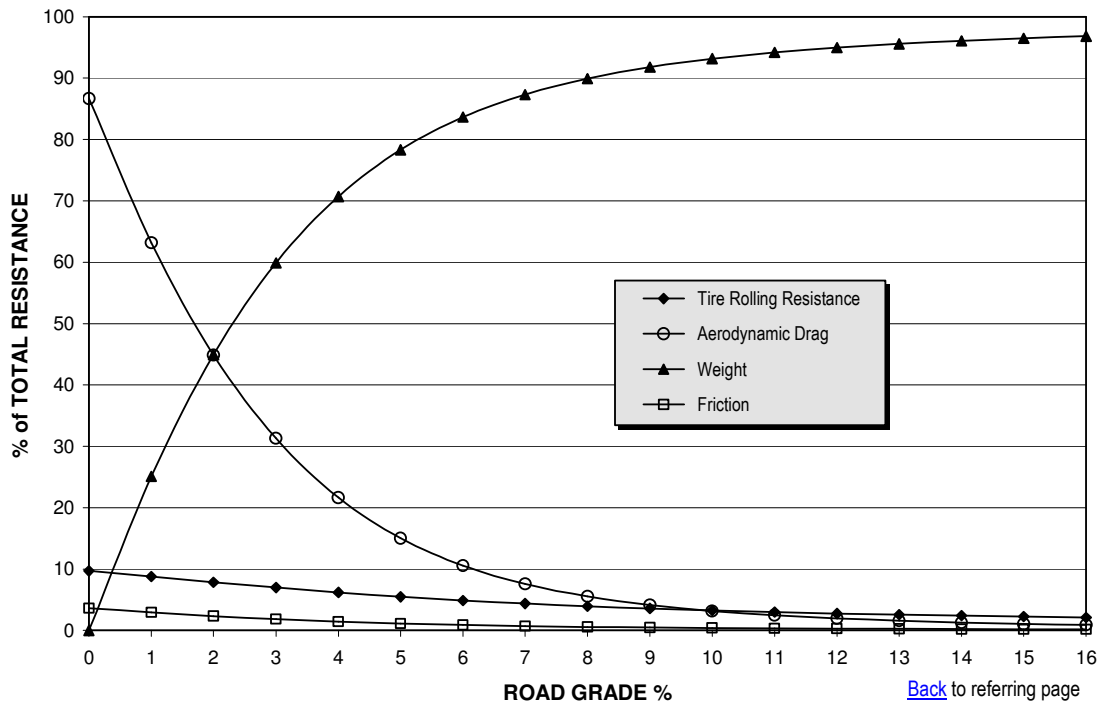

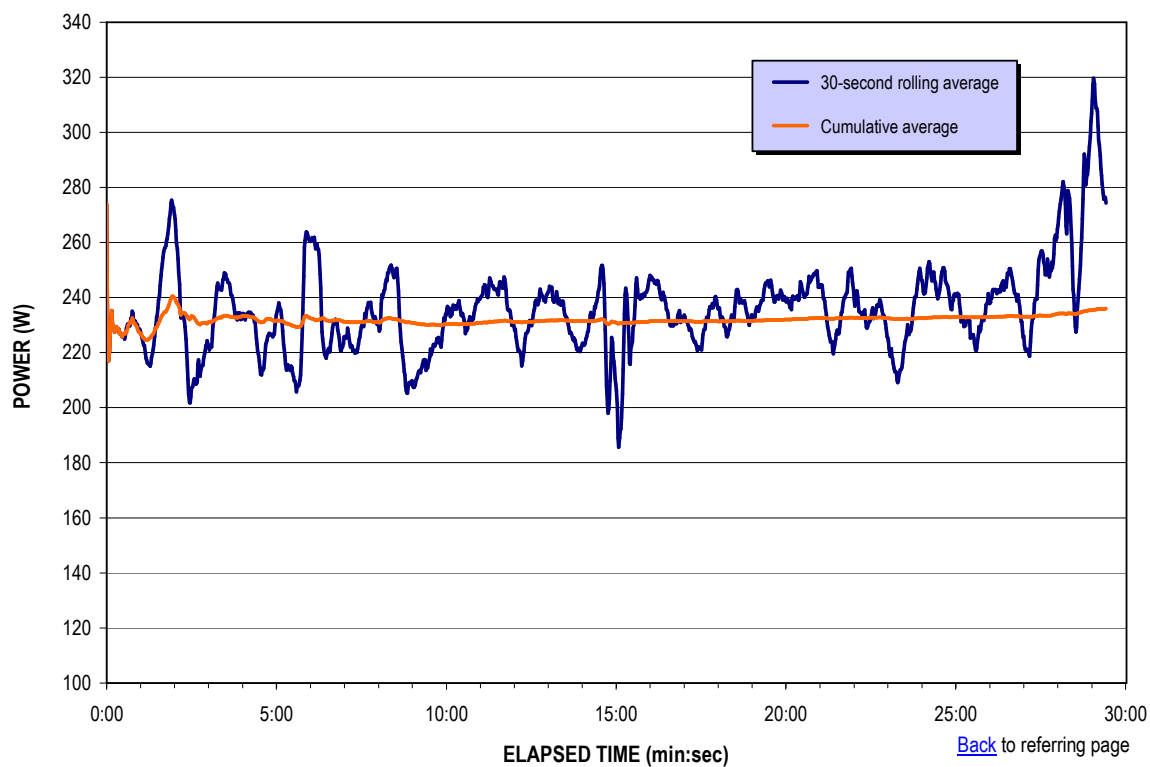**Fig. 4.** Relative distribution of resistive forces on an 80 kg bicycle/rider at 300 W over varied terrain.

Fig. 5. Cumulative and rolling 30-second average power in a flat-terrain time trial (27 June 2003).
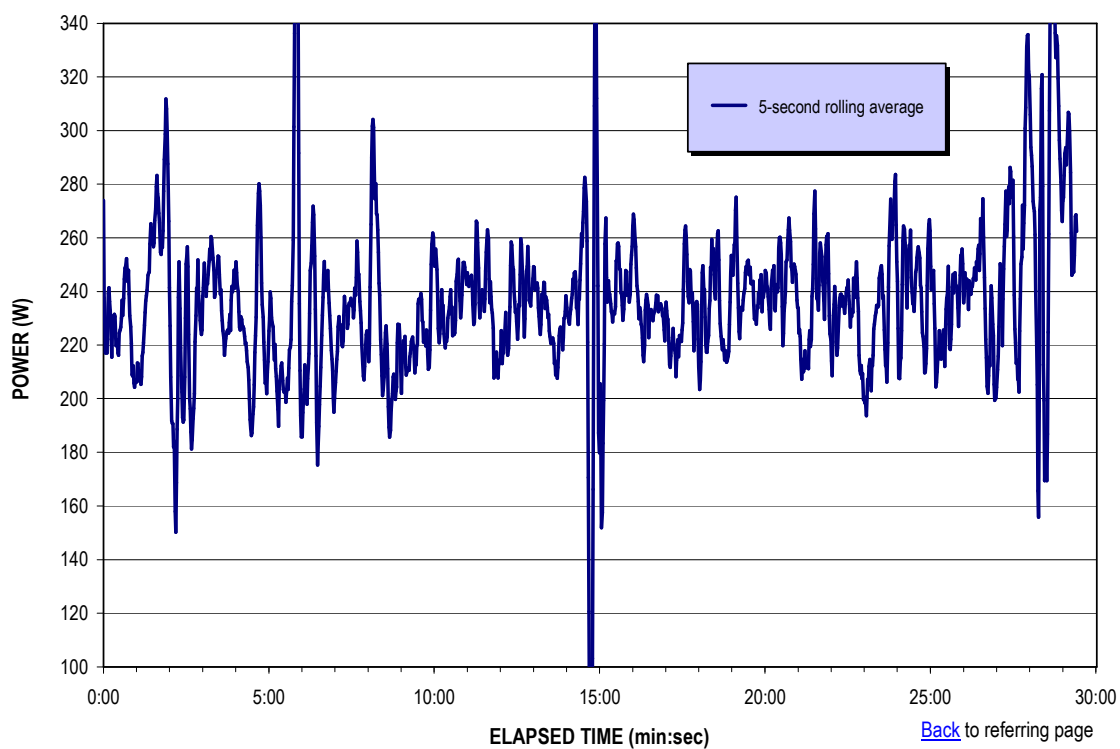
Fig. 5a. Rolling 5-second average power in a flat-terrain time trial (27 June 2003).

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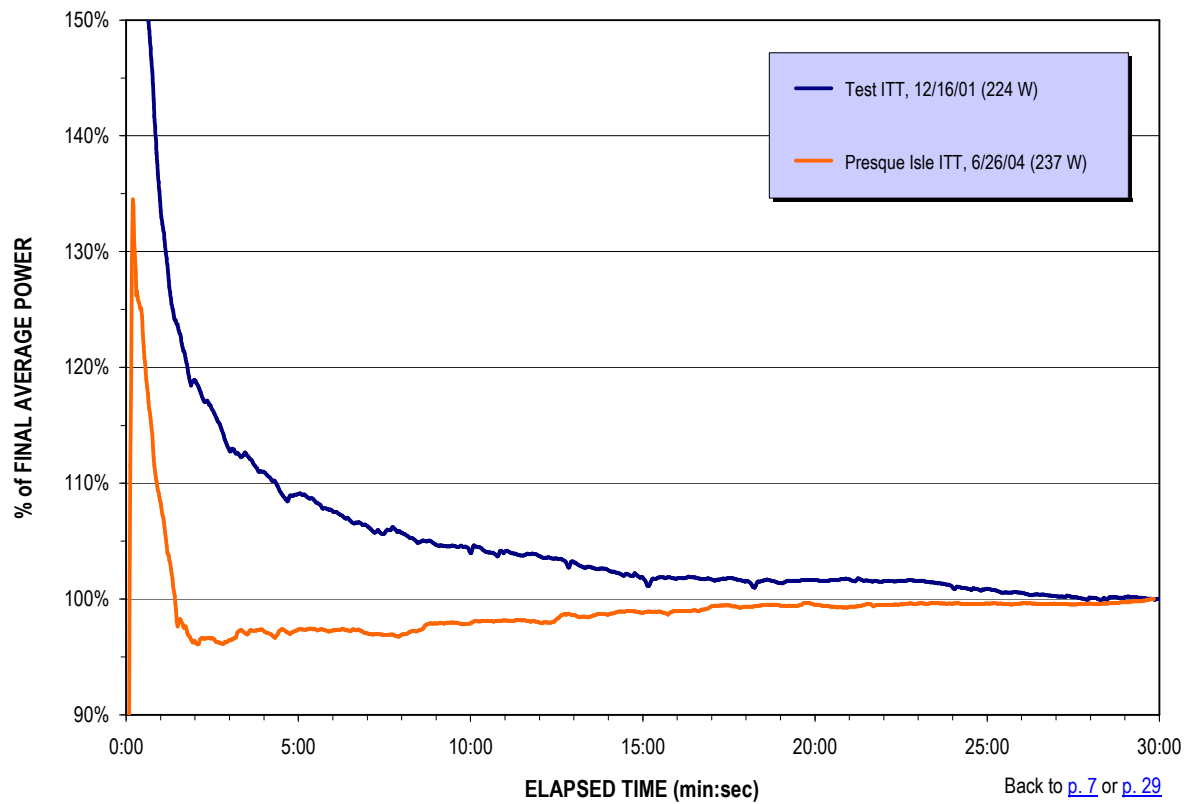
Fig. 6. Running average power as a percentage of final average in two flat-terrain time trials.
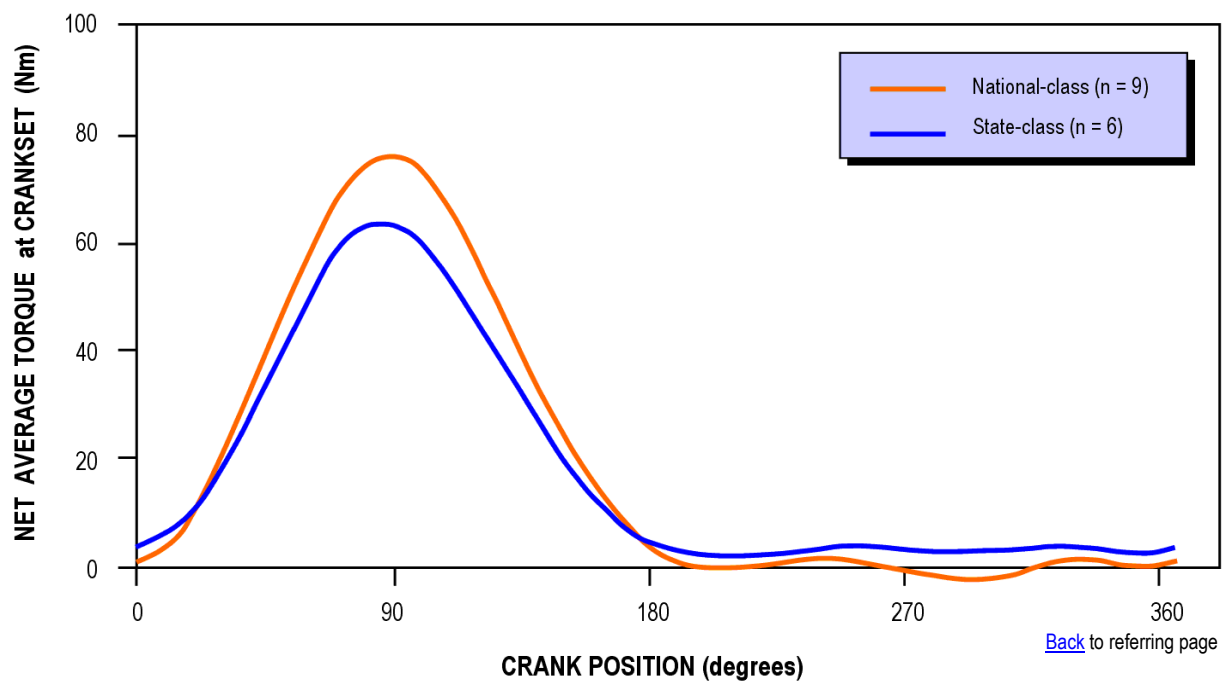
Fig. 7. Net average crankset torque for two groups of riders (in: Coyle, E.F. et al. Physiological and biomechanical factors associated with elite endurance cycling performance. *Medicine and Science in Sports and Exercise* 23(1):93-107, January 1991).

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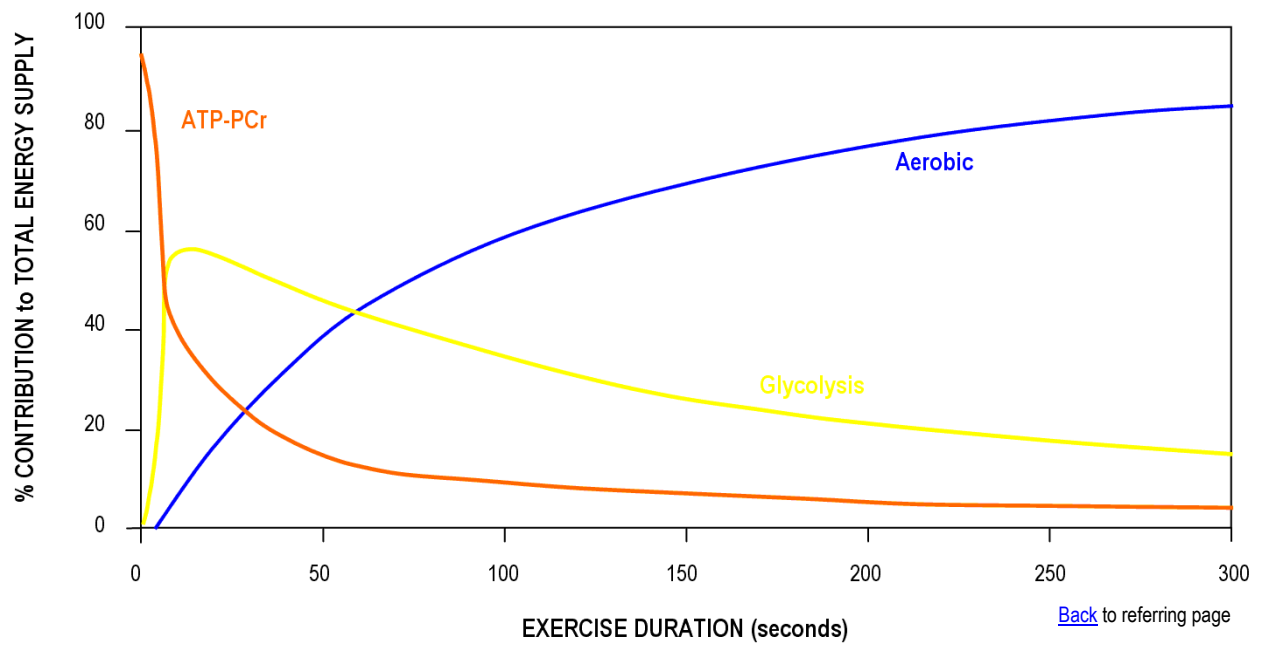
Fig. 8. Relative contribution of three energy systems to exercise (in: Gastin, P.B. Energy system interaction and relative contribution during maximal exercise. *Sports Medicine* 31(10):725-41, 2001.)
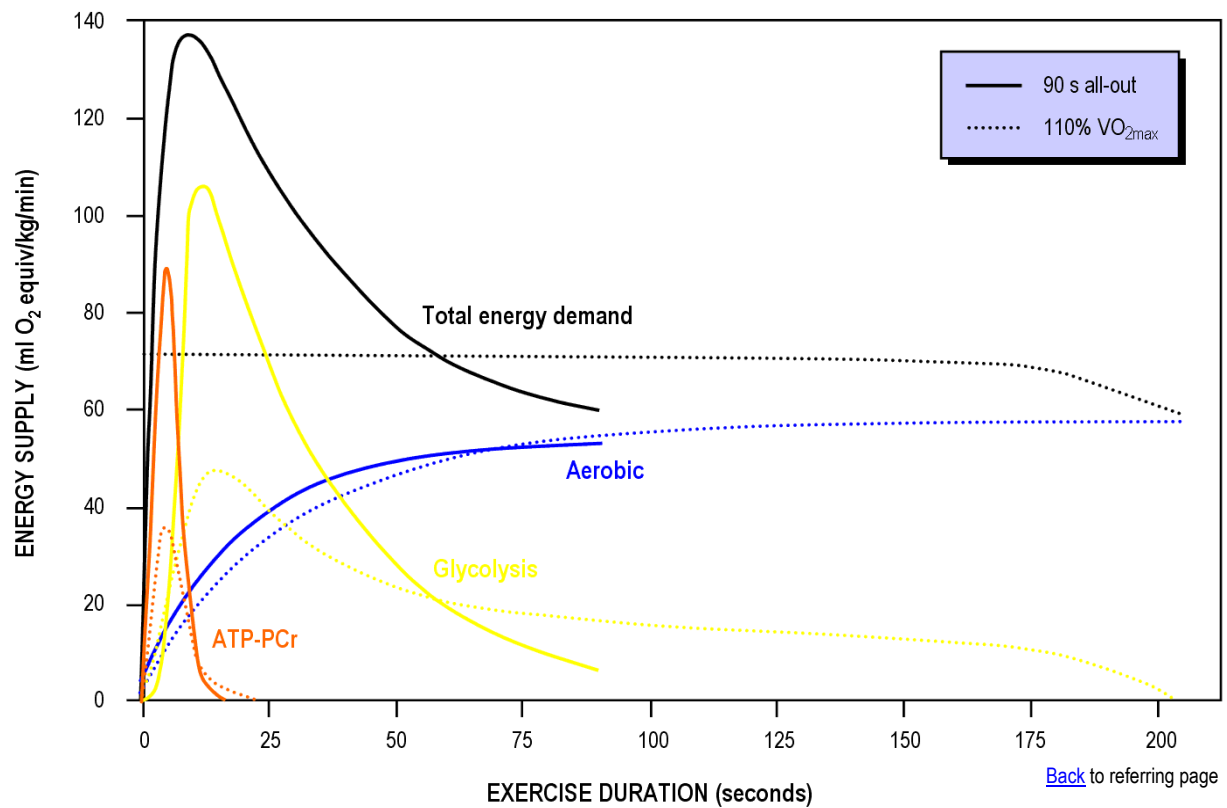
Fig. 9. Energy systems contribution at two exercise intensities (in: Gastin, P.B. Energy system interaction and relative contribution during maximal exercise. *Sports Medicine* 31(10):725-41, 2001.)
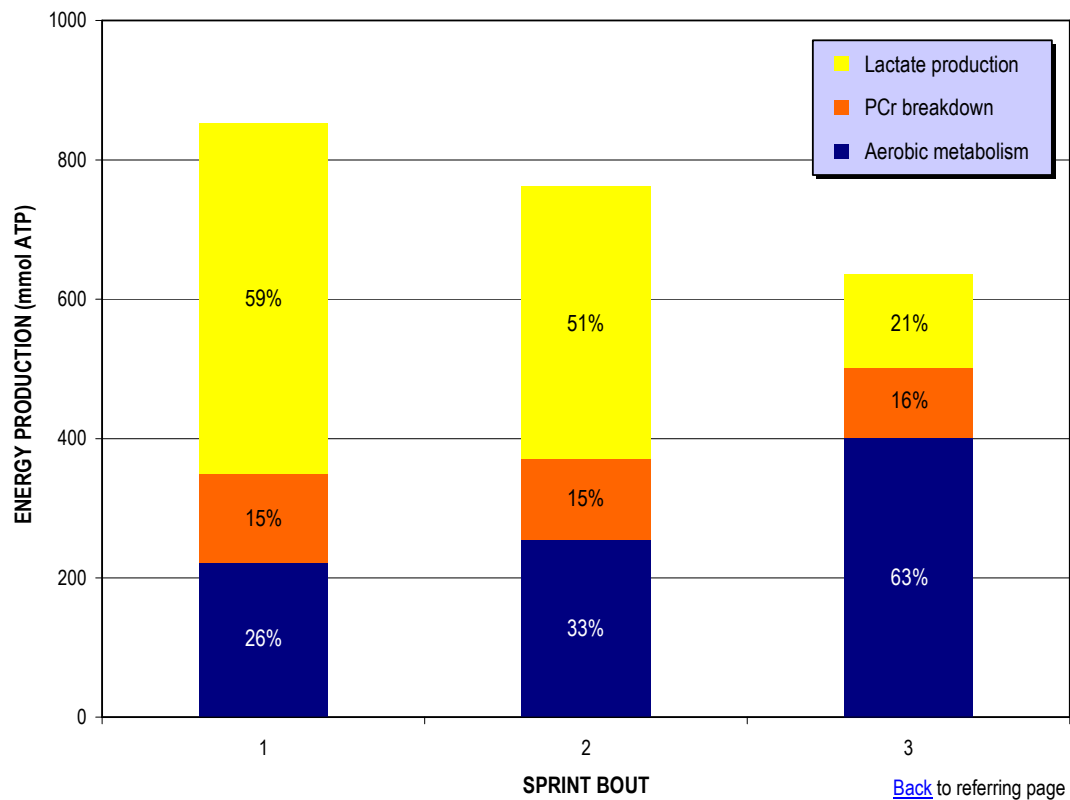
Fig. 10. Contribution of three energy systems to three 30-second maximal exercise bouts separated by 4 minutes complete rest (in: Putman, C.T., et al. Skeletal muscle pyruvate dehydrogenase activity during maximal exercise in humans. *American Journal of Physiology* 269(3 Pt. 1):E458-68, September 1995.)
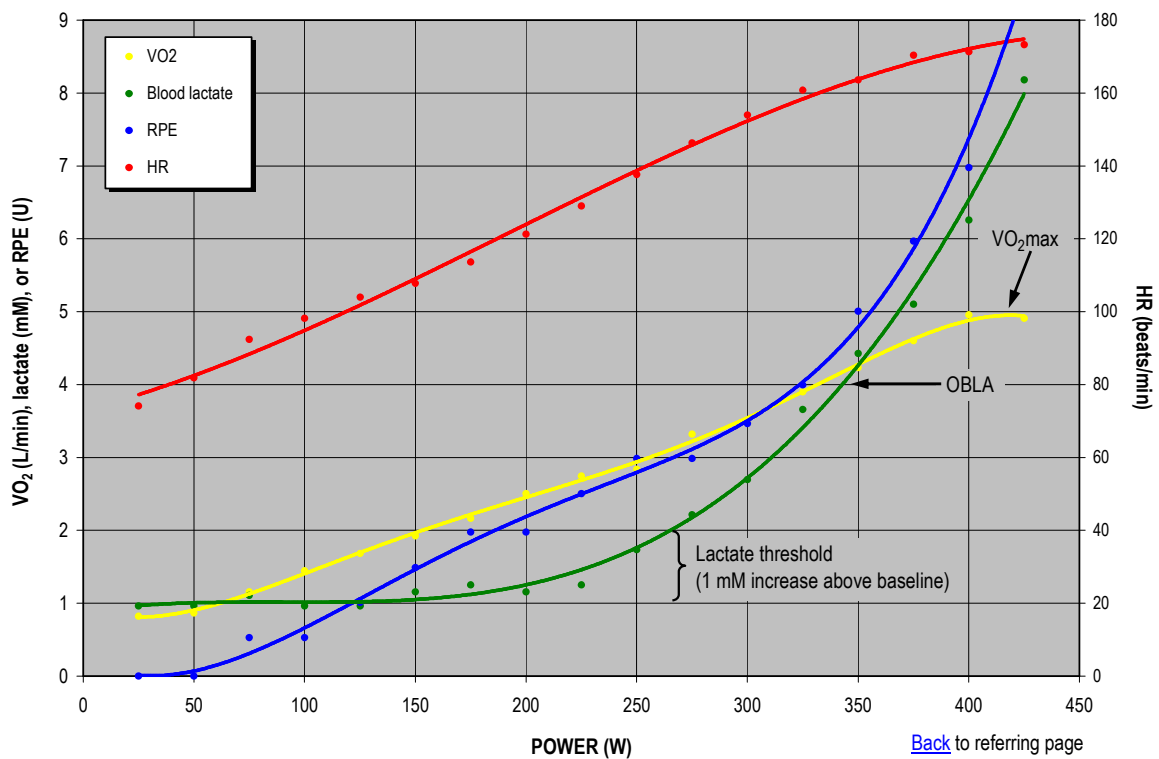
Fig. 11. Typical responses of several physiological variables during an incremental exercise test to exhaustion.
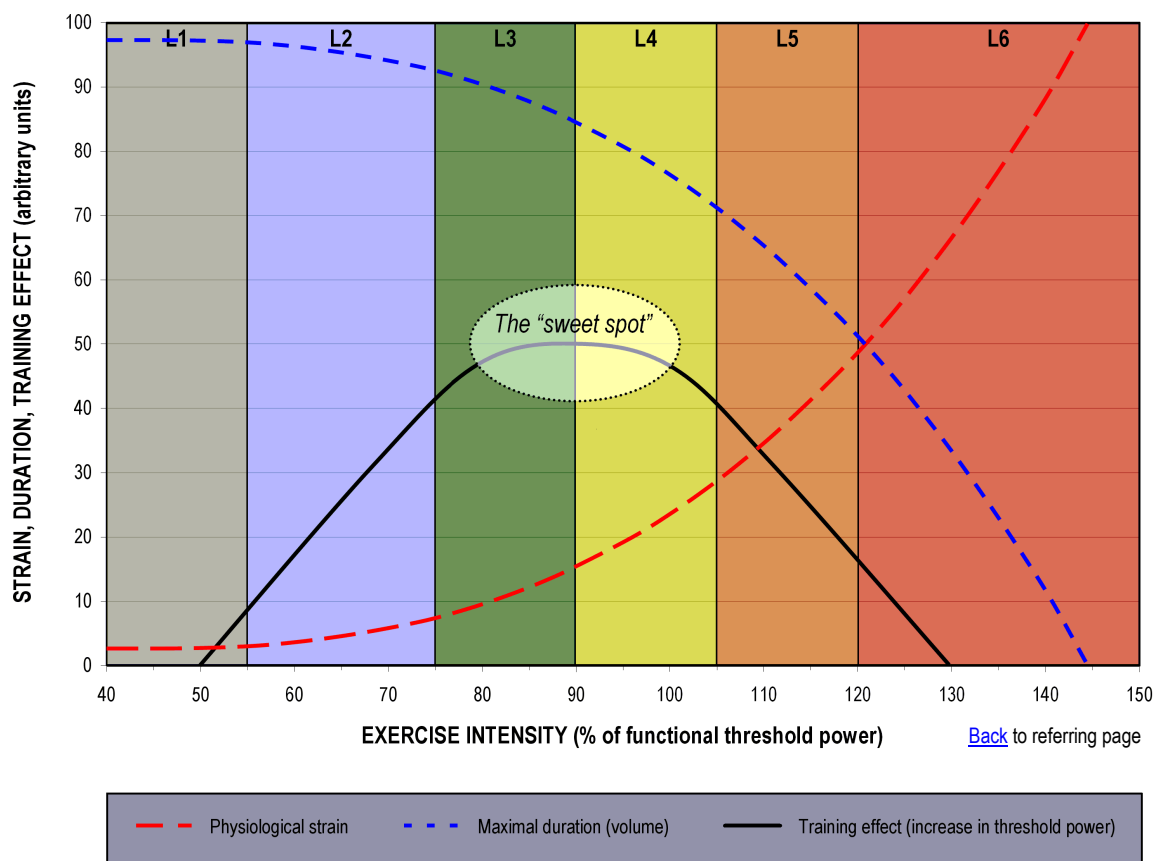
Fig. 12. Training load optimization for increasing threshold power.

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Appendix A: power-based training resources

GENERAL INFORMATION AND HELP

A good place to start is trainwithpower.net, the most authoritative, up-to-date resource for all that's happening in the world of power-based training, while the FAQ for power-based training answers many basic questions.

Tom Compton's analyticcycling.com is quite possibly the coolest power-related site ever! Here you can gain a real understanding of interrelationships of power, force, and speed while riding a bicycle. Similar sites are http://www.kreuzotter.de/english/espeed.htm and http://www.2peak.com/tools/powercalculator.php.

Still have a question? The Wattage Forum (Google membership required) can provide help and advice from that list's many members, as can the power training section of cyclingforums.com, while TrainingPeaks software offers a dedicated forum for its users.

More baffled than ever? Perhaps it's time to find a coach through the twp.net directory of power-based coaches.

BOOKS AND COMPREHENSIVE ARTICLES

Empower your training, by Charles Howe, is a brief, introductory article (PDF, 301 KB).

Power: the Ultimate Training Metric (PDF, 1.4 MB) is rider-journalist J. P. Partland's guide available through the Competitive Cyclist site.

Training and racing using a powermeter: an introduction (PDF, 452 KB), by Andrew Coggan, Ph.D., was originally written for the USA Cycling™ coaches' manual (backup sites: 1 and 2).
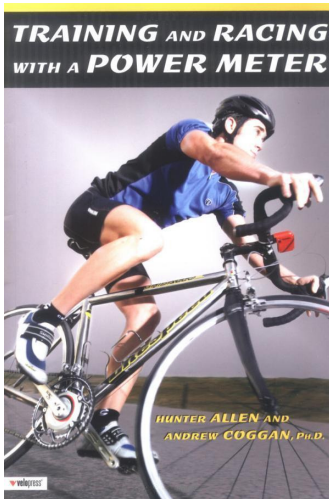
Training and Racing with a Powermeter, by Hunter Allen and Andrew Coggan, Ph.D., is a 248 page mass-market paperback book available through VeloGear.

See Alex Simmons's review here (scroll down to pg. 12).

ARTICLES

They may be commercial in purpose, but the Cycling Peaks Software, FasCatcoaching, Velodynamics, and PowerTap sites have numerous useful articles.

biketechreview.com, although primarily concerned with component testing, has numerous useful articles related to power-based training.

In the category of blogs/personal web sites, Robert Chung brings a statistical analyst's insight to power data (old site here), while Steve Wagner's powertapgeek.com bills itself as "All Things PowerTap – News, Tips, Reviews, Training, Data Files, and More!" Many others can be found at the Wattage Forum's blog page.

POWERMETER PRODUCT INFORMATION AND TROUBLESHOOTING HELP

Robert Chung did what is likely the first simultaneous test of several powermeters, and Kraig Willett followed that with a side-by-side test and comprehensive review (backup here) of three systems (Polar, PowerTap, and SRM). Here are links to product information and help sites:

> The SRM (introduced 1986; history here) is a torque-measuring crank that replaces your present model (also see The Bike Age site for troubleshooting help and other usage tips).
>
> The Saris/CycleOps PowerTap (1998) is a torque-measuring hub that builds into a wheel.
>
> In 2001, suffering pangs of guilt for inflicting the heart rate monitor on endurance training, Polar introduced a unique power-measuring system that uses a vibration sensor mounted on the right chainstay to determine chain tension (a force), then multiplies this by chain speed, as determined by a sensor on the rear derailleur. Presently, they offer three models, the S720i, S-725X, and CS600. Check out this review of the CS600, and Sandiway Fong's set-up instructions for the original model, the S710.
>
> The Ergomo (2002) is a torque-measuring bottom bracket available in ISO square-taper or Shimano OctaLink (see also BicyclePowermeters.com).
>
> Like the Ergomo, the Bush & Muller PowerReport (2005?) is a bottom bracket that measures torque and angular velocity, but is not yet available in the U. S.
>
> MicroSport's REVOLUTION Power System (announced 2006, due out in 2008) uses force-sensing insoles, and estimate cadence from the pattern of pulses detected by the insoles.
>
> The iBike Pro, introduced in June 2006, takes a novel approach: instead of measuring total strain at a single point (e.g., the hub, crankset, bottom bracket, chain, or shoes), it attempts to quantify each force separately. First, values for effective frontal area of rider/bike, as well as for tire rolling resistance, are obtained via a coast-down test, and entered into the system's handlebar-mounted data processing/display unit, along with rider/bike mass. Then, using a pressure sensor to obtain air resistance, plus an accelerometer for road gradient and changes in kinetic energy, power output is calculated as the product of road speed and the sum of all forces resisting forward motion. iBike's initial problems with accuracy on rough roads, which seemed to interfere with the accelerometer, are said to be solved with a firmware update, however, some remain skeptical about its performance when rider position changes from the coast-down test. To learn more, see this discussion group for iBike users, and check out this review.
>
> The Quarq CinQo (announced August 2007, introduced July 2008) is a spider with 10 strain gages that is compatible with (i.e., bolts on to) several crankarms currently on the market, then transmits data via wireless digital RF to a handlebar-mounted computer. Presently, Quarq owners must use a compatible computer either by Garmin and iBike, but a unit with many advanced features, called the Qranium, is planned.
>
> *Note:* contrary to occasional claims, Ciclosport models **do not** actually measure power, rather, they only give a rough estimate based on speed, total mass, and elevation change (as measured by changes in barometric pressure). This may be accurate enough on steeper grades, but is useless on flat terrain, particularly in group rides or if any wind is present.

Last but certainly not least, TrainingPeaks WKO+ is an aftermarket software for analyzing power data, with many advanced tools that make it superior to what is provided with the SRM, PowerTap, and Polar systems.

Appendix B: power-based category guidelines for men and women

The purpose of these guidelines is *not* to actually assign categories, since the assumed conditions can vary, and some riders excel, for instance, at criteriums, within the same group they time trial poorly against. Furthermore, categories are based on results in mass-start races in actual practice, so the validity of these guidelines may vary from one region to another (especially for lower categories), within a season, and even from year to year.

Rather, they are meant to suggest mean levels of peak seasonal performance for each category, to be used for self-assessment, e.g., if a female rider can clock 59:15 or better with a modicum of aero equipment (deep section front wheel with ≤20 bladed spokes, rear wheel cover or disc wheel, and clip-on aero bars), she should have the "strength" to ride in a Cat. 1 field at criteriums and moderately hilly to flat road races, if not the bike handling/pack riding skills, sprinting ability, team support, intelligence, or just plain luck to excel. In other words, time trialing ability is used as a predictor of racing category, rather than vice-versa; if you can ride by yourself for an extended period at a given pace, then you must have a certain VO_{2max}, lactate threshold, and efficiency to sustain that power output. Again, there is obviously much more that determines mass start racing success, but functional threshold power provides the physiological basis for the proposed racing levels.

CLASS/CATEGORY	40 km TIME TRIAL PERFORMANCE		
	Δt (h:m:s)	P (W/kg)	$C_D A$ (m²)
Men			
World class	0:48:30	5.79	0.231
UCI Div. I/II	0:50:00	5.40	0.235
UCI Div. III	0:51:45	5.01	0.240
Cat. 1	0:53:45	4.59	0.245
Cat. 2	0:56:00	4.19	0.252
Cat. 3	0:58:30	3.80	0.258
Cat. 4	1:01:50	3.40	0.268
Women			
World class	0:54:30	4.86	0.222
UCI Elite	0:56:40	4.45	0.227
Cat. 1	0:59:15	4.03	0.233
Cat. 2	1:02:10	3.61	0.238
Cat. 3	1:05:15	3.21	0.242
Cat. 4	1:09:00	2.81	0.247

For men, power estimates are based on 80 kg total mass (rider = 71.2 kg, equipment = 8.8 kg), while for women, these values were 66.5 kg (58 kg, 8.5 kg), with environmental conditions of 22° C, 760 mm Hg, and calm air assumed for both. W/kg values are normalized to body mass only (i.e., do not include equipment).

Changes in power from one category to the next are nearly linear. Power values are in a ratio of ~0.85 between corresponding female/ male categories, while male:female times = ~0.90, as seems consistent with respective World Hour Records and recent U.S. National Time Trial Championship results.

Comparable category guidelines have been proposed for men, and see http://topica.com/lists/wattage/read/message.html?mid=908748113 for a related comment.

Performance benchmarks for men's one hour average power are 442 W by Chris Boardman on September 7, 1996, and 510 W by Miguel Indurain on September 2, 1994, both approximately 6.4 W/kg, and both shortly prior to breaking the World Hour Record. Similarly, Lance Armstong's time of 38 minutes 1 second in climbing L'Alpe d'Huez during the 2001 Tour de France required an estimated 6.2 W/kg, which came at the end of a 209 km stage with two prior "hors categorie" (beyond category) climbs, and at a mean elevation of 1300 meters that caused a ~4-7% reduction in power (see Appendix C). In setting a women's record of 54 minutes 2 seconds at the 2002 Mt. Washington (NH) Hillclimb, Geneviève Jeanson averaged an estimated 278 W (5.56 W/kg).

Appendix C: altitude adjustment (estimating the effect of elevation on power output)

The effects of altitude on VO_2 uptake (and hence on power output) vary by individual, so it cannot be precisely predicted how any one person will be affected, but as a general rule, elite athletes have a greater decline in VO_2max under conditions of reduced ambient pO_2 (partial oxygen pressure) as compared to normal individuals. This is due to their higher cardiac output, which results in a decreased mean transit time for the erythrocytes (red blood cells) within the pulmonary capillary, and thus less time for equilibration between alveolar air and blood in the pulmonary capillary.

These equations from Bassett et al.[1] were generated from 4 groups of highly trained or elite runners, so they are population-specific to that group, but they can be used to estimate aerobic power at a given altitude as a percentage y of what is normally available at sea level, where x = elevation above sea level in km:

for acclimatized athletes (several weeks at altitude): $y = -1.12x^2 - 1.90x + 99.9$ $(R^2 = 0.973)$

non-acclimatized athletes (1-7 days at altitude): $y = 0.178x^3 - 1.43x^2 - 4.07x + 100$ $(R^2 = 0.974)$

Whereas Peronnet et al.[2] found

$y = -0.003x^3 + 0.0081x^2 - 0.0381x + 1$

Here is a table derived from these equations:

ELEVATION (feet above sea level)	AVAILABLE AEROBIC POWER		
	Bassett et al.[1]		Peronnet et al.[2]
	acclimatized	*non-acclimatized*	
0	99.9%	100.0%	99.9%
1,000	99.2%	98.6%	98.9%
2,000	98.3%	97.0%	97.8%
3,000	97.2%	95.2%	96.8%
4,000	95.9%	93.2%	95.6%
5,000	94.4%	91.1%	94.4%
6,000	92.7%	88.9%	93.1%
7,000	90.7%	86.5%	91.6%
8,000	88.6%	84.2%	89.9%
9,000	86.3%	81.7%	88.1%
10,000	83.7%	79.3%	86.0%
11,000	80.9%	77.0%	83.7%
12,000	78.0%	74.7%	81.1%
13,000	74.8%	72.5%	78.2%
14,000	71.4%	70.4%	75.0%

[1]Bassett, D.R. Jr., C.R. Kyle, L. Passfield, J.P. Broker, and E.R. Burke. Comparing cycling world hour records, 1967-1996: modeling with empirical data. *Medicine and Science in Sports and Exercise* 31:1665-76, 1999.

[2]Peronnet, F., G. Thibault, and D.L. Cousineau. A theoretical analysis of the effect of altitude on running performance. *Journal of Applied Physiology* 70(1):399-404, 1991.

Special thanks to David Bassett, Jr., Ph.D., for his contribution to this section.

Appendix D: a general training model for the road cyclist

The training model presented here is based on the concepts and methods of New Zealand Olympic running coach Arthur Lydiard (1917-2004). With slight modifications, these can be summarized as follows:

1. Performance in any endurance activity (i.e., longer than 3 minutes) is largely determined by the available rate of aerobic energy production, and this common basis allowed Lydiard to successfully use the same training program for all his runners, from 800 meters through the marathon, until their period of specialization. Aerobic development is essentially unlimited; the only constraints are training opportunities (available time, environmental conditions), training capacity, motivation, and resistance to injury/illness. "The wider and deeper the base, the higher and more sustained the peak."

2. Aerobic capacity is developed through at least 10-12 weeks of mainly steady-state tempo/threshold runs of ~2 hours long, totaling ~8-12 hours per week. The goal of this is increased energy production at lactate threshold ("endurance" or "metabolic fitness") by inducing peripheral adaptations (i.e., within the working muscles), including increased capillary density (allowing greater removal of waste metabolites), increased mitochondrial mass (which improves muscle respiratory capacity), and interconversion of slow-twitch muscle fibers (which improves cycling economy). Aerobic power may be 'peaked' toward the end of this period with once-a-week, intermediate-intensity interval workouts (e.g., 5 × 5 minutes).

3. The distribution of energy expended during aerobic training should be governed by the interaction of intensity and perceived exertion, such that there is a greater second-half output in each workout, leaving the athlete exhausted only at the very end, feeling "pleasantly tired" shortly afterward, and thus able to sustain a gradually progressive training load almost indefinitely; workouts may be somewhat challenging to complete, but not a struggle, with something always left in reserve. "You must exhaust the body systematically and sensibly. Not go ahead and kill yourself," Lydiard summed up in a 1964 interview, and his frequent refrain of "**Train, don't strain**," is now justifiably famous. Recently, a client captured this perfectly another way: "Work, don't suffer."

4. Since the metabolic strain of sprint training is limited, speed can and should be developed throughout the year with short, intense efforts of no more than 15 seconds, with emphasis on technique and form.

5. When aerobic conditioning has proceeded as far as possible, ~7 weeks are devoted to anaerobic capacity training (4 weeks lower-intensity hill workouts, 3 weeks high-intensity track intervals) during which aerobic fitness is maintained. The reason for this sequencing is not so much that aerobic training is needed to prepare for anaerobic workouts, rather, the latter interferes with and limits the former, and so should be forestalled until aerobic fitness is as complete as possible, then be applied in a concentrated manner, as a kind of "icing on the cake."

6. This is followed by a 4-week 'coordination period' of over-and under-distance training races and/or other specific workouts meant to simulate the neuromuscular demands and variable pace of competition.

7. Finally, 7-10 days of 'sharpening and freshening' leaves the athlete rested and in peak form for a period of competition and recovery.

This approach can be applied to cycling in a quantitative manner with the power-based training levels laid out by exercise physiologist Andrew Coggan, Ph.D., as well as the analytical tools he has created: Training Stress Score (TSS), Chronic and Acute Training Load (CTL and ATL), and Training Stress Balance (TSB). All of these are incorporated in the Training Peaks WKO+ Performance Manager.

Perhaps because they feel threatened by them, some coaches are quick to condemn and dismiss training models as "cookie cutter" or "pre-fab" in nature, and insist that all training must be individualized. The question is, individualized from what? Preparation for any given event arises from known demands and is governed by established underlying principles, so a logically-constructed model can provide, at the very least, a useful starting point for most any runner or cyclist (savvier coaches take advantage of this by offering power-based training plans designed for specific goals). It is certainly true that different athletes can respond in significantly varying degrees to a particular workout, or have varying training load capacities as well as recovery needs, yet this is akin to the exception that proves the rule: most responses fall within a predictable range.

Thus, no model program should be applied rigidly, but must be adapted to the athlete for whom it is intended. In addition to physical constitution, other factors that shape the training prescription include competitive priorities/preferences (which races you want to do well in, which you want to use for training, and which you enjoy the most, since motivation determines how diligently you train), role within a team, age, training status/history, individual characteristics (strengths and weaknesses), weather, training opportunities (e.g., local availability of roads/trails, terrain, traffic), work schedule and other responsibilities, etc. A coach can provide valuable aid in offering objective advice as well as customizing and adjusting the training plan.

PHASE I: PRE-SEASON PREPARATION

Aerobic Conditioning

Period 1 ("Base"): aerobic endurance and lactate threshold (8-10 weeks)

- ▸ OFF or Level 1 (30-60 min.) – Monday

- ▸ 1 Level 4 functional threshold power, or FTP, test (40-50 min.) per week – Tuesday

- ▸ 3-5 Level 2-3 rides (1.5-4 hr.) per week; primarily steady-state, with one **controlled** variable-pace (e.g., group/rolling terrain) ride per week

- ▸ 1 Level 7 workout per week, prior to a Level 2 ride, with each effort no longer than 15 seconds to limit metabolic stress, and complete recovery (5 minutes) in between each effort

- ▸ Build CTL by 3-6 pts. per week (20-35 TSS pts.), or (less preferably) volume by 25-45 min.; use last ride of the week to reach weekly target. Use TSB in relation to perception of fatigue to evaluate and adjust load and rate of overload progression.

Period 2 ("Build"): lactate threshold and maximal aerobic power (4 weeks)

- ▸ OFF or 30-60 min. Level 1 – Monday

- ▸ 1 Level 5 workout (5-6 x 5 min. @ ~110% FTP, uphill or flat) per week– Tuesday

- ▸ 1 FTP test (40-50 min.) every other week – Wednesday

- ▸ 3-4 Level 2-3 rides (1.5-4 hr.) per week; primarily steady-state, with one or two **controlled** variable-pace (e.g., group/hilly terrain) ride each week

- ▸ CTL rate of increase slows or is maintained at sustainable plateau; repeating a week occasionally, as needed when higher CTL levels are reached, can help to assimilate (consolidate) training. Professional/elite riders should generally aim for a CTL of at least 110 by the end of Phase 2.

PHASE IA

Anaerobic Capacity/Aerobic Maintenance

Period 3: anaerobic capacity training (3 weeks)

- ▸ OFF or Level 1 (30-60 min.) – Monday

- ▸ 2-3 Level 6 workouts per week (e.g., 8-12 x 1 min. @ ~150% FTP) on appropriate terrain, alternated with . . .

- ▸ 2-3 Level 2 rides per week; no FTP test

- ▸ CTL maintained or allowed to fall slightly

PHASE II: COMPETITION

Long (>30 min.), Flat TT Emphasis

Period 1: specificity/taper (7 days)

- ▸ 2 practice TTs of similar duration, using TT bike and all equipment

- ▸ 2 Level 2 rides (1.5-2 hr.)

- ▸ 2 days OFF or Level 1 (30-60 min.)

- ▸ TSB should be positive or nearly neutral the day before the event

Criterium emphasis   TT emphasis (2)   Road race emphasis

PHASE IB

Criterium Emphasis

Period 4: race specificity/taper (2-3 weeks)

- ▶ 1-2 criterium training races, motorpacing, or microinterval workouts per week
- ▶ 2-3 Level 2 rides (~2 hr.) per week
- ▶ 2 days OFF and/or Level 1 rides (30-45 min.) per week
- ▶ TSB should be positive at end of period

PHASE IB

Road Race Emphasis

Period 4: race specificity/taper (2-3 weeks)

- ▶ 1-2 training races and/or 'spirited' group rides per week
- ▶ 2-3 Level 2 rides (~2 hr.) per week
- ▶ 2 days OFF and/or Level 1 rides (30-45 min.) per week
- ▶ TSB should be positive or nearly neutral at end of period

PHASE II: COMPETITION

Short (<25 min.) TT Emphasis

Period 4: specificity/taper (10 days)

- ▶ 1 FTP test (30-40 min.)
- ▶ 2 practice TTs of similar terrain/duration, using TT bike and all equipment
- ▶ 4 Level 2 rides of up to 1.5-2 hr.
- ▶ 4 days OFF or 30-45 min. Level 1
- ▶ TSB should be positive at end of period

Long (>30 min.), Hilly TT Emphasis

Period 4: specificity/taper (10 days)

- ▶ 1 FTP test (40-50 min.)
- ▶ 2 practice TTs of similar terrain/duration, using TT bike and all equipment
- ▶ 4 Level 2 rides of up to 1.5-2 hr.
- ▶ 4 days OFF or 30-45 min. Level 1
- ▶ TSB should be neutral or slightly positive at end of period

PHASE II: COMPETITION

Period 5: racing and recovery (up to 6 weeks)

- ▶ 1 midweek and 1-2 weekend races interspersed with Level 1, and occasional Level 2 rides, depending on time between races

Period 6: recover and rebuild (4-5 weeks)

- ▶ after an initial week of low volume and intensity, endurance/threshold are rebuilt with Level 2/3 rides
- ▶ increases in training load from week-to-week (the 'ramp rate') are higher than in Period 1
- ▶ Level 6/5/4 "combination" workouts are used to "refresh" anaerobic capacity and maximal aerobic power

Period 7: racing and recovery (5 weeks)

- ▶ 1 midweek and 1-2 weekend races interspersed with Level 1, and occasional Level 2/3 rides, depending on time between races

PHASE III: OFF-SEASON

Period 8: stabilization and maintenance (14-18 weeks)

After a 1-2 week hiatus, cycling continued at up to ~50% the previous season's peak weekly load (including maintenance of each energy system), supplemented with aerobic activities such as skating or x-c skiing, plus some strength training. Muscles, tendons, and joints are allowed to recover and rebuild through "active recuperation," rather than rest alone. Adjustments to bicycle fit and any lingering medical issues should also be addressed at this time.

Useful 'Cogganisms'

1. "Training is testing, and testing is training."   4. "The best predictor of performance is performance itself."
2. "Alls I can do is alls I can do."   5. "It's an aerobic sport, damn it!"
3. "The more you train, the more you can train."   6. "Specificity, **specificity**, <u>**SPECIFICITY!**</u>"

The top 10 things I've learned from using a power-measuring system

1. As Andrew Coggan is fond of saying, "Specificity, **specificity**, <u>**SPECIFICITY!**</u>" – but don't neglect progressive overload. The body responds optimally to steady, gradual increases in training stress that produce moderate fatigue, and the use of power information to more precisely apply the training "dose," coupled with a periodized plan that allows a progressive training load to be consistently sustained, are the most important use of a power-measuring system.

2. The plan is more important than the powermeter. Formulating, keeping to, and adjusting or revising a seasonal plan goes hand-in-hand with training by power. Gauging intensity is only part of the equation; managing training load and duration among each training level requires an individualized plan that is laid out logically and progressively in relation to competitive goals and rider characteristics. It may take a season or two to gain a sense of what is optimal, and until then, "Better to undertrain a little than overtrain," at least in the early season.

3. During time trials and intervals, pacing is a top priority, and the integration of power and PE (rather than HR) should determine intensity: PE modulates power, while power provides an objective reference standard that 'calibrates' PE. I knew the importance of pacing before training by power, and did it the best I could, but the powermeter showed me how far off I was. HR might be useful in the initial conversion period to power, and as a measure of intensity during indoor training, but like PE, it responds slowly to the demands of cycling, making a powermeter nearly indispensable in the early going of most any time trial/interval session, although the importance of PE increases on an unfamiliar or technical/hilly course.

4. Progress comes incrementally rather than in dramatic fashion, and so is best assessed, not from day-to-day, and perhaps not even week-to-week, but from one training phase to the next, and even year-to-year. Patience is a virtue, and good things take time – this is not merely a wise aphorism that is 'good for the soul,', but is also true of physiological adaptation (years of intense, specific training correlate with lactate threshold).

5. Don't over-analyze. For well-paced, "isopower" workouts, a surprisingly small amount of data and rather simple post-hoc analysis can be used to summarize the session, and if judicious use is made of the interval feature (on the Power Tap), downloading may not even be necessary. (Note: this observation was made before the advent of NP, TSS, CTL, ATL, TSB, etc.)

6. The better you recover, the better your workouts will be, and the more progress you will make. Diet, rest, non-training stress levels, and massage all have a direct impact on the extent and quality of recuperation. Like many of the other points made here, I already knew this, but the powermeter has further demonstrated and reinforced it.

7. Forget sprinting. The powermeter has taught me that I stink at it. It's taught me I'm bad at everything else, too – but especially so at sprinting.

8. My C_DA. Wind tunnel testing is still the gold standard for determining effective frontal area, but aero testing with a powermeter, if done carefully, may help refine position in combination with visual guidelines.

9. Don't worry about stopping to turn around or for stop signs during interval training. If kept brief, it doesn't ruin the workout.

10. As discussed previously, training by power and a structured plan are not for everyone. For some, it's just too much hassle, and training by HR or 'feel' alone *does* produce improved performance – but most likely to a lesser extent than with the proper plan plus a powermeter.   – *Charles Howe*