MUSCLE OXYGEN

Introduction to Muscle Oxygen Monitoring with Moxy

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Introduction to Muscle Oxygen Monitoring with Moxy

The purpose of this eBook is to provide an overview of how the Moxy Muscle Oxygen Monitor works, what it measures, and how it is used in athletic training.

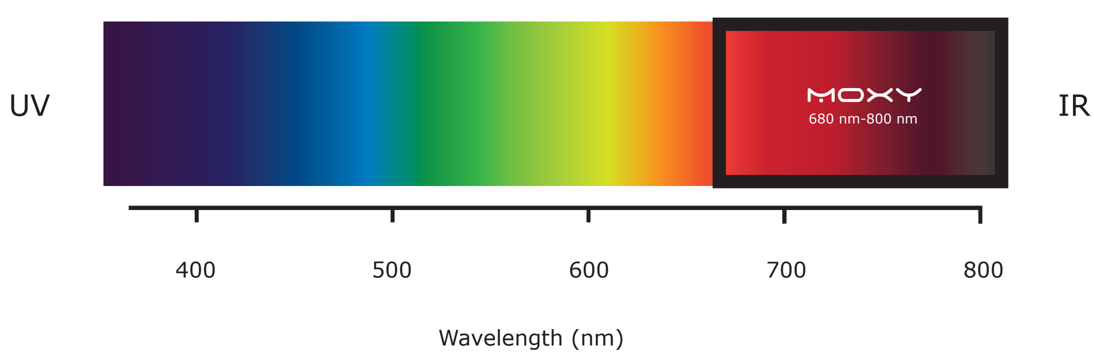
We invite you to refer to our sport-specific eBooks at www.moxymonitor.com for practical information on how to Train with Moxy.

How it Works

As its name suggests, Moxy Muscle Oxygen Monitor provides continuous measurement, or monitoring, of the oxygen saturation (SmO^2) levels in muscle tissue of athletes.

Muscle Oxygen Monitoring utilizes a technology called Near-Infrared Spectroscopy, which is often abbreviated as NIRS. The “Near Infrared” element means that the device uses light that is at and just beyond the red end of the visible spectrum. Moxy uses light from about 680 nm which is clearly visible, to about 800 nm, which the human eye almost doesn’t detect at all.

Visible Spectrum

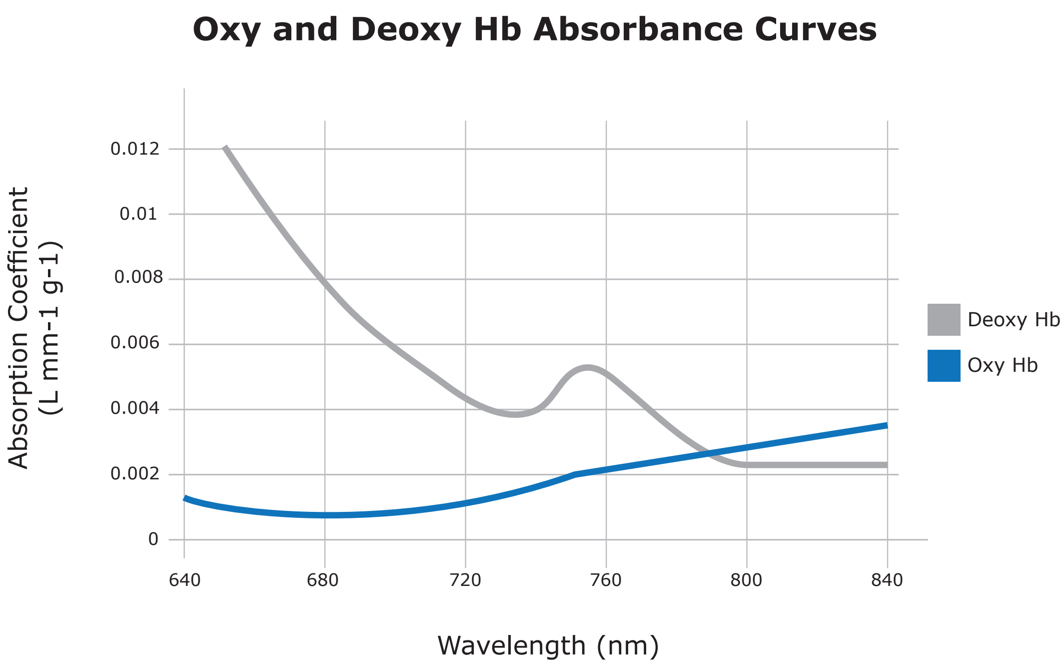


Near-Infrared light works well for this type of measurement because it can travel for long distances through skin, fat, and muscle without being completely absorbed. The light is scattered through the tissue rather than traveling in a straight line, which makes quantifiable measurements a bit challenging but still possible.

