POWER TAP

TRAINING WITH POWER

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This is the second version of "Training With Power." Two years ago, in 1999, my purpose in writing the original guide was to accelerate the learning curve as other coaches, athletes, and sports scientists began using and writing of their experiences with power-based training. Surprisingly, there has been little written in the popular literature on this topic in the last two years. However, I have now coached scores of cyclists and triathletes who have trained with power and have a greater depth of understanding of its use. Based on this experience I have revised and expanded the original guide. Much of the original remains unchanged. The most significant new portion is in the section "Power and Heart Rate Training" where I expand on the concept of combining power and heart rate into a single workout.

If you're new to power-based training you may find the information in this guide overwhelming. There is a lot of material here including concepts that may be entirely new to you. Much of it is technical. As with any new technology the range of options can be confusing at first. To get started training with power I suggest merely riding with your Power-Tap for several days while becoming acquainted with its many functions. Pay special attention to the instantaneous power outputs you produce when doing familiar rides and workouts-easy rides, climbs, tempo, and sprints. Notice what happens to power when you shift gears. Try the interval mode. After every ride check your average power, max power, and energy expended. Along the way gradually begin to incorporate power as a determiner of training intensity. Test and establish your "Critical Power" zones over the course of a few weeks. Eventually, what you read here will begin to make sense and soon you will find yourself thinking of cycling performance in terms of power. But the best part is that your fitness and racing will improve as monitoring power improves your training.

WHY POWER?

Workout duration is easy to measure. How far did you ride? How many minutes were you on the bike? It's so easy that we've typically equated the distance covered in training with fitness. "I've been riding 400 miles a week," is just another way of saying, "I'm in great shape." And yet research shows that the most profound physical responses occur when the focus of training is on intensity rather than on duration. Monitoring training intensity is therefore critical to improvements in performance. You will see that the most effective, accurate, and meaningful way to monitor intensity is by measuring power. Power cuts through all of the compromising factors that dilute the significance of time, distance, speed, or heart rate as measures of performance.

In the last few years the importance of intensity for peak fitness was more likely to be accepted by athletes due to the increasing use of heart rate monitors. The problem is that many athletes have come to believe that heart rate is the only valid indicator of workout intensity-and even of performance. Indeed, it is a good way of peeking into the body to see what is happening during a ride, but there are many other ways of gauging intensity. Let's briefly examine all of them.

Rating of Perceived Exertion (RPE)

Before heart rate monitors, or even handlebar computers, athletes gauged workout intensity by rating their perceived exertion. Today all riders still use this method, although often unknowingly. They might say that a ride was "hard," " moderate," or "easy." These terms are vague, but they convey to others something about the intensity experienced during a workout or race. To improve the accuracy of using RPE, 1-to-10 and 6-to- 20 scales were developed so the athlete could express intensity with a number.

Regardless of the rating system used, it has been demonstrated that experienced athletes have a well-developed sense of exertion. They are so adept at monitoring the body's many systems-such as breathing, muscle fatigue, and lactate build-up-that most can pinpoint intensity, such as the lactate threshold exertion level, almost as well as a scientist can using all sorts of sophisticated equipment. This makes RPE a valuable method for gauging intensity.

The major problem with using RPE is its subjectivity. Using RPE requires the rider to become skilled at paying attention to his or her body-often while in the heat of an event or hard workout. While a valuable skill, that can be hard to do. There is also a tendency for riders to underestimate their exertion level to appear tough or brave. A RPE valuation should not be influenced by one's ego referenced against another's perception, but rather a cold and calculated judgement.

Figure 1 illustrates a typical RPE response when climbing a hill and then coasting down. Note that RPE rises when climbing a long hill even though the pace remains constant. This is due to the onset of fatigue.

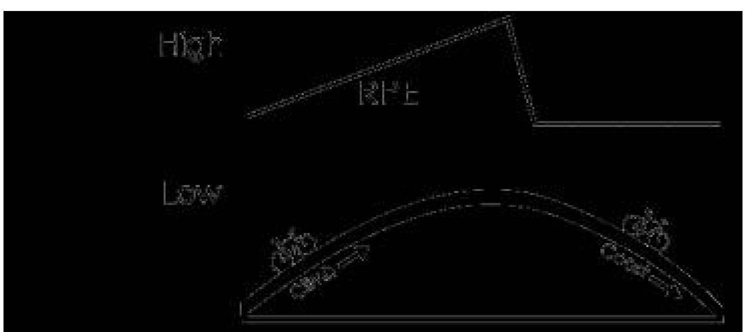

Figure 1 RPE while Climbing and Coasting

Velocity

Accurately measured velocity is readily available to every rider at a reasonable price, and is also easily used and understood. For example, if the goal is to break one hour for a 40-km individual time trial, one must produce an average velocity greater than 40 kph (24.8 mph).

The downside of using velocity to measure cycling intensity is that it is greatly influenced by environmental factors such as wind and hills. In our 40-km time trial example, if a variable and shifting wind is at the rider's back for the first 20 km on an out-and-back course, the challenge becomes to decide how fast to ride given these conditions. Throw in a few minor grade changes and the equation is even more complex making it difficult to accurately gauge progress toward the goal time.

Climbing a hill and then coasting down the other side creates a velocity curve that is nearly the opposite of the RPE curve for the same hill. This is shown in figure 2.

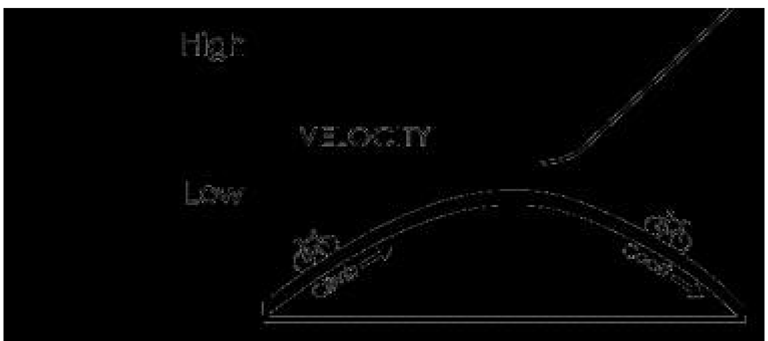

Figure 2 Velocity while climbing and coasting

Heart Rate

In the early 1980s the wireless heart rate monitor was introduced and it revolutionized training. As coaches and athletes became more sophisticated in using heart rate to measure intensity, training changed. The heart rate monitor not only allowed us to reach for and assess intensity, but also to set upper limits on training intensity in order to allow for recovery. With an accurately measured heart rate, training over a broad range of intensities was encouraged.

But heart rate-based training has its limitations. One is that heart rate is subject to certain conditions-such as air temperature, humidity, nervousness, and diet. These conditions confuse the relationship between heart rate and RPE when compared with velocity. For example, a ride at a standard velocity feels more difficult (higher RPE) and the heart rate is elevated when the air temperature is high.

Another limitation of heart rate-based training is the time lag that occurs between a change in intensity and the resulting shift in heart rate. For example, at the start of an interval, heart rate takes several seconds, or even minutes, to "catch up" with the RPE. It also takes some time for heart rate to drop following an intensive effort. This "lag" may be seen after climbing a hill as demonstrated in figure 3.

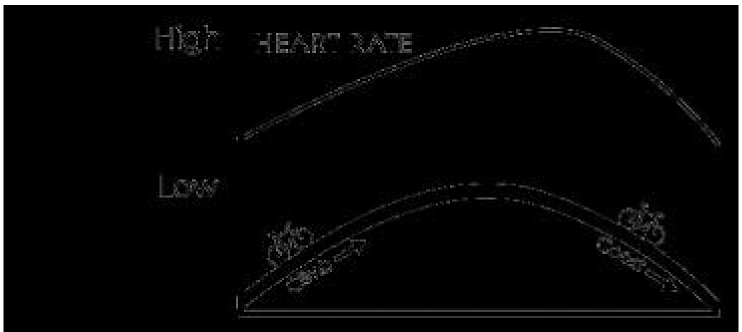

Figure 3 Heart Rate while climbing and coasting

Additionally, during a coasting recovery between intervals, heart rate remains elevated for some time even though pedaling has stopped. For intervals shorter than about two minutes, heart rate is suspect as a valid indicator of intensity. For short repetitions lasting only a few seconds, heart rate is of no value. All of this has led some coaches and athletes to decide that a high-intensity interval doesn't really begin until heart rate reaches the prescribed level. This unnecessarily lengthens intervals, artificially increasing the stress experienced by the athlete. But for longer intervals and steady state types of training, heart rate is effective intensity measuring device.

Lactate

Scientists in laboratories have been able to accurately measure lactate within blood samples for decades, but it wasn't until the mid-1990s that measuring lactate on the road, trail, or track was possible for the average rider.

Lactate accumulation in the blood is an effective indicator of effort. When carbohydrate is converted to energy within the muscle cell a by-product is lactic acid. As this acid seeps out of the cell and into nearby capillaries, it changes chemical composition by giving off hydrogen ions with the resulting blood-borne salt called "lactate." Since carbohydrate is continually used to produce energy, even at rest, lactate is always present in the blood. At low activity levels, the body efficiently removes it so that there is no accumulation. But as exercise increases in intensity more lactate is produced. Eventually so much is pouring out of the muscles that it can't all be processed. As a result, lactate collects in the blood. The point at which accumulation begins is called the "lactate threshold" (LT). Determining lactate levels, therefore, is an accurate way of measuring intensity: The more lactate in the blood, the greater the intensity of exercise.

There are four problems with using lactate to gauge effort. The first is that it requires sticking needles into a finger or ear lobe. Few of us enjoy such treatment and it is not possible during a ride. The second problem is that the blood collection technique requires precision that can be difficult in a workout. The third is that lactate measurement does not provide instantaneous feedback. There is a delay of minutes, if not days, in getting the information. For this reason lactate measurement is best used in a testing situation, such as confirming lactate threshold or measuring fitness improvement in a lab or other controlled setting. Finally, lactate production, like heart rate, lags behind the athlete's effort-it's not a "real-time" measure of intensity.

The lactate curve produced when climbing and coasting down a hill is similar to the heart rate curve, as is shown in figure 4.

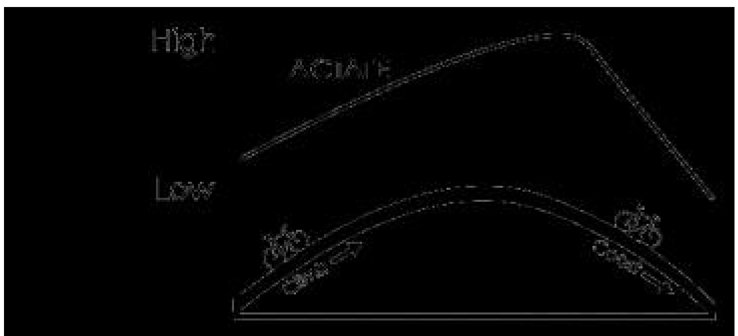

Figure 4 Lactate while climbing and coasting

Power

Power is a direct measure of the rate of work produced by a cyclist. If there is a certain amount of work to be done, such as riding up a hill, the faster you get it done the more power it takes. Or if a greater amount of work is done in the same amount of time, more power is required. For example, if you and a friend ride to the top of a hill together, and the combined weight of your friend's bike and body is twice yours, he produced twice as much power on the climb. On the other hand, if he took twice as much time to climb the hill, your power production was equal.

Power is expressed in equations as:

Power = work / time

Power = force x velocity

With regards to cycling, what this equation is telling us is that power is determined by pedal force multiplied by leg speed. So, as force applied to the pedals goes up with constant pedal speed (or cadence), then power goes up. Conversely, if cadence goes up with constant pedal force, power also increases.

Power, measured in "Watts," is an excellent gauge of training intensity. There are no subjective rating problems as with RPE. Hills and wind don't confuse it as happens with velocity. In contrast with lactate measurement, power information is immediate and doesn't require developing new sampling skills. Power is also more sensitive and responsive to intensity changes than is heart rate.

Figure 5 illustrates what happens to power when steadily climbing a hill and then coasting down the other side.

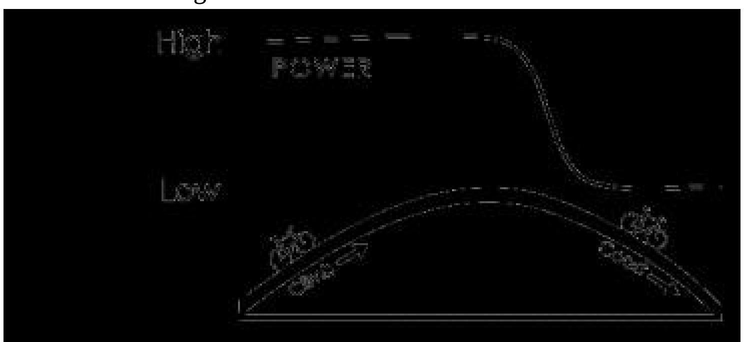

Figure 5 Power while climbing and coasting

We also know that power is directly related to cycling performance. The more power you can generate, the greater your potential is for getting good results in races. For example, according to one study (Hawley, 1992), the peak power produced during a graded-exercise test to exhaustion is a better predictor of a 40-km, time trial race outcome than is aerobic capacity (VO2max). Power-based training allows you to closely monitor and bring about improvements in this critical performance indicator.

If power is such a good thing, why wasn't it available for riders long before now? The answer has to do with technology. Historically, the obstacle to using power to measure intensity on the road, trail, or even an indoor trainer was the cost of accurate, reliable, and lightweight equipment. With the Power-Tap, precise power measurement on a bike is only now coming within the financial reach of most riders.

Multisystem Training

Training is most effective when multiple intensity measures are concurrently monitored. Up to now, cyclists have been able to do this using RPE and heart rate. But as previously shown, these have serious limitations. Power monitoring remedies this situation. With power the rider sees the world of training more completely than ever before. It's like the difference in viewing a picture in three dimensions rather than only two-everything is clearer. Training makes more sense. Let's take a look at how this may occur.

Figure 6 shows what happens as the hill is climbed at a steady velocity and on the downhill section as pedaling stops and velocity increases with gravity pulling on the rider and bike. Notice that as the hill is climbed, RPE, heart rate, and lactate increase. During the downhill coast RPE quickly drops, heart rate continues to increase even after the hill is crested and the downhill coast begins, and lactate follows a similar curve. Both heart rate and lactate are telling the rider his or her level of aerobic conditioning-the steeper the decline toward resting rates of these two measures, the greater aerobic fitness is. During the coast down, heart rate drops rapidly and lactate is quickly removed from the blood in a highly fit rider. These happen more slowly in a less fit person. While coasting downhill the body is trying to "catch up" with the fuel and oxygen demands placed on it by the working muscles during the climb.

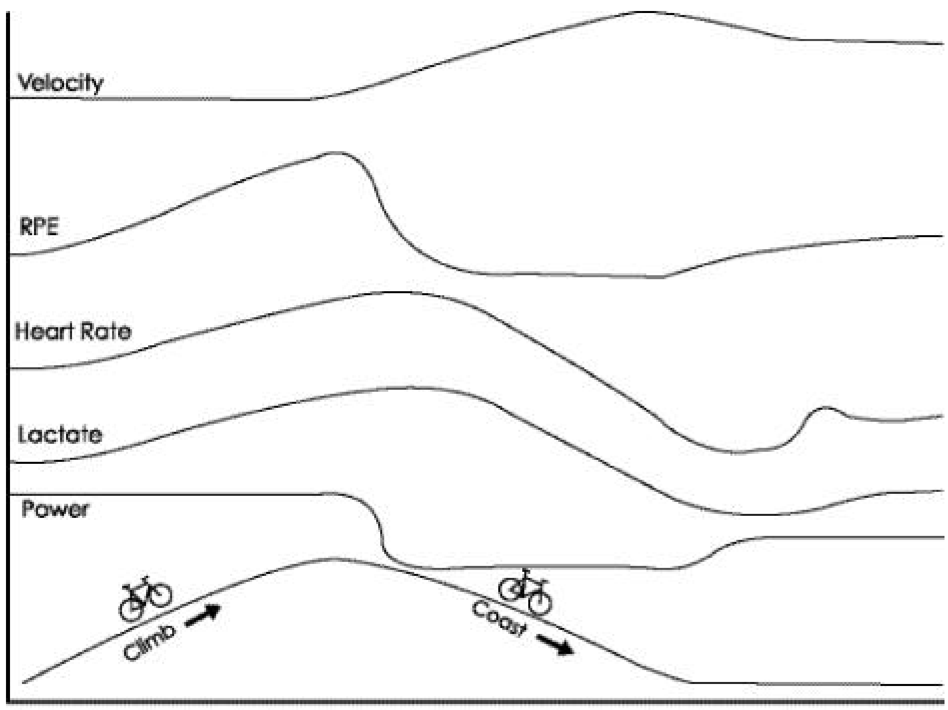

Fig. 6 Comparison of intensity measures while climbing, coasting, and or flat terrain.

Figure 6 shows that during the climb into a head wind, velocity is low and power is high. Both hold steady on the hill climb, although with an opposing relationship. The higher the average power on the uphill, the greater is the rider's performance potential. The same can be said of velocity. Only velocity and power are directly related to performance. RPE, heart rate, and lactate tell us nothing about the rider's ability to climb the hill or quickly cover the flat sections. But they do provide insights into what the rider is experiencing and indications ofaerobic fitness.

Also notice the effect the barking dog has on heart rate-there's a "blip" where the "fight or flight" response is briefly stimulated, but no other markers respond. Had the dog actually come after the rider there would have also been an immediate increase in power, RPE, lactate, and velocity (I hope!).

Blending power with heart rate and RPE provides us with a complete picture of the athlete's experience in riding the course. All are important. Monitoring only one measure of intensity without also monitoring one or more of the others limits training and growth as an athlete.

CRITICAL POWER TRAINING

Now let's look more closely at how to use measured power in training. If you have trained with a heart rate monitor, you are probably familiar with the concept of training "zones." The typical heart rate-based system employs five zones derived from percentages of maximum or lactate threshold heart rates. This system appears to successfully offer particular physiological benefits when training in these heart rate zones, but there is no research to support such a system for power-based training. There are, however, several studies that endorse the concept of training using power (see references below). Don't let the name scare you off; Critical Power is just another way of saying "average power"-the power you can maintain for a given time. Let's further examine this important concept.

Critical Power Zones

Have you ever raced in an individual time trial and expended your energy so carefully that you crossed the finish line feeling totally spent, as if another mile was not possible? If you had a Power-TapÔ that day it would have been possible to determine average power output for the race-what I refer to as the "Critical Power" for that race duration.

Why is this distinction significant? To understand, let's use an example. Say the time trial distance was 20 km, your time was 30 minutes flat, and average power was 320 watts. We could then say that for 30-minutes you are capable of averaging 320 watts. But if the race time was doubled to 60 minutes, would you still be capable of averaging 320 watts? No, because at that power output you would be exhausted at 30 minutes and unable to continue. What if the duration was shortened to 20 minutes-would a higher average power be possible? Undoubtedly, yes, because there would be energy still in reserve at 20 minutes. On this day, however, you were capable of maintaining exactly 320 watts for exactly 30 minutes. This average power output was critical to a 30-minute duration. In the same way, you would have average power outputs for 60 and 20 minutes that would be critical to those durations.

What this means is that for any given duration you have a Critical Power, and by consistently training at or near that Critical Power the ability to perform at that workload improves. And since Critical Power training at any given workload produces physiological adaptations, fitness specific to that workload also improves. Let's use another example to understand this. We know that lactate threshold fitness improves when training near one's lactate threshold, which is the power output that can generally be maintained for about 60 minutes by a fit rider. By knowing the Critical Power for 60 minutes, it's possible to train very precisely using an accurate power-measuring device to optimally stress the physiological systems that limit lactate threshold. It's not a good idea to regularly attempt non-stop, 60-minute workouts at your Critical Power for 60 minutes, but breaking the workout into intervals is quite effective. Such a workout might be 5 intervals of 12 minutes duration each with 3-minute recoveries. The intensity of the work intervals would be the Critical Power for 60 minutes plus and minus 5% thus establishing a training zone. Let's call this zone "CP60." If the 60-minute average power is found to be 300 watts, CP60 is 285 to 315 watts.

$$300 \times 0.05 = 15$$
$$300 - 15 = 285$$
$$300 + 15 = 315$$

In the same manner, Critical Power zones may be determined for other durations that are conceivably related to various physiological fitness adaptations. Suggested Critical Power zones are for 12 seconds (CP0.2), 1 minute (CP1), 6 minutes (CP6), 12 minutes (CP12), 30 minutes (CP30), 60 minutes (CP60), 90 minutes (CP90), and 180 minutes (CP180). Each of these Critical Powers can be determined by simply carrying out a time trial at the prescribed duration using a Power-Tap and then computing a zone by adding and subtracting 5% of the average power. Testing at the longer durations is difficult to determine in training, but it appears that these zones may be predicted by graphing and projecting from the shorter, mostly aerobic Critical Powers of CP12 through CP60.

Table 1 describes how these Critical Power zones may be used in training based on the Workout Types" as described in my books-The Cyclist's Training Bible, The Mountain Biker's Training Bible, and The Triathlete's Training Bible.

Table 1 Critical Power Zones

Critical Power	Workout Type	System challenged	Physiological adaptations
CP0.2	Power	Alactic-anaerobic	Fast twitch muscle development Increased muscle fiber developmen Increased neurological recruitment
CP1	Anaerobic Endurance Speed	Lactic-anaerobic	Improved lactate clearance Increased blood buffering of lactate Improved muscular development Improved economy
CP6	Anaerobic Endurance Force	Aerobic capacity	Increased heart stroke volume Increased glycolytic enzymes Increased blood volume Improved economy
CP12	Anaerobic Endurance Force	Aerobic capacity	Improved stamina Increased stroke volume Slow twitch muscle development Increased oxidative/glycolytic enzymes Increased blood volume
CP30	Muscular Endurance Force	Aerobic-anaerobic	Elevated lactate threshold Slow twitch muscle development Increased oxidative/glycolytic enzymes Improved economy
CP60	Muscular Endurance	Aerobic-anaerobic	Improved stamina Elevated lactate threshold Increased oxidative/glycolytic enzymes
CP90	Aerobic Endurance Muscular Endurance	Aerobic	Improved endurance Elevated lactate threshold Slow twitch muscle development Increased oxidative/glycolytic enzymes Increased connective tissue development
CP180	Aerobic Endurance	Aerobic	Improved cardiovascular endurance Slow twitch muscle development Increased oxidative enzymes Increased connective tissue development Increased muscle fuel storage Increased capillarization
<0.5 x CP1	Active Recovery	Aerobic	Removal of metabolic waste Regeneration

Testing Critical Power

Your Critical Power for each duration may be tested by simply conducting a time trial at the prescribed time length using the Power-Tap interval mode. It's not necessary to test all of the durations. Measuring the five durations on the left end-CP0.2, CP1, CP6, CP12, and CP30-will provide a slope and help project the other Critical Powers. These tests may be completed in a two- or three-day period at the end of a recovery week, every third of fourth week of training. Record the test results in Appendix A at the back of this booklet.

It is important to keep the conditions of subsequent testing periods similar. This means that state of recovery, time of day, pre-exercise meal, weather, course, and warm-up should remain as similar as possible from one test to the next. (It is OK to change gears during a test.) One way to help ensure this is to test on an indoor trainer. One of the beauties of using the Power-TapÔ is that it makes any indoor trainer, regardless of the quality, into a laboratory-quality testing device.

There is a learning curve associated with Critical Power testing. It's possible that the first time you attempt a time trial at a given duration you will go out either too fast or too slow-probably the former. This will cause you to fade before time expires or finish with too much energy in reserve. The average power produced is then not a good reflection of your ability for that CP zone. The more times you do a test duration, the more reliable your results, and therefore your Critical Power zones, become. What should you do if you go out too fast and "blow up?" Stop the test as soon as you sense an inability to maintain power and graph your average power at the terminal duration. It will serve as a good predictor. It is preferable to learn how to pace yourself for any given Critical Power test as this provides the most useable results and is also a skill all accomplished riders must master.

Once you have established Critical Power at each duration, it is useful to construct a "profile." This is a graph that compares Critical Power with duration in order to see your present level of fitness and predict the non-tested durations. Appendix B is a graph you may use to create a personal profile. To illustrate how to do this, figure 7 is provided as a profile for a hypothetical rider.

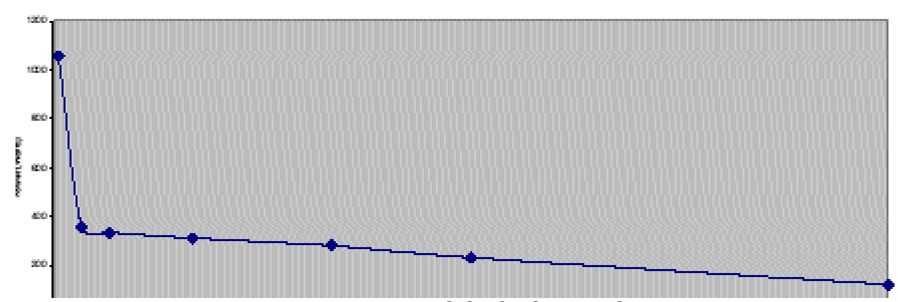

Figure 7 Power while climbing and coasting

Notice in figure 7 that as the duration increases from 12 seconds to 180 minutes power decreases. Also notice that as the duration approaches levels that are aerobic, starting at about 6 minutes, the slope of the line flattens. This makes it possible to predict Critical Power levels for longer durations without the need to carry out exhaustive time trials. To do this, use Appendix B to graph your Critical Powers through CP30. Then extend the slope of the line through CP180.

An attractive feature of power-based training is that power is sensitive to changes in fitness, more so than heart rate. So as your fitness increases or diminishes, previously established Critical Power zones will also vary in the same direction. This makes it necessary to regularly check your Critical Power with self-testing. I recommend this every three to four weeks during the general and specific race preparation periods of training ("Base" and "Build"). A good time to test is near the end of a recovery week when you are likely to be rested and experiencing an increase in fitness. Critical Power zones for the next three or four weeks of training are then based on the results of the most recent tests.

When fitness improves, what you should see when graphing subsequent self-tests of Critical Power is that the line moves up the chart from its previous position. In other words, the average power output is greater. The increases may not always be consistent across the graph-Critical Power at some durations may improve more or less than others. You can expect those that are utilized most frequently in training will improve the most.

Training with Critical Power

The way in which you use Critical Power to train depends on how your personal strengths and weaknesses match the demands of the high-priority events you do. For example, if the event is a one-hour, road criterium, the major demands are Power, Anaerobic Endurance, and Aerobic Endurance (see table 2; for a more detailed discussion of the concept of "limiters" see The Cyclist's Training Bible, The Mountain Biker's Training Bible or The Triathlete's Training Bible as listed under "References"). Let's assume that your Power and Aerobic Endurance are up to the task, but Anaerobic Endurance, especially lactate clearance and buffering is lacking-during and following long sprints and other brief power increases there are signs that lactate accumulation is limiting performance. From table 2 you can see that lactate clearance and buffering improve when challenged by CP1 training. This means that in the last few weeks of the pre-competition period, CP1 workouts should be regularly included.

Your training would also include CP0.2 and CP6 as they are also required for success in the criterium. And since the event is one hour in duration and therefore mostly aerobic, some training is also included at the longer-duration Critical Powers. But the focus is most definitely on CP1 since improvement of this personal "limiter" is crucial to your success.

Critical Power zones may also help you in racing. The best use is in individual time trials which demand a steady workload at a maximal level for the event duration. The slope of your graph may allow you to predict the average power required for the race duration. You may discover that once the Critical Power zone is determined for the race, you are capable of holding a higher output than the actual average power predicted. Racing has the ability to bring out the best in us, physiologically speaking. This is where adding 5% to the average power when determining a Critical Power zone applies. You'll probably be able to time trial near the upper limit of the zone.

Of course, it's also necessary to include recovery days to prevent training breakdowns. Riding at power outputs well below CP180 will provide an optimal, active recovery workload. I've found that riding at less than half of CP12 is effective for encouraging recovery.

Avoiding Overtraining

For the serious cyclist the greatest challenge is to train at a weekly workload that is sufficient to produce maximal fitness without overtraining. This is not easy as the overtraining threshold is constantly changing as fitness changes. The workload one can handle at the start of the early general preparation period of training (Base), say in November, is much different than what the same athlete can manage in the late specific-preparation period (Build) five months later in April. It may take years for the sophisticated rider to develop the skills necessary to evaluate his or her needs given such a moving target without some sort of reliable feedback.

The subjective nature of such decision making further complicates the matter for the self-coached athlete. Often the passion for improvement obscures objective thought. It is at times like this that a more objective mechanism is needed to help make workload decisions. The Power-TapÔ provides this with the total energy expenditure mode expressed in kiloJoules (kJ). This is a measure of the total work accumulated on the bike during the training session.

At the conclusion of each workout session, it is useful to record the total energy expenditure as kJ in your log. By compiling and analyzing this data for weekly microcycles, or even four-week mesocycles, your training limits may be determined and workload may be accurately gauged. This is largely a matter of trial and error, but by planning workouts to stay below the excessive workloads, avoiding overtraining while training at an optimal level is possible. It is still necessary, however, for you to consider other unusual physical stresses, such as yard work or manual labor, as well as psychological stress in order to avoid overtraining.

POWER AND HEART RATE TRAINING

You combine power training with heart rate training in order to produce exceptional fitness. Heart rate is best used in low-intensity, steady, aerobic rides. Such training is good when establishing and maintaining basic endurance. Typically, more than half of a rider's weekly training is done this way with greater amounts in the Base training period and less in the final preparation before an A-priority race. Heart rate works well here.

When the purpose of a workout, however, is to enhance Power, create greater Anaerobic Endurance, develop improved Muscular Endurance for time trial efforts, or build basic leg Force for climbing and driving big gears, power-based, rather than heart rate-based, training is the way to go.

Let's take a look at one way to combine power- and heart rate-based training into a single workout. For the example we'll examine ways to improve Muscular Endurance for events such as time trials and multisport racing. But first, a little background is needed.

Training Muscular Endurance With Power and Heart Rate

There is a physiological middle ground between the lower intensities suitable for heart rate training and the highest efforts best done with a powermeter. This pivotal point is called "Muscular Endurance" (ME). In training and racing, ME is the effort that occurs when you are near your lactate threshold. It combines the abilities of big-gear Force and long-duration Aerobic Endurance.

ME is one of the most basic abilities in bike racing. It is the deciding factor in mountain bike, cross country races; long time trials; and triathlon and duathlon bike legs - especially on relatively flat courses. In road races ME also means the difference between hanging with the group as speed gradually picks up and being spit out the back. On long climbs ME is what keeps you steady and hanging with the group.

ME is a basic requirement of all bike racing regardless of your talent in other areas. For example, even the top sprinters must have solid levels of ME for without this it doesn't matter how good their sprint is - they won't be there to contest the finish.

Combining power- and heart rate-based training into a single workout can fully develop ME. What prevents you from having greater ME is that you eventually go anaerobic when turning a big gear. It may take several minutes, but when riding above the lactate threshold you can feel the lactate accumulating as heart rate drifts higher. If your aerobic endurance could maintain the higher power effort you could stay in that gear and cadence combination longer - perhaps long enough to ride a swifter time trial, hang in with a hard-riding group, or climb a long grade faster.

So the trick is to power the greater gear-inches that eventually cause you to go anaerobic while staying aerobic longer. Since aerobic effort is best measured with a heart rate monitor and upper-end power is best gauged with a powermeter, we can combine the two to get the best possible workout. Intervals are the way to go for this. Use the powermeter to determine top-end intensity and heart rate to decide when the interval should stop. Let's look at the details.

Power-Pulse Training

The first step in combining power- and heart rate-based training into a ME interval workout is to determine what the power output should be for each interval. You could do this by setting a goal power to be maintained for a given period of time based on training and racing experiences when you've had the powermeter on-board. Or, if you're good with numbers and want to be precise, go to http://www.analyticcycling.com and check out the "Power, Given Speed" link. This will guide you through the process of determining what power you'll need to maintain a given speed while taking into consideration air density, frontal area, drag coefficient, and other variables.

Another way is to use a standard critical power zone such as CP12. This is the average power (plus and minus five percent) that you can maintain for 12 minutes. When you found this with a time trial you went deeply anaerobic within a few minutes. But now what we'll try to do is ride at this same power on each interval without going anaerobic.

Plan on doing five work intervals at this predetermined power level within a single session once or twice each week. They may be done on a flat road, track, or hill. It's best to simulate the conditions under which you will be racing when choosing a course. Allow at least 72 hours for recovery between these workouts.

Each interval is done at the selected power level and continues until heart rate exceeds three beats per minute above lactate threshold heart rate. Recover by spinning easily for a time that is about one-fourth of the preceding work interval's duration. So if the work interval lasted eight minutes then the recovery is two minutes.

What will probably happen as you do the five intervals is that each will be shorter than the previous one. But as fitness at this power output improves the intervals will get longer meaning the workout time accumulated at the high workload will also increase. This is what you're after - the ability to maintain a higher power output for a longer time.

If you do one or two of these sessions weekly it may take six to 10 weeks to achieve your power-duration goal, assuming it was reasonable at the beginning. If you haven't achieved your goal by 12 weeks either the goal was too high relative to your potential or you are overtrained.

CRITICAL POWER ZONE WORKOUTS

Now that you understand the concept of training with power, let's get down to your primary interest-power-based workouts. The following workouts are grouped into six categories that correspond with Table 1. The first three categories Aerobic Endurance, Force, and Speed-are the most basic and should be included in the general preparation (Base) period of training. The last three-Muscular Endurance, Anaerobic Endurance, and Power-are more advanced, race-specific categories applied in the specific preparation (Build, Peak) training period. The exception is Muscular Endurance that may start at a low to moderate volume in the late general preparation period and continue to increase into specific preparation.

What follows is not an exhaustive listing of the workout possibilities, but simply a few examples of how to train with power to improve basic cycling fitness in each category. With a little creativity and reference to Table 1, many more may be devised to fit your exact needs and training environment. For guidelines on how to use heart rate and RPE to gauge intensity in these same workouts, see The Cyclist's Training Bible, The Mountain Biker's Training Bible, and The Triathlete's Training Bible. These books will also offer instruction on how to plan and organize the workouts within your season.

Warm-Up and Cool Down

Each of these workouts assumes that you have completed a thorough warm-up before starting the high intensity portion. In its most basic format, this means the power output at the start of the ride is well below CP180 and gradually rises during the first several minutes of the training session. At least 10 minutes of such warm-up is necessary, but more may be useful depending on your capacity for workout duration and the nature of the training session. The cool down following the workout is a subdued, mirror image of the warm-up, although it may be shorter.

Interval Mode

Many of the following workouts are intervals. On your Power-Tap there is an interval mode. Become acquainted with this as you will be using it frequently. For short work intervals, on the order of five minutes duration or less, it may be helpful for you to use the average power function of the interval mode. This will allow you to closely monitor how the session is progressing. For longer intervals staying in the instantaneous power function is best so that you can monitor and maintain power outputs on each interval. Regardless of which you use, after each interval confirm that your average power was in the appropriate critical power zone. If average power is below the zone you need to decide if you can go faster without overextending yourself or if you are already at your limit. If the latter is the case then the interval session should be stopped.

Aerobic Endurance Workouts

Aerobic Endurance training increases respiratory and cardiovascular fitness. These are based on long, steady rides done at low levels of power.

· **Active recovery.** Ride at less than half of your CP12 power zone in the small chain ring on a flat course or on an indoor trainer. An active recovery ride may hasten recovery depending on your experience and level of fitness.

· **Aerobic development and maintenance.** Ride a flat to gently rolling course with grades slight enough so that you primarily stay in CP180. Power will vary slightly with the course undulations, but should be on the low end of the Critical Power spectrum. These are generally your longest workouts.

Force Workouts

Force training improves muscular strength development. Climbing hills at a moderate power focuses on the muscular system.

· **Hilly endurance ride**. Select a course that includes moderately steep hills of up to 6% grade that take several minutes to climb, or into a strong head wind if no hills are available. Stay seated on all climbs with an emphasis on minimal upper body movement, the work being done primarily by the legs. Maintain cadence at 60 rpm or higher while in CP6 to CP30 on the climbs. On the flat sections ride in CP180.

· **Big-gear climbs.** Find a hill with a moderate, 4-6% grade that takes 1-3 minutes to climb. Select a gear that lowers cadence, but not below 50 rpm, and maintain CP6 while staying seated on each climb. Focus on smooth pedaling. Recover for 2-3 times or as long as it took to climb the hill. When doing this workout the first time, start with about 6-10 minutes of total climbing on this hill within a single session (for example, 3 x 2 minutes). After a few sessions experienced riders may build up to 20-30 minutes of accumulated climbing time in one workout. Be especially cautious with your knees. If you tend to have knee problems avoid this workout. Or, if you sense discomfort at any time, abandon it.

Speed Skill Workouts

Speed skill training develops pedaling and bike-handling efficiency. The emphasis here is on training the neuromuscular system to function in a smooth and synchronous manner. Power output is relatively low.

· **Spin-ups.** On a slight downhill grade, with a tailwind, or on an indoor trainer set to light resistance, gradually increase cadence to maximum over a period of 30 seconds. Maximum is the highest cadence you can maintain without bouncing. Relax as much as possible during each spin-up. Hold your maximum for several seconds. Recover for a few minutes after each. Repeat several times. Heart rate and power measurements, although low, are not significant for this workout, but cadence monitoring is critical

· **Isolated Leg.** On an indoor trainer, place a foot on a chair or stool and pedal only with one leg. Maintain a cadence of 80-100 rpm and concentrate on smoothing out the "dead" spot at the top of the stroke by pushing the toes forward in the shoes as the foot approaches the top position. Change legs when fatigue begins to set in. Repeat several times. While low, heart rate and power are not important for this workout. Monitor cadence.

· **Form Sprints.** Early in a ride do 6-10 sprints on a slight downhill or with a tailwind. Each sprint lasts about 10 seconds with a several-minute recovery. These sprints are done only for form, so select a lower gear than you would normally sprint in and focus on technique. Power is CP1. Do these alone.

· **Off-road handling skills.** If you're a mountain bike rider, the better you become at maneuvering your bike, the faster you'll race. Riders at all levels need to work on these skills weekly throughout the year. Early in the general preparation period (Base) go to a park and practice bunny hopping, jumping, wheelies, balancing, and slalom. As the training year progresses head for the trails and practice those skill elements which cause you the most trouble. These off-road speed workouts generally should be done at a low power output early in the training session. The best time to work on skills is when you are well rested.

Muscular Endurance Workouts

Muscular Endurance is the combination of the Aerobic Endurance and Force abilities. It is apparent in the ability to use a relatively big gear for an extended time. It is crucial to success in time trialing, road racing, mountain bike cross-country, and multisport racing. Long, steady rides done at CP30 to CP90 zones improve this form of fitness.

· **Tempo.** On a mostly flat course or on an indoor trainer, ride at CP90 for an extended time without recovery. The tempo workout is best included in the second half of the session. Avoid roads with heavy traffic and stop signs. Stay in an aerodynamic position throughout while pedaling with your most comfortable time trial cadence. Start with 20-30 minutes of tempo and build to 45-60 minutes by adding 5-10 minutes each week. This workout may be done two or three times weekly.

On a relatively flat course or an indoor trainer complete 3-5 intervals that are 6-12 minutes long. Intensity is CP30 and cadence is what you would use in a time trial. Recover for 2-3 minutes after each work interval. Recovery power is less than half of CP12. This workout is best included in the second half of the session. The first cruise interval workout of the season should total 20-30 minutes of work intervals (for example, 4 x 6 minutes). Increase the duration of each work interval weekly. Stay relaxed, aerodynamic, and closely monitor your RPE by listening to your breathing and paying attention to how you feel. This workout may be done once or twice weekly.

· **Hill cruise intervals.** This is the same as cruise intervals except the work intervals are done on a long 2-4% grade. Use time trial cadence or slightly lower. Complete two or three cruise interval workouts on flat terrain before doing them on a hill.

· **Criss-cross threshold.** On a mostly flat course with little traffic and no stops, ride 20 to 40 minutes alternating between CP90 and CP30 every two minutes. Use your time trial cadence and an aerodynamic position.

· **Threshold.** On a mostly flat course with little traffic and no stops, ride 20 to 40 minutes non-stop at CP60. Stay relaxed, aerodynamic, and monitor your RPE by listening to your breathing and paying attention to how you feel. Pedal at the cadence you normally use in a time trial. Don't attempt a threshold ride until you've completed at least four cruise interval workouts.

· **Shifting cruise intervals.** This is the same as cruise intervals, except shift between a higher and lower gear every 30-60 seconds. Maintain CP30 for 60 seconds and then shift to a higher gear and hold CP12 for 30 seconds. Repeat this pattern throughout each cruise interval. Cadence is what you would use for a time trial. Maintain an aerodynamic position. The maximum, total interval duration for this workout is about 30 minutes.

Anaerobic Endurance Workouts

Anaerobic Endurance is the combination of the Aerobic Endurance and Speed Skills abilities. It is the ability to maintain an efficient and high pedaling cadence for an extended time, as in a long sprint, intense hill climb, or other high-power activities as found in criterium racing, mountain bike cross country starts, and track events. These workouts are done at high levels of power. Most of the flat-course, interval workouts described below may be done on an indoor trainer. If done on the road, seek out courses with no stop streets, few if any intersections, and light traffic. Remain alert to cars around you at all times. Do not focus solely on your Power-Tap.

These workouts should not be done more than twice in a week-only once for most riders-and are best avoided until the last 8-12 weeks before a high-priority event. Over reliance on such training throughout the training year is likely to cause premature peaking, incomplete Aerobic Endurance development, injury, frequent illness, burnout, and overtraining.

· **Anaerobic Endurance intervals.** On a mostly flat course with no stop streets and light traffic, do 4-6 intervals of 3-5 minutes duration. The cadence is high-higher than for the anaerobic portions of your event. Power is CP6. Recover at less than half of CP12 for the same time as the preceding work interval. Stop the workout if RPE seems unreasonably high relative to your power output. In other words, if the workout feels much harder than normal for the CP6 power zone, it's time to stop. Also, if average power for an interval falls below the CP6 zone while RPE feels normal for CP6, it's time to stop.

· **Pyramid intervals.** These are done the same as the above intervals except the intervals are 1-, 2-, 3-, 4-, 5-, 4-, 3-, 2-, 1-minutes in CP6. For the shorter work intervals aim for the higher end of the CP6 zone. The recovery after each is equal in duration to the preceding interval. Recover at less than half of CP12.

· **Hill Intervals.** Following a thorough warm-up, go to a 6-8% hill that takes 3-4 minutes to go up and do 4-8 climbs. Stay seated with relatively high cadence for your event requirements. Power is CP6. Recover at less than half of CP12 by spinning down the hill and at the bottom for a total of 3-4 minutes, depending on the duration of the climb.

· **Lactate tolerance reps.** Do this on an indoor trainer or on a flat to slightly uphill course or into the wind. After a long warm-up including several brief, high-power accelerations, do 3-5 sets of 40-second repetitions. Intensity is CP1. Cadence is very high given your event. Recovery after each rep is 20 seconds at the easiest effort possible. After each set recover for 5 minutes with light spinning at less than half of CP12. The total of all the repetitions should not exceed 12 minutes. Start with about 6 minutes total interval time for the first of these workouts within a season as they are quite stressful. An example of such a workout is 3 sets of 40-second reps done 4 times with 20 seconds recovery after each rep and 5 minutes of recovery between sets. Do this workout no more than once or twice a week and recover for at least 48 hours before attempting another strenuous session. Do not do this workout if you are in the first two years of training for cycling.

· **Hill reps.** After a thorough warm-up, go to a 6-8% hill and do 4-8 reps of 90 seconds each. The first 60 seconds are done seated in the CP6 zone. In the last 30 seconds, shift to a higher gear, stand, and drive the bike to the top in the CP1 zone. Cadence throughout each rep is relatively high for your event, but should be higher for the last 30 seconds. Recover completely for 4 minutes after each rep. Do not do this workout if you are in the first two years of training for cycling.

· **Race simulation.** Ride with a group that is appropriate for your ability level. Treat this as a race by utilizing all of the Critical Power zones required of your event. Be aware of how you feel. If tired, sit in or break off and ride by yourself. If fresh, ride aggressively practicing race tactics common to your event.

Power Workouts

Power workouts combine the Force and Speed Skills abilities. As was previously discussed, power is the ability to produce a high level of work very quickly using a high gear, as in sprinting, especially for short distances. These workouts are essential for track racing, mountain bike downhill, criteriums, field sprints, and any event that requires maximal and nearly instantaneous power production. They may be done up to three times a week once economy and the ability to use high gears have been established with Speed Skill and Force workouts in the general preparation (Base) period.

· **Jumps.** After a thorough warm-up do 3-5 sets of 5 jumps each for a total of 15-25 jumps. Concentrate on producing explosive power from the very first pedal stroke. Each jump is 10-12 revolutions of the cranks (each leg) while standing on the pedals and holding onto the handlebars deep in the drops. Cadence is very high. Intensity is CP0.2. Recover at less than half of CP12 for at least 1 minute between jumps and 5 minutes between sets. Maintain good form on each jump.

· **Match Sprints.** Within an Aerobic Endurance ride include several 10-15 second, race-simulation sprints done at CP0.2. These can be done with another rider or with a group. Designate "finish lines" such as road signs. Employ all of the techniques of form sprints and jumps, only now at a higher and sustained intensity. To improve power there should be at least 5 minutes of recovery between sprints.

· **Hill Sprints**. Early in the workout, after a good warm-up, go to a hill with a 4-6% grade. Do 8-12 sprints of 8-10 seconds each. Use a flying start for each sprint taking 5 seconds or so to build power on the flat approach while standing. Climb the hill applying maximal force standing on the pedals with a high cadence. Intensity is CP0.2. Recover for 5 minutes at less than half of CP12. Emphasize good form.

· **Crit Sprints.** Warm-up and then go to a course with curbed corners, clean turns, and little traffic. Do 6-9 sprints of 25-35 seconds duration each including corners, just as in a criterium. Always seek the best line for each corner. Intensity is CP1. Recover at less than half of CP12 for 5 minutes after each sprint. This may be done with another rider taking turns leading the sprints.

Combined Workouts

Two or more of the workout elements described above may be combined into a single session. For example, an Aerobic Endurance ride done in the late general preparation period (Base) may also include form sprints early in the session and a tempo ride in the latter portion. Generally, it's best to include Speed Skills, Power, Force, and/or Anaerobic Endurance (in that order) early in a training session with Aerobic and Muscular Endurance components last. Combined workouts are especially beneficial in the specific preparation (Build and Peak) period when race specificity is emphasized.

Indoor Workouts

Nearly all of the above workouts can be done on an indoor trainer. One of the benefits of using a Power-Tap is that it turns any trainer into a sophisticated training and testing device. With rear wheel sensing and continual function display on the handlebar computer, the power, interval, duration, cadence, distance, and energy expenditure elements of any workout done are available the same as if you were on the road or trail-and it's always on the bike you're used to using. Plus, you can take your bike out on the road and accurately compare indoor and outdoor power levels.

Indoor training has some advantages over road and trail training. While riding a trainer there are no cars, stoplights, or dogs; hills and changes in wind direction are non-existent; and flats rarely happen. This makes the indoor trainer the perfect place to do many of your workouts and to test Critical Power progress. Although it does not change the power requirement, elevating your front wheel an additional 4-6 inches while on the indoor trainer simulates riding position on hills. About the only aspects of road riding that can't be duplicated indoors are the aerodynamic feedback you get from good and poor bike set-up positions while riding into a wind, and bike-handling skills such as cornering. Indoor trainers are so effective that many top athletes do at least one of their weekly rides indoors year round. Unless training specifically for hot and humid race conditions, whenever you ride indoors set up one or two fans to help maintain body temperature.

When to Stop a Workout

Have you ever experienced difficulty with a workout, such as intervals, and wondered if you should stop it and go home? In the past riders have compared heart rate to RPE or velocity to find the answer. But there are frequently times when these measures don't provide a solution. Power eliminates all confusion on this issue. Whenever your average power fails to achieve a CP zone, or a reasonable power goal is not attained, it's time to stop the intense portion of the session. You are probably not fully recovered.

Safety

It makes sense to familiarize yourself with the Power-TapÔ functions while indoors so you can focus on the computer display without the risk of leapfrogging parked cars. Once you've become adept at navigating the menus and start spending more time on the road or trail, make sure you stay focused on your surroundings and not become overly focused on the computer display.

GOAL SETTING

Success in cycling depends, in part, on how precisely goals are defined so that workouts may accurately produce the desired physiological demands. Power measurement provides the most effective method for ensuring such accuracy. The following are examples of specific performance goals and a key workout for each, expressed in terms of power. A key workout type should be repeated once or twice weekly for four to eight weeks to produce the desired results.

Goal: Break one hour for a 40k individual time trial by riding at an average of 320 watts.
Key Workout: 4 x 10k at 304 to 336 watts average with 8-minute recoveries. Reduce recovery intervals by 30 seconds each week.

Goal: Climb the Manyunk Wall at 660 watts average.
Key Workout: 5 x 2 minutes on a 12% grade at 627 to 693 watts average with 3-minute recoveries. Extend interval duration by 10 to 20 seconds weekly.

Goal: Sprint at 1100 or more watts.
Key Workout: Accelerate from 400 to 1100 watts or more in 12 pedal strokes (each leg). Recover for 5 minutes and repeat 4 to 6 times. Decrease pedal strokes by 1 each week.

FINAL THOUGHTS

Once you begin using power, I believe you'll find, as I have, that there is less guesswork in training and that your performance begins to reflect the subtle changes that occur in your perception of what fitness is all about. In the final analysis, how closely workouts simulate or even exceed the demands of racing determine your fitness levels and eventual race results. Power-based training now makes all of this possible.

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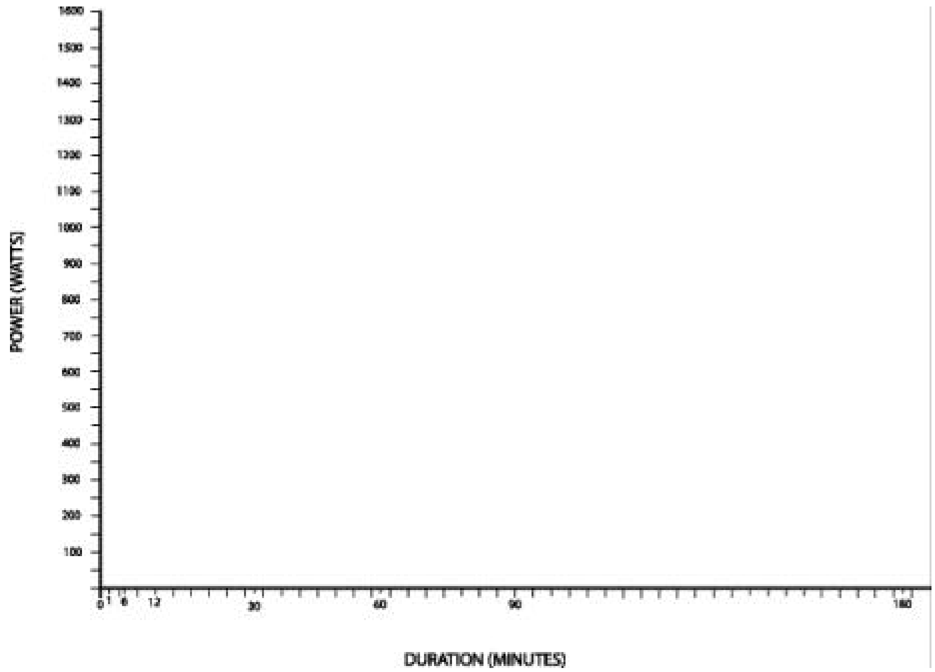
APPENDIX A
MY CRITICAL POWER ZONES

CP Duration	Average Power	CP Zone	Test Date	Test Course
CP0.2	____________	______-______	________	__________
CP1	____________	______-______	________	__________
CP6	____________	______-______	________	__________
CP12	____________	______-______	________	__________
CP30	____________	______-______	________	__________
CP60	____________	______-______	________	__________
CP9	____________	______-______	________	__________
CP180	____________	______-______	________	__________

APPENDIX B


POWER (WATTS)
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
1
6
12
30
60
90
180
DURATION (MINUTES)