Empower your training

Power-measuring systems can help the competitive cyclist maximize training and performance

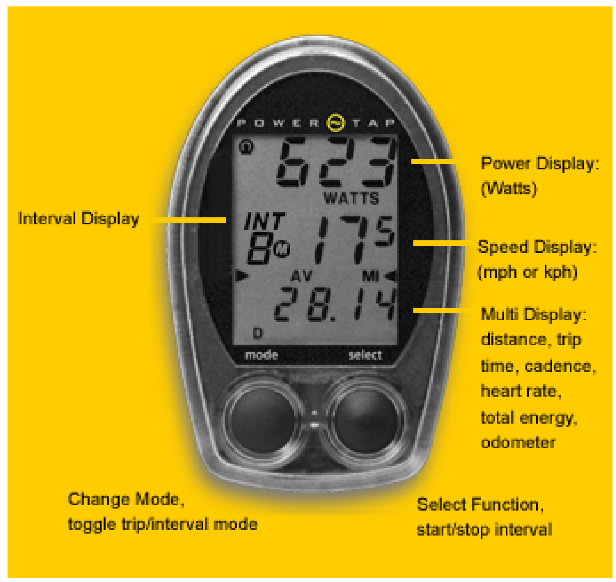
BY CHARLES HOWE

Cyclists are confronted with a constant stream of technological developments that claim to improve performance. Most often, these fall into the category of mechanical devices or "breakthrough" nutritional supplements, and many are of unproven benefit or questionable value.

One of the most promising trends of the last several years has been the introduction of affordable and accurate on-bike power measuring systems, which consist of a force-measuring device, such as strain gauges placed in the rear hub or bottom bracket; a handlebar-mounted computer with digital display and associated wiring which transmits the signal to the computer; a computer interface for downloading workout data to a personal computer; and software which allows interpretation of the data. These systems enable the rider to precisely quantify her power output, or the rate at which work is performed, both during the ride (for purposes of controlling workout intensity) and afterward (for further analysis).

cyclingnews.com

A PowerTap computer and hub (disassembled).



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The PowerTap computer.

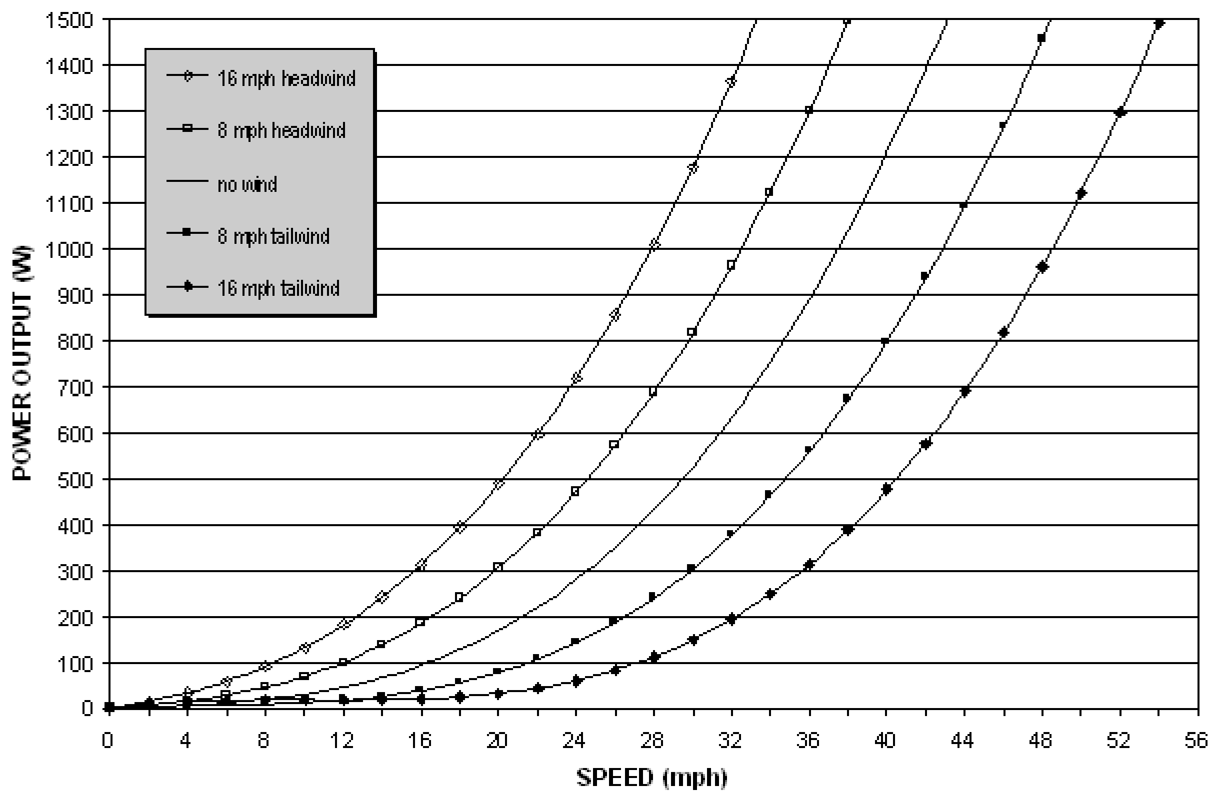
What is power?

Power is the rate of doing work or transferring energy, such that power = work/time, or $P = W/\Delta t$. As relates to cycling, it is measured in international system (SI) units called Watts (W), rather than the familiar English unit of horsepower that is used as a measure of engine power (1 horsepower = 746 W). Since work = force applied through a distance, or $W = F \times \Delta x$, the above equation can be rearranged to express power as the product of force and speed $P = F \times s$, and this may be the best way to think of it: *the speed you are traveling times the total force resisting your forward motion.*

Similarly, power can be defined as pedal force × cadence, which means that you can increase power by exerting more force (pressure) on the pedals at a given cadence, by increasing cadence while exerting the same pedal force, or by doing both. Here are some examples that give an appreciation for units of power:

56.5 W are required to raise a 20 lb dumbbell 25 in. overhead in one second. For his 1994 World Hour Record, Miguel Indurain averaged 510 Watts, or ~6.4 Watts per kilogram.

A 57 kilogram (125 lb) rider traveling on a 9 kg (19.8 lb) bike at 16 mph in on flat ground in calm air requires about 93 W; at 18 mph, this increases to 127 W; at 20 mph, 169 W; and at 22 mph, 220 W. Thus, the power requirements of flat terrain cycling are non-linear:



Effect of wind on power as a function of speed on flat terrain (bicycle/equipment mass = 66 kg).

Why train by power?

Three variables to control in any training program are intensity, duration, and frequency; of these, duration and frequency are easy to quantify objectively – the former is measured in hours, and the latter in sessions per week (the product of the two is volume). Intensity, on the other hand, has traditionally been measured by speed, perceived exertion (PE), and/or heart rate (HR). Power, however, is the true measure of how hard you are working, and as such it directly determines both physiological and perceptual responses to exercise.

It has always been possible to gauge intensity by "feel," or perceived exertion (PE), either on a 10-point scale, or the original 6-20. PE is subjective in nature, with its precision limited accordingly, and yet, perceptual responses to exercise are an *extremely* important source of feedback during training, since they actually integrate more physiological variables than HR, and may be used to modify wattage goals as seems necessary.

In their initial attempts to quantify exercise intensity, cyclists naturally took their cue from distance runners by adopting pacing guidelines (for time and distance) to gauge intensity. Such an approach may have some reliability at a given velodrome, so long as temperatures do not vary significantly and the air is calm, but is unlikely to be useful under the ever-varying grade and wind conditions present on the road, with the possible exception of a standardized (and sufficiently steep) uphill course.

It is lamentable that heart rate monitors preceded power meters to market, rather than the other way around, since HR has become equated with exercise intensity in the popular mind. HR tracks well enough with power at low, steady intensities, where it provides apparently more "stable" feedback than power, due to the cardiovascular system's slow (lagging) response to the rapid changes in intensity so characteristic of road cycling, so it can be useful for relatively easy, steady-state endurance rides, but as wattage increases and/or becomes more variable, the correlation between HR and power becomes weaker, and HR becomes less and less reliable as an indicator of exercise intensity. Furthermore, HR is subject to numerous environmental and physiological factors: lowered barometric pressure at higher altitudes, environmental heat, dehydration, upward "drift" as exercise progresses, lack of sleep, time of day, medication, recent illness/infection, diet (e.g., caffeine), psychogenic factors (e.g., nervousness), and possibly even position on the bicycle (such as when time trialing), are all documented to elevate HR. On the other hand, it is normal for HR to be depressed by recent heavy training, or by accumulated fatigue/lack of recovery (overreaching). Finally, mere day-to-day variability in HR can be up to 4%, whereas performance, as measured by power, is normally reproducible to +/-2%.

Thus, each of these attempts to quantify intensity serves as a kind of 'filter' which introduces 'noise' that obscures the stress load being imposed – and power output itself is the actual stress load. One physiological measure – VO_2, or the rate of oxygen uptake – can serve as an accurate proxy for energy expended, however, it responds as slowly to exercise demands as HR, and cannot practically be measured "in the field."

The beauty of power is that it serves as a "bottom line" index of performance, integrating the three physiological determinants of endurance performance: maximal VO_2, the percent of VO_2 that can be sustained (lactate threshold), and efficiency, which is the ratio of work output to the amount of internal energy expenditure it requires.

BENEFITS OF POWER-BASED TRAINING

1. *It eliminates guesswork from gauging exercise intensity.* Even those with exceptional "feel" are unlikely to judge their wattage any better than to within perhaps 10%, whereas a power meter is accurate to +/-2% or less, enabling workouts – the training "dose" – to be carefully controlled.

2. *It allows performance to be precisely quantified, and training load to be more realistically assessed and effectively managed.* In conjunction with a progressive, periodized program, training becomes less haphazard, and advanced analytical tools, such as those incorporated in CyclingPeaks Software, allow peak performances to be more predictably achieved, while helping to prevent overtraining and injury.

3. *Power data from races allows training programs to better prepare riders for the actual demands of competition.* From the graph below of Dede Demet-Barry's win in the Women's World Cup in Montreal a few years back, for instance, we can see the demands of the race with each of the 11 ascents of Mont Royale. The race as a whole can roughly be broken down into two parts: the first 159 minutes, where average power was 197 W, and the final 19 minutes in which she averaged a full 100 W more as she broke away en route to a surprise win after a 20-month competitive hiatus. For the inspiring story of this memorable race, see Giana Roberge's account at cyclingnews.com. Now, back to the sci-geek stuff! ☺

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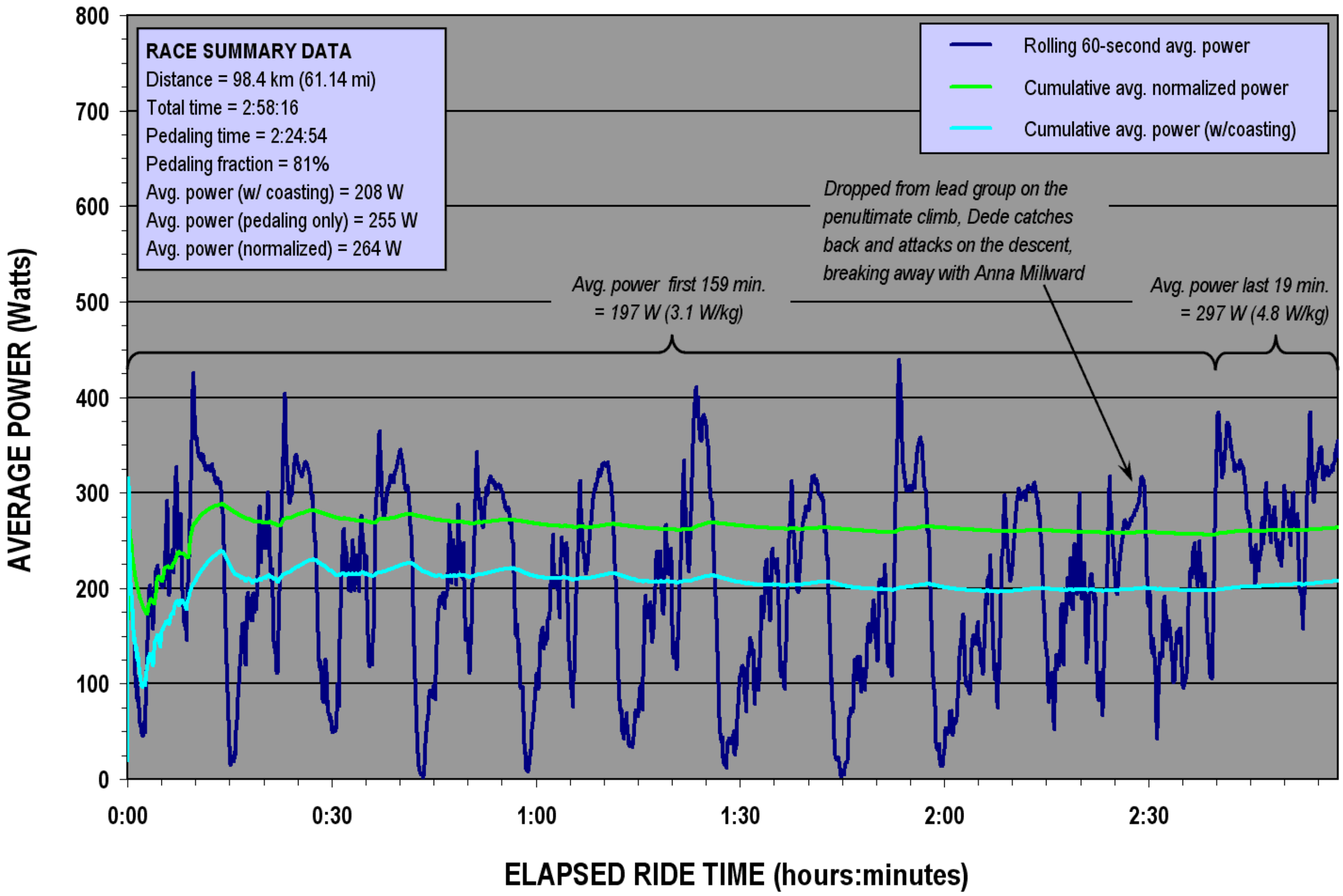
Montreal Women's World Cup, 1 June 2002

Marked by Anna Wilson (Saturn), Dede Demet-Barry breaks away in what would prove the winning move. Note the turned-down power meter on her handlebars!



Power data from Dede Demet-Barry's winning ride at the 2002 Montreal Women's World Cup.

4. *Power meters have other uses, such as pacing during interval training and time trials, aerodynamic testing, indoor trainer calibration, and perhaps even as an aid to weight control and dieting.* Although time trialing may seem like an obscure specialty within the sport, its basis (i.e., measured, paced intensity) has many applications in mass-start racing, such as bridging up to a breakaway or chase group, and (more obviously) the solo breakaway. A power meter can help even experienced riders refine and sharpen their sense of pacing. For time trials themselves, it is indispensable for pacing on all but the shortest and most technical/hilly of courses, where there might not be convenient opportunity to monitor the computer display.

Since they accurately measure energy output in kilojoules (kJ), power meters can be used to *estimate* metabolic energy expenditure in kilocalories (simply "calories" in common usage.) Since the body is ~20-25% thermodynamically efficient, this roughly cancels out the unit conversion factor (4.184 kJ = 1 kcal), and the work accomplished in kJ during a ride is pretty near equal to kcal burned by the body. Unfortunately, efficiency varies during a ride, increasing directly with intensity, and it must be determined in a lab, but here are factors for converting kJ to kcal over a range of values for efficiency:

If you are 25% efficient, kJ × 0.96 = kcal
for 23% efficiency, kJ × 1.04 = kcal
for 21% efficiency, kJ × 1.14 = kcal
for 19% efficiency, kJ × 1.26 = kcal

DRAWBACKS TO TRAINING BY POWER

As useful as power-based training can be, it is not without its limitations:

1. *Even the most affordable models are still 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." Power meters 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. It should be emphasized too that a power-measuring system is not needed by beginning riders, who need to learn basic skills first, while gaining a sense of judgment and proportion in their training.

2. *It lends itself to a structured program, while demanding discipline and patience.* Use of a power meter 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 from through cycling.

3. *It is conducive to (but does not require) solitary training.* Power-based training works best when referenced to the rider'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. *It requires a degree of technical sophistication.* Not everyone is inclined, whether by background or temperament, to take a quantitative approach to training. For such individuals, a coach may be necessary (yet another expense).

In summary, an accurate and reliable power-measuring system can bring greater precision to quantifying intensity and overall training load, in order to optimally prepare the energy systems specific to competitive demands. To be used effectively, however, it requires discipline and perhaps a change of training habits, as well as specialized knowledge from the rider and/or coach. Its use should be preceded by a mastery of basic racing skills, as well as an individualized, appropriately-structured training program.

For further reading

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

The Ergomo (introduced 2002) is a torque-measuring bottom bracket available in square-taper or Shimano OctaLink (see also BicyclePowermeters.com).

The iBike Pro (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.

In 2001, 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. Sandiway Fong has set down some very complete set-up instructions for the original model, the S710.

The Saris/CycleOps Power-Tap (1998) is a torque-measuring hub that you build into a wheel.

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 Quarq CinQo (announced August 2007) is a spider with 10 strain gages that is compatible with (i.e., bolts on to) several crankarms currently on the market, and transmits data via wireless digital RF to the Qranium, a handlebar-mounted computer that promises many advanced features.

(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. This may be accurate enough on steeper grades, but is useless on flat terrain, particularly in group rides or if any wind is present.)

Finally, CyclingPeaks is an aftermarket software package with many advanced analytical tools.

Knowledge, in this case, is truly power, and the last few years have produced a robust discussion of power-based training:

FAQ for power-based training   trainwithpower.net

Still have a question after visiting those two? The Wattage Forum can provide ready help and advice from that list's many members, as can the power training section of cyclingforums.com, while CyclingPeaks offers a dedicated forum for users of its software.

Training and racing using a powermeter: an introduction (PDF, 495 KB), by Andrew Coggan, Ph.D., was 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.

The Road Cyclist's Guide to Training by Power, by Charles Howe.
Part I: An Introduction (PDF, 1.1 MB)   Part II: Advanced Topics (coming later)

Power: the Ultimate Training Metric (PDF, 1.4 MB), by J.P. Partland.

They may be commercial in purpose, but the CyclingPeaks, FasCat Coaching, Velodynamics, and PowerTap sites have numerous useful articles. biketechreview.com, although conceived as a testing site, has numerous useful articles related to power-based training, and although the active site was overrun by hackers, the archived version of bicyclewattage.com can still be accessed.

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

Among personal web sites, Robert Chung brings a statistical analyst's insight to power data (original site here); Scott Thor uses power information to analyze his training and racing; and Steve Wagner's powertapgeek.com bills itself as "All things PowerTap – news, tips, reviews, training, data files, & more!"

Charles Howe has been involved in the sport of cycling since 1973 as a tour director, race promoter, official (road, Cat. 2), club officer, and even (gasp!) as a recreational/competitive rider. A strong advocate of power-based training, his interest in cycling power output dates to the early 1990s, when he wrote a brief article which modeled the effect of weight reductions on bicycle performance for the now-defunct Cycling Science *magazine. A frequent contributor to the Wattage Forum, has also written the above-referenced FAQ on power-based training and training guide, while more recently founding trainwithpower.net, an informational web site for power-based training. After advising riders informally for several years, Howe founded Velodynamics in 2005 to meet increased requests for technical assistance.*