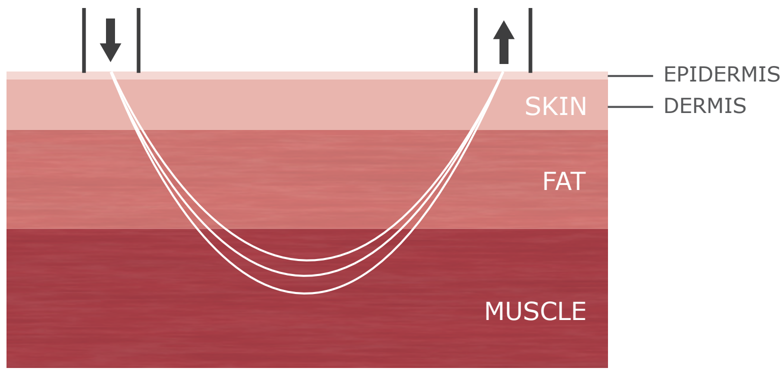
The following photograph shows a hand held over a flashlight. You can see that the skin glows red. The violet, blue, green, and yellow light are absorbed, so only the red light passes through.

The other favorable feature of Near-Infrared light is that it is absorbed differently by hemoglobin and myoglobin molecules that have oxygen bound to them, as opposed to those that don't. This is the "Spectroscopy" aspect of NIRS. The percentage of hemoglobin and myoglobin molecules that are carrying oxygen can be inferred by taking optical measurements at different wavelengths.

The following graph shows the difference in absorbance for hemoglobin; myoglobin absorbance is very similar.



In order to use NIRS to take quantifiable measurements in human tissue, a model is required to calibrate the measurement system. Some devices use a physical model like a tissue phantom or actual human measurements. Moxy uses a theoretical model because it allows the accommodation of a much wider range of physiologic variables, and the only cost is working out some challenging mathematics. Moxy uses a four-layered tissue model consisting of epidermis, dermis, fat, and muscle.



What Moxy Measures

Understanding precisely what Moxy measures is critical to understanding how it's used for athletic training. The primary Moxy measurement is ***Hemoglobin and Myoglobin Oxygen Saturation in the Capillaries of the Muscle***. Let's break this down.

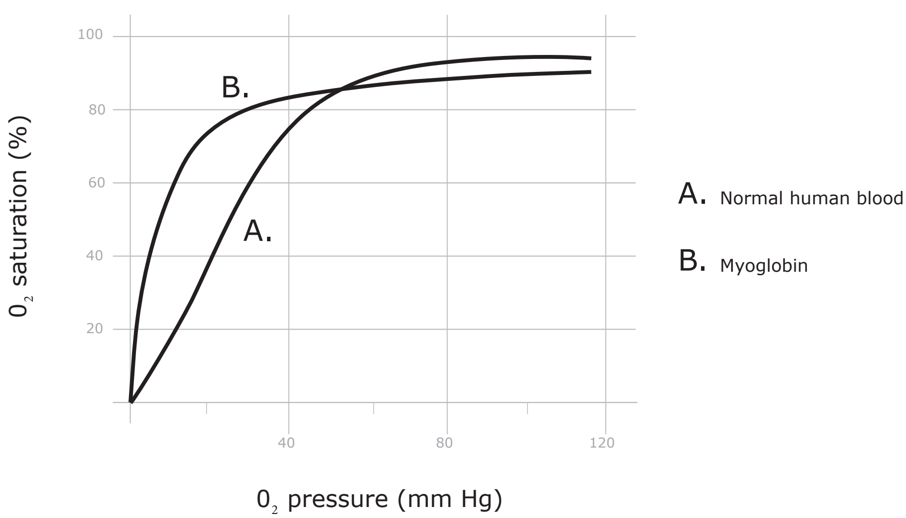
Hemoglobin and Myoglobin

Hemoglobin is the molecule in red blood cells that transports most of the oxygen in blood. Hemoglobin binds oxygen when it passes through the lungs and then releases the oxygen when it passes through the capillaries of the tissue that needs it.

Myoglobin is a molecule in muscle cells that also is capable of binding and releasing oxygen and acting as a store of oxygen in the muscle. As noted above, these molecules change their optical absorbance depending on whether or not they have oxygen bound to them; the resultant color change is what is actually being measured.

It is not known how much of the NIRS signal is due to hemoglobin and how much is due to myoglobin. The relative contribution of each depends on the total amount of hemoglobin present. Various studies have suggested that the myoglobin contribution ranges from less than 10% of the NIRS signal to more than 50% of the NIRS signal.

It is important to note, hemoglobin and myoglobin are not the end of the oxygen transport chain, but somewhere in the middle. In the final stages of oxygen transport, the oxygen is released from the hemoglobin and then diffuses through the interstitial fluids and into the cells which will ultimately use it. How much of the hemoglobin releases its oxygen depends on the level of oxygen dissolved in the surrounding fluids. Myoglobin also binds or releases oxygen depending on the dissolved oxygen around it, but at different levels than hemoglobin. This is shown in the following dissociation curves.



It is crucial to note that the hemoglobin dissociation curve is NOT fixed. Factors such as temperature and pH can shift the curve to the right or left. Low pH (more acidic) tends to make hemoglobin release its oxygen more easily. The level of CO2 in the blood affects the pH through changes in buffering so that increased CO2 levels also tend to make hemoglobin release its oxygen more easily. These factors are significant in working muscle, so it is important to remember that Moxy measures oxygen bound to hemoglobin and myoglobin and not dissolved oxygen. Sometimes the shifting of the dissociation curve is referred to as affecting the "bioavailability" of oxygen, or making the hemoglobin become "less sticky."

Oxygen Saturation

Oxygen saturation simply refers to the percentages of hemoglobin and myoglobin that are carrying oxygen. It is derived by taking the amount of oxygenated hemoglobin + myoglobin divided by the total amount of hemoglobin + myoglobin and then multiplying the result by 100 to express it as a percentage.

$$\left(\frac{\text{Oxygenated hemoglobin + myoglobin}}{\text{total amount of hemoglobin + myoglobin}} \right) \text{X } 100 = \text{Oxygen Saturation}$$

Oxygen saturation can vary from 0% to 100%. Whenever abbreviations like **SmO_2, SpO_2, SaO_2, $ScvO_2$**, etc. are used, the "S" refers to saturation in this same way. The lower case letter refers to the measurement location or measurement type:

$$S(x)O_2$$

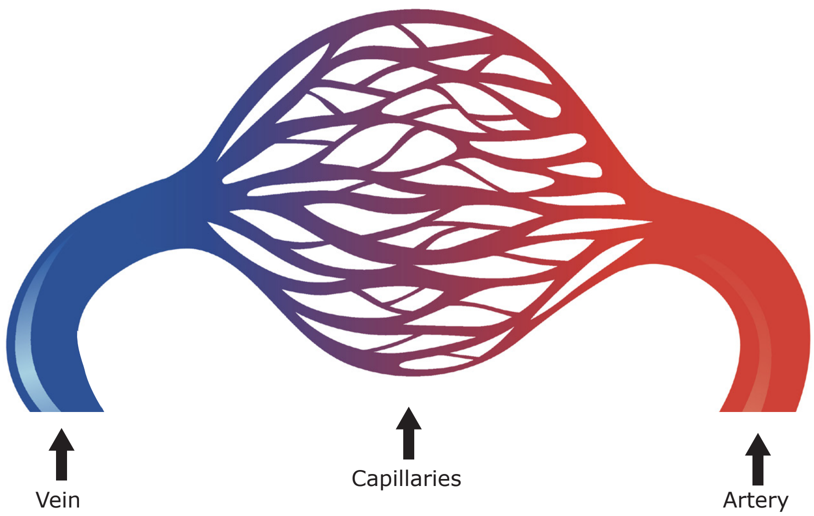
S **Saturation**

X **Measurement Location or Measurement Type**

- **m** - Muscle
- **a** - Arterial
- **p** - Measured by a pulse oximeter
- **cv** - Central Venous

O_2 **Oxygen**

Capillaries



The physiologic location of the oxygen saturation measurement is also critical to understanding how to apply it. The optical arrangement and the algorithm of the Moxy are designed so that the measurement comes from the capillaries. The measurement tends to exclude large vessels, because the hemoglobin concentration there is so high that all light interacting with those vessels gets absorbed. The light that is able to make it back to the detectors had to travel through the less optically dense areas, which include the capillaries.

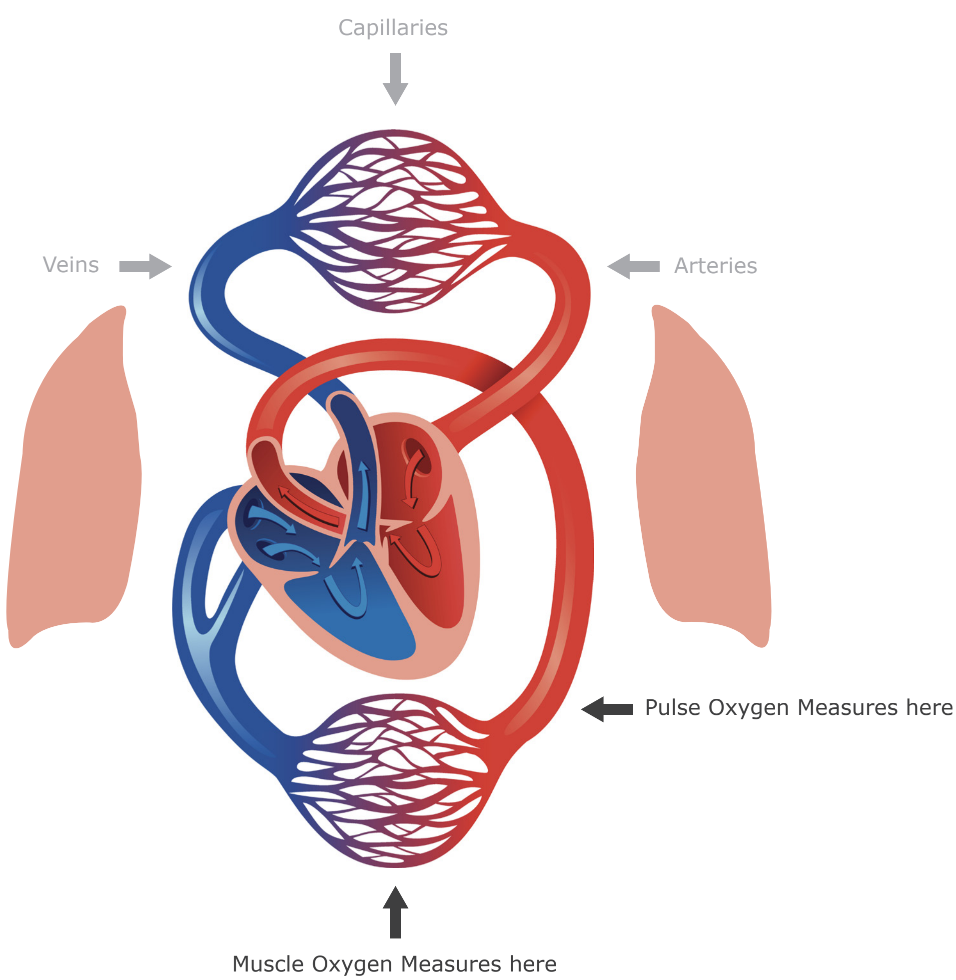
Oxygen remains bound to the hemoglobin molecules from the time the blood leaves the lungs until it gets to the capillaries. The amount of oxygen released from the hemoglobin in the capillaries is dependent on the surrounding dissolved oxygen levels reflected in the hemoglobin dissociation curve.

This leads to a simple idea that Moxy measures the balance between supply and demand for oxygen in the tissue around the capillaries. If more oxygen is being demanded than is being delivered, as indicated by lower dissolved oxygen levels in the tissue, the oxygen saturation will go down.

The measuring of oxygen levels in the capillaries is a very important difference between Moxy and a Pulse Oximeter. Pulse Oximeters pick up on the pulsating signal caused by expansion and contraction of the arteries with each heartbeat, which allows them to measure oxygen saturation in the arteries. Since hemoglobin does not typically release its oxygen in the arteries, arterial oxygenation is nearly identical throughout the entire body.

When hemoglobin enters the capillaries, however, the amount of oxygen released depends on the local level of dissolved oxygen in the tissue, and thus can vary widely depending on the location.

The following graphic helps highlight the point that Pulse Oximeters measure in arteries and Moxy measures in capillaries.



Muscle

The final point is that Moxy is designed to measure in the muscle. The optical configuration and the algorithm are designed to have high sensitivity to the muscle layer and low sensitivity to the skin and fat layers. This is also important to understanding how to apply its measurements, because changes in skin blood flow do occur during exercise primarily as a cooling mechanism for the body.

Total Hemoglobin

Moxy also performs a secondary measurement that is called total hemoglobin (THb). There are several factors that contribute to the absolute value of the total hemoglobin measurement, including the following:

- Adipose (fat) layer thickness
- Blood Hemoglobin Concentration
- Relative contribution of Myoglobin
- Volume of blood in the muscle

The Total Hemoglobin reading is not useful in an absolute sense because the values of these 4 factors are not typically independently known and vary significantly.

However, if only a single measurement site on a single athlete is considered and the time duration is short, it can be useful to assume that the adipose thickness, blood hemoglobin concentration, and contribution of myoglobin remain constant. Then any change in the total hemoglobin measurement can be assumed to be caused by changes of the volume of blood in the muscle.

Increases or decreases in the volume of blood and some information on the relative magnitude of changes can be inferred under these assumptions.

An example of changes in the total hemoglobin reading that can be observed in athletes is at the onset of exercise. The HR increases and the blood vessels in the working muscle tend to dilate. This can cause the amount of blood in the muscle to increase which shows up as an increase in THb.

How Moxy is used in Athletic Training

This section describes how Moxy is applied to athletic training from two different perspectives. The first compares how Moxy is used for Assessment and Workout Guidance, and in Competition. The second perspective gives a high level overview of how Moxy is used in Endurance, