Muscle Oxygen Monitoring for Cycling: An Introduction
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Muscle Oxygenation is a measurement of how much hemoglobin is carrying oxygen in the capillaries of the muscle. It is expressed as a percentage from 0 to 100 and is often abbreviated as SmO2. Muscle Oxygenation is a localized measurement that depends on the exertion level, blood flow, and relative changes in the hemoglobin dissociation curve. It is measured optically with near-infrared light, so it is completely non-invasive. The different absorption spectra of the infrared light passing through the muscular tissue can identify the relative amount of hemoglobin that is carrying oxygen compared to the amount that is not.
Oxygen transportation and utilization is considered a key determining factor in an athlete’s endurance capacity. Much of modern exercise assessment revolves around the notion of VO2 and VO2 max as a determinant of oxygen transportation and utilization. The idea behind this notion is that a higher VO2 max indicates a higher capacity to use oxygen to produce energy in an oxygen-dependant energy pathway. VO2 can be calculated using the Fick equation which states that VO2 is a product of cardiac output and arteriovenous oxygen difference. The arteriovenous difference is rarely directly measured due to the invasive nature of the measurement, and therefore arteriovenous difference is measured as change in the oxygen content of inhaled air in relation to exhaled air. This is where the usefulness of the Moxy Muscle Oxygen Monitor device comes into play, as it offers a direct and non-invasive measure of oxygen saturation levels in the muscle.
Muscle oxygenation dynamics helps us understand changes in muscular metabolism and therefore can be used to guide different exercise sessions. The purpose of *Moxy* during endurance training is to help the user achieve and maintain a training intensity that leads to the desired profile of improvement. SmO2 can identify changes in Oxygen utilization and transportation to establish different training zones, from intensities of active recovery to high intensity. During strength training, interval training, or other forms of high-intensity training, the focus shifts from intensity control to recovery control. In other words, we use SmO2 as an indicator of recovery to identify when the desired level of recovery has been reached and the next set can begin.
While there are many different devices available for performance diagnostic and training guidance, Moxy offers many benefits other devices cannot. Firstly, Moxy is compact, wireless and non-invasive, all vital properties for in-the-field exercise and physiological application. This differs from many devices that either are immobile, wired, or invasive in nature. When it comes to physiologically-relevant metrics for athletes, Moxy delivers. SmO2 gives the user a real-time view of muscle oxygen utilization and delivery from the desired active sites. This differs from metrics such as blood lactate, which have extended lag times and are systemic in nature rather than muscle specific. Lastly, in comparison to other high-tech physiological equipment for athletes, Moxy is very affordable.
**Assessment Protocols**

**Equipment Needed**

The following assessment protocols require a Muscle Oxygen Monitor, a bicycle with some way to measure power or intensity, and a timing unit. Several options are available for measuring power:

- A crank or hub-based power meter on the bicycle.
- Speed and cadence data and a calibration curve for your particular trainer. PeriPedal* and Trainer Road software offer this functionality.
- A stationary bike based which measures speed and resistance.

*PeriPedal software works very well for this protocol because it guides the athlete on the power steps, records muscle oxygen data, and has options for recording data from a power meter or calculating power for many types of trainers.
For cycling assessment, the *Moxy* sensor should be attached to the side of the quadriceps on the muscle belly of the vastus lateralis, halfway between greater trochanter and lateral femoral epicondyle. In bright ambient light conditions such as direct sunlight, a small area of skin around the sensor may need to be covered with an opaque material to allow the *Moxy* optical sensors to function properly.
More information can be inferred from this test protocol if additional information is recorded. This could include:

- Heart Rate
- Stroke Volume
- Cardiac Output
- Respiratory Frequency
- Tidal Volume
- VO2
- Blood Lactate Measurements
- Speed and Cadence
- RER

Muscle Oxygenation gives the user insight into the working muscle and the rate of oxygen delivery and utilization; however, the view is limited to the working muscle being measured. This means even though the human body is a system that works together to create performance, the SmO2 measurement does not provide a direct indication of limitations in cardiac function, respiratory function, and other vital systems. For this reason, further physiological measurements will be useful to maximize the understanding of our physiological system, especially at an individual level.
IMPORTANT: The athlete should begin the test WITHOUT warming up. It is important to capture the warm-up as a part of this test. The athlete should pedal at their natural cadence for each power level.

