THE HEART OF THE MATTER

By Dario Fredrick

One of the simplest and most effective ways to monitor training intensity is by measuring heart rate. The heart rate monitor has become a common tool among endurance athletes but its effectiveness depends on understanding the heart rate response to exercise. Heart rate values are also unique to the individual, so knowing one's individual heart rates at various workloads increases its usefulness in training.

Heart Rate Defined

The heart is basically a pump that actively moves blood throughout the body. During exercise, blood is used to transport oxygen and fuel to working muscles, to transport signaling chemicals (hormones) regulating system functions, and to remove waste by-products. Each heart beat expels a certain amount of blood. This output of blood is measured as stroke volume (SV), while heart rate (HR) is simply the number of heart beats per minute (bpm). The total output of the heart, called cardiac output (Q), is the product of these two measures, stroke volume and heart rate (Q = SV x HR). Cardiac output depends on the demands for blood by the body and is commonly regulated by altering either stroke volume or heart rate.

Thinking about Heart Rate

The best way to think about heart rate in cycling is not as an absolute measure of intensity, but as a floating, gradual response. Heart rate is a variable feedback mechanism to muscular work. The muscular work of pedaling a bicycle can be most directly defined as workload, or angular force (torque) and frequency (cadence). The product of force and its frequency is power (torque x cadence = power). Power measured in watts is the most direct measure of cycling workload.

However, power alone does not tell us how hard the body has to work to produce a particular workload, only that it is producing that workload. This is where heart rate becomes a valuable tool. Heart rate is the body's response to a given workload, representing how hard it's working. Yet this response is not always a real-time gauge, and it can vary significantly depending on a variety of factors. Understanding how and why different factors affect heart rate will allow the athlete to best apply this measurement to training.

Factors Affecting Heart Rate

There are numerous immediate factors that affect heart rate during exercise, both internal and external to the body. These factors include muscular demands, temperature, hydration, sleep, rested state, chemical stimulants and psychological influences. Longer-term factors include training effects such as blood volume, heart volume and contractility.

Muscular Demands

An increased demand for oxygen and fuel by working muscles is the primary influencing factor of heart rate during exercise. Blood carries and unloads oxygen to active muscles so that aerobic metabolism is possible. Glucose and fats are transported to the muscles to be used as fuel. Transport of these substances increases as heart rate increases from rest to submaximal exercise based on their demand.

In cycling, extremely high cadence (low force) pedaling will inflate heart rate for a given power output. In this case, the muscles are contracting and relaxing in quick succession, requiring a high ratio of aerobic/anaerobic metabolism to energize the workload. Aerobic metabolism requires delivery of oxygen and glucose via blood circulation, stimulating heart rate. Furthermore, skeletal muscles act as pumps squeezing and releasing veins that run through them, affecting the rate of blood return to the heart based on their contractility.

Extremely low cadence (high force) results in a lower than average heart rate for a given workload, since high force muscle fibers require a higher energy contribution via anaerobic metabolism. Their fuel supply is locally available as glycogen, relying less on heart rate's delivery of fuel via the blood.

Temperature

Heart rate is directly affected by temperature. One of the most important regulatory functions in the body is maintaining a narrow range of core temperature. Blood makes up about one quarter of the extracellular fluid in the body, and since blood is nearly 60% water, it plays an important role in temperature regulation. About 75-80% of the energy expended to pedal a bicycle is lost as heat. Once exercise begins, the body's means of dissipating this extra heat in order to maintain core temperature is accomplished by circulating blood to the skin. Cooling takes place at the skin's surface where the evaporation of sweat cools the passing blood, returning it back to the core like a radiator. As the body heats up, this cooling mechanism is stimulated, increasing cardiac output by raising heart rate and sending more blood to the skin. Temperature regulation is one of the main reasons for cardiac drift, a significant increase in heart rate not resulting from an increase in workload.

The influence of the cooling mechanism on heart rate becomes very apparent when exercising in the heat. If you measure your heart rate regularly, you have probably noticed on very hot days that your heart rate numbers can be quite exaggerated. Conversely, when the body is not well-warmed up or the ambient temperature is cold, heart rate can be suppressed and underestimate cycling workloads. In this situation, since the body is seeking to maintain core temperature and the external temperature is much lower, less blood is sent to the skin reducing cardiac output via lower heart rate.

Hydration

Since blood plasma makes up a large portion of the body's total fluid, hydration levels affect blood volume. Even with good hydration practices on the bike, it is not possible to keep up with fluid losses during multiple hours of endurance cycling, especially in hotter temperatures. As fluid levels in the body decrease throughout a ride this reduction is reflected in the blood. Total blood volume affects the amount of blood that circulates back to the heart. If there is less volume, less blood returns to the heart, reducing stroke volume with each heart beat. If working muscles require the same cardiac output at a lower stroke volume, heart rate increases to maintain cardiac output (Q = SV x HR). This compensatory mechanism is another direct cause of cardiac drift where heart rate is inflated for a given workload.

Sleep – Rested State

Insufficient sleep can affect heart rate during exercise. Early in a ride at low to moderate workloads, sleeplessness can inflate the heart rate response. In this situation the stress response to exercise is exaggerated, increasing stress hormone production. A similar response is common in an under-rested or overtrained state. For example, if you are not well recovered from hard training or racing, the following day will see a similar early response in heart rate as with lack of sleep. Heart rate will often be inflated at low to moderate workloads, while it becomes difficult, if not impossible to raise heart rate beyond a certain workload. This effect can also be attributed to depleted glycogen stores which reduces the maximum amount of force a muscle can produce, reflected in a lower heart rate response for a given perceived effort.

Chemical Stimulants

Since heart rate is influenced by stress hormone production, chemicals that stimulate these hormones (stimulants) will inflate heart rate. The degree to which heart rate is affected depends on the type and amount of the stimulant taken. The most common stimulant taken by cyclists is caffeine. Caffeine may raise heart rate at lower workloads, but at moderate to high workloads (with normal doses) its effects are diminished. Other stimulants, such as pseudoephedrine found in nasal decongestants, will tend to inflate heart rate at all workloads.

Psychological Factors

Psychological effects on heart rate can be surprising. For example, the anticipation of exercise can raise heart rate significantly. If you have ever noticed your heart rate at the start line of a race, or in any anxiety-producing situation, it becomes apparent that heart rate responds to more than just physical demands. These effects are primarily the result of stress hormone production.

Training Effects – Blood Volume

One of the very first adaptations to aerobic endurance training is an increase in blood volume. This occurs more significantly when untrained people train, but fit individuals experience some change as well when going from a significant rest period to a period of training. One of the effects of increased blood volume is a reduction in heart rate at all workloads, suggesting an increase in cardio-vascular efficiency. Greater blood volume means more blood returns to the heart during circulation, increasing stroke volume. If stroke volume increases, heart rate can decrease to maintain the same relative cardiac output. The heart is a muscle, and reducing its work when appropriate can save energy.

Heart Volume/Contractility

Heart volume is determined by size of the heart and the thickness of its muscle walls. Endurance training increases heart size and volume. The contractility of the heart also increases with training. Contractility is the forcefulness with which each heart beat contracts and expels blood. Increases in both heart volume and contractility improve stroke volume, reducing heart rate for a given cardiac output.

Individual Heart Rate Values

Heart rate is an individual response to exercise and varies from person to person. The absolute number does not reflect how strong you may be or whether you will ride faster than the next person. Take for example two cyclists, cyclist A with a threshold heart rate of 170 bpm, and cyclist B at 186 bpm. Does this mean that cyclist B will ride faster than cyclist A? Not necessarily. Cyclist A could have much higher threshold power than cyclist B despite having a lower threshold heart rate. Comparing heart rate with other riders is not useful unless you have similar heart rate training zones.

Determining your individual heart rate zones is what gives the numbers meaning and the way to maximize the usefulness of a heart rate monitor in training. Choosing the right method to determine heart rate zones can mean the difference between over- or under-training and training at intended intensities. Without a valid method of evaluating heart rate even the best designed training program will be less effective.

Heart Rate Zone Measurement, Performance Testing and "Thresholds"

One of the simplest and common methods of heart rate zone determination is by estimating maximum heart rate (HR_{max}) and using percentages of HR_{max}. The 220 minus-your-age formula has been used for many years for the general fitness population but for well-trained cyclists it has dubious usefulness. The 220-age formula has an error range of ±12 bpm. If you were to try and maintain a heart rate in training that was always ~10 bpm higher than your true target, you might easily overtrain.

There are also drawbacks to basing training zones on maximum heart rate. From a purely practical standpoint, determining HR_{max} is physically difficult and at times impossible.

HR_{max} also varies with training and declines with age. More important to training application, heart rate zones are not fixed percentages of HR_{max}.

For example cyclist A and cyclist B may each have a HR_{max} of 195 bpm. If we were to use percentages of HR_{max} to determine training, such as 95% of HR_{max} as one's performance threshold, we assume that both cyclists will time trial at ~186 bpm. It is possible however, that cyclist A has a threshold heart rate of 186 bpm and cyclist B of 176 bpm. In a time trial effort, at 186 bpm cyclist B will likely blow up after ~3 to 5 minutes.

A better method for determining heart rate training zones is to base them on an individual's maximum sustainable output or performance threshold. Rather than performing a time trial each time you want to determine your training zones, a valid performance test that accurately and reliably measures your threshold is a shorter, relatively easier and more descriptive method of measurement.

Most performance tests designed to determine threshold values are called ramp tests. Ramp tests begin the cyclist at a relatively low workload, gradually increasing the workload to the point of fatigue. The design of the test is critical to the data gathered from the testing session. Heart rate response is dependent upon the rate and size of workload changes throughout the test.

A VO_{2max} test for example, typically starts at a very low workload with short stages that increase by large workload increments throughout. An example VO_{2max} protocol would begin a cyclist at 50-100 Watts and increase by 20-30 Watts or more every minute until exhaustion. The rate and size of workload changes in each stage are faster and larger than heart rate can adjust to during the progression of the test, commonly underestimating threshold heart rate.

Ventilatory Threshold (VT) describes the inflection point for ventilation during a VO_{2max} test. Ventilation increases at about the same rate as oxygen consumption up to about 50-70% of VO_{2max} (depending on the athlete's trained level). At this point, ventilation increases exponentially (just beyond the ventilatory threshold). Although ventilation is not a limiter of performance, some researchers have found that power at VT predicts average power for a 40 km TT. However, since the method to determine VT is typically a VO_{2max} test, the design of the test does not give us an accurate prediction of TT heart rate. As most cyclists use a heart rate monitor for training, predicting 40 km TT power alone is insufficient.

Anaerobic Threshold (AT) was a term applied to the lactate inflection point, or the point at which the appearance of lactate in the blood accumulates faster that its rate of removal/use. It was once thought (incorrectly) that a lack of sufficient oxygen to muscle shifted energy delivery to anaerobic metabolism, resulting in an increase in lactate production thus causing fatigue. Since lactate does not cause fatigue, nor does it determine anaerobic metabolism, the misnomer anaerobic threshold was rejected as a concept nearly two decades ago. No "anaerobic" threshold exists.

Lactate Threshold (LT) is a more descriptive term for the lactate inflection point described above. Due to the misconception about lactate as the source of fatigue, it was thought that the workload just below lactate accumulation in the blood reflected a maximum sustainable level of performance (typically measured as a 1 hr time trial). Despite the fact that LT is a better name for the lactate inflection point than AT, it tends to underestimate time trial performance. Furthermore, there are multiple LT test protocols with little agreement among the scientific community. And since performance test data are directly affected by the design of the test itself, the consistency of LT as a standard of performance is questionable.

Regardless of lactate appearance or the rate of ventilation, we each have a “threshold” power output and corresponding heart rate that is maximally sustainable for a given period of time. As cyclists we really just want to know how hard to ride in training or how fast we could potentially go in a race. We are interested in measuring and predicting our performance in the real world, our performance threshold. The performance threshold or maximum sustainable output for 30 minutes is called the Maximal Steady State (MSS).

Heart rate zones based on one’s individual MSS are reliable for training. A valid and reliable testing method is one which accurately predicts MSS heart rate and power each time you test. An effective test will also reveal your power output in each of your heart rate training zones so that re-testing can show the changes over time at different relative levels of intensity. If you do not have a testing facility available, you can determine your MSS heart rate with a field test. Warm up well then measure your average heart rate for a 30 minute, moderate gradient, uphill time trial.

Training with Heart Rate

Cycling trains muscle recruitment and how it is energized. Training zones may be arranged differently by various coaches or trainers, but physiologically, training zones should be representative of specific muscle fiber type recruitment and energy delivery (metabolic pathway ratio: aerobic/anaerobic).

Since there is some variability in heart rate during training, heart rate zones comprise ranges of heart rate rather than a single value. Early in a training ride your heart rate will be lower for a given workload, while later in the ride that same workload will often elicit a slightly higher heart rate. So if your plan is to stay at a particular output for the majority of your training ride, start at the lower end of the range, gradually building toward the upper end later in the ride.

Keep in mind heart rate's delayed response. For short efforts where heart rate has insufficient time to reflect, it is easy to produce large workloads without seeing the corresponding heart rate value. Short, steep hills are an example of this situation. Even if heart rate does not rise much, any acceleration is a large impulse of power. In addition to paying attention to your heart rate, an awareness of the muscular work of the legs is useful. For example, when doing specific interval training, the interval starts the moment the work begins, not when your heart rate finally reaches the intended number.

While there are many factors that can affect heart rate, the three most influencing are muscular demands (workload), temperature and hydration. Wearing proper clothing and staying well hydrated reduce the influence of cardiac drift. Recognizing when influencing factors skew heart rate from simply reflecting your cycling workload will improve the application of the numbers to training.

Summary

Although the popularity and application of powermeters have grown considerably, heart rate is still a useful guide to measuring your cycling intensity. Its usefulness is dependent upon understanding its limitations and in knowing your unique heart rate values. Accurate determination of your individual training zones using a valid and reliable method will allow you to train more effectively when using HR values. Training zones should be based on your unique Maximal Steady State, a real-world 30 minute performance threshold.

The heart of a good training approach is in understanding how hard your body is working. While power is the direct measure of your cycling workload, heart rate is the body's response to producing that work. Recognize the variability of heart rate during training, be aware of muscular effort, and heart rate can help guide you well on the bike.

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