During endurance training, it is important to understand how the body produces energy in order to ensure the proper energy pathways are activated and trained for appropriate gains. SmO2 can help identify changes in oxygen delivery and utilization – two determining factors in energy production. Basic trends in SmO2 will identify changes in energy metabolism. These trends can be identified through a simple testing protocol that will give the athlete basic zonings for endurance sports. It is important to note that these assessments are sport specific. This means a cycling assessment will yield zones for cycling but will not necessarily be accurate for running or other sports.

Assessment Protocol

The testing protocol is a simple 5-minute incremental step test using a power meter and the Moxy sensor. Start the test at a low intensity, for example at 80watts, and maintain this intensity for 5 minutes. After 5 minutes, increase your intensity by approximately 20watts - 30watts and maintain this new intensity for 5 minutes. Continue this increase of 20watts - 30watts per step, every 5 minutes, until you see a continuous and sharp decline in SmO2 on your Moxy Monitor. Once you see this decline the test is complete, and you are ready to analyze your data.
The test will allow you to create 3 or 4 zones depending on a multitude of factors; the 4 possible zones are outlined here and illustrated in the graph below. To identify these zones, look at the trend SmO2 takes during your 5-minute incremental step test.

An increasing trend at the beginning identifies the **Active Recovery (AR)** zone, as signified by the colour green (if you do not have an increase at the beginning of your test, you should redo the test but start at a lower intensity). The plateau at the highest point of SmO2 identifies the **Structural Endurance Intensity (STEI)** zone, as signified by the colour yellow. A second SmO2 plateau is possible at a lower SmO2 value, but may not necessarily be seen; this would be the **Functional Endurance Intensity (FEI)** zone, identified by the colour orange. A clear and continuous decrease in SmO2 identifies the **High Intensity (HI)** zone, and is signified by the colour red. Please look at the graph for an example of how zoning can be established.
Assessment Protocol

This protocol involves a series of intermittent steps that follow the pattern of 5 minutes of activity and 1 minute of break and so on, as seen in the image below. Each binary step in essence reuses a given wattage before a new binary step is started with a higher wattage resistance. For example, the first step has a wattage resistance of 60 watts. The step lasts five minutes and is followed by a 1-minute break; this was the first half of the binary step. In the second half, the same wattage is reused, namely 60 watts for another entire 5 minutes, followed again by a 1-minute break; together, these two parts make up one binary step.

The next binary step follows the same formula but with an increase in wattage, as in our example of 20 watts (remember this is just an example!). Due to the extended number of intermittent steps and longer duration per-step, the difficulty with this kind of test is time frame. For this reason, unlike other testing or assessment protocols, it is very important to correctly judge starting wattage individually and to adjust wattage increases individually as well. To do this properly, an athlete and or coach should know the person being assessed and how his or her SmO2 may react; in other words, knowledge from prior tests, perhaps from different protocols, is very useful.

The first binary step should use an intensity that would show an increase in SmO2 during activity. The second binary step should increase to an intensity where SmO2 has reached and maintains a maximum plateau of SmO2. The increase of intensity between binary steps should be the same value: if you increase wattage by 40 watts from binary step 1 to binary step 2, the same increase should occur to binary step 3. The test is completed when a clear and continuous decrease of SmO2 is seen during exercise, this also means that the athlete does not have to complete both parts of the final binary step if that is not possible.


**Zoning**

The test will allow you to create 3 or 4 zones depending on multitude of factors; the 4 possible zones are outlined here and illustrated in the graphic below. The increased complexity of this assessment makes the interpretation of the results a little bit more difficult, requiring a greater degree of experience; however, the resulting analysis can yield more information and a greater degree of accuracy.

The basic zoning works in a similar manner to the 5-minute incremental step tests, in that to identify each different zone you must look at the trend SmO2 takes during your binary steps. An increasing trend at the beginning identifies the **Active Recovery (AR)** zone, as signified by the colour green (if you do not have an increase at the beginning of your test, you should redo the test but start at lower intensity). The plateau at the highest point of SmO2 identifies the **Structural Endurance Intensity (STEI)** zone, as signified by the colour yellow. A second SmO2 plateau is possible at a lower SmO2 value, but may not necessarily be seen; this would be the Functional **Endurance Intensity (FEI)** zone, identified by the colour orange. A clear and continuous decrease in SmO2 identifies the **High Intensity (HI)** zone, as signified by the colour red. This is where the homeostasis can no longer be achieved. Please look at the graph below for an example of how zoning can be established.

*Graphical representation on following page*

The difficulty of interpretation can be seen when, within a binary step, different SmO2 dynamics are witnessed. For example, if a plateau of SmO2 is established in the first part of the binary step, but in the second part a continuous decrease in SmO2 is seen, this indicates a failure to return to homeostasis, even though the first part of the binary step was able to plateau. For this specific example, you can self-check the results by repeating the binary step again to see what happens. The general rule of thumb is that if the second part of the binary step does not match the first, the second takes precedence.
PHYSIOLOGICAL ASSESSMENT OF HOMEOSTATIC DISRUPTION
Having identified your different exercise zones, we will now look at a few common training types and how they can be applied to your zones.

**Long Slow Distance**

Long slow distance training is standard for most endurance-based sports such as cycling. This involves long-duration training sessions maintaining a desired intensity. The purpose of long slow distance is to increase endurance; to do this properly, energy pathways must be trained. This is where our zones come to play. The **Structural Endurance Intensity (STEI)** is an intensity that ensures maximal oxygen availability for energy production - exactly what we are looking for during long slow distance training.

Long slow distance training therefore resembles the graph below in that it is characterized by a training session exceeding 50 minutes in length and maintaining an intensity in the STEI zone. To control this intensity, keep an eye on your SmO2 level; it should be similar to the maximum value seen during your assessment in the STEI and should remain relatively stable there.
Interval training is a type of training that has been used for many years to increase endurance and power. It is important to remember that there are numerous variations of interval trainings and the graph below is just an example of one. The idea of interval training is to have intermittent bouts of high-intensity work followed by periods of rest or low-intensity work. This, for example, is where your High Intensity (HI) zone may come into play, in conjunction with your Active Recovery (AR) zone. As shown in the graph below, 90 seconds of low intensity in your Active Recovery (AR) zone is followed by 30 seconds of high intensity in your High Intensity (HI) zone or above. This pattern should be repeated, keeping an eye on your SmO2, especially on how it recovers during the recovery phases of low intensity. As marked out by the red recovery line, you can see that during the recovery phases SmO2 returns to its baseline value at the recovery line. Once this is no longer the case, the interval training is over.
Recovery training is used for many reasons; this is why identifying the active recovery zone is very important. In the Active Recovery (AR) zone, SmO2 is always increasing to a maximum value and therefore ensuring that the supply of oxygen exceeds demand, therefore minimizing stress on the active muscle. However, during exercise cardiac and respiratory function is increased, bringing blood to the working muscles at an expedited rate. If the workload on the muscles is low, this kind of training can speed up recovery. This is also the type and intensity level of training at which a cool down would be conducted after a competition or strenuous training.

**Competition Preparation**

Having spent the offseason increasing your Structural Endurance Intensity (STEI) with many long slow distance trainings, it is time to prepare for competition by maximizing your functional endurance. This also means maximizing your structural potential through quick adaptation in the neurological system and enzymic function. To do this, begin by identifying the approximate duration of your competition (as an example, functional adaptation training for a 60-minute time trial should be 60 minutes). Then, attempt this duration or distance at your Functional Endurance Intensity (FEI), at the maximal end of this zone if possible, in order to maintain for the entire distance or duration.
WHAT IS MOXY MONITOR?

Fortiori Design has developed the Moxy Muscle Oxygen Monitor system to measure the oxygen levels of muscles in athletes while they exercise. Its accurate, real time measurements are fundamental to athletic performance. Oxygen is the fuel that drives the muscles, and muscle oxygen levels are constantly changing with exercise intensity.

Moxy provides the feedback on exercise intensity that athletes are looking for. Our technology is superior to existing measurements because it is completely mobile, continuously recording, and totally non-invasive.

WHY MOXY MONITOR?

Moxy is **Accurate**: Its sensor utilizes cutting-edge medical device technology to produce accurate and consistent readings of SmO2 muscle oxygen levels.

Moxy is **Easy** to Use: Its small sensor and strap can be easily fitted to measure virtually any muscle group.

Moxy is **Durable**: Its water resistant, lightweight industrial design is built to withstand the rigors of elite training.

Moxy is **Fully Mobile**: Sensor data is displayed on a wristwatch, so athletes can monitor their muscle oxygen throughout each workout.

Moxy is **Affordable**: With a price point similar to a GPS heart rate monitor, it is accessible to individual athletes.

Check out what’s happening with Moxy on social media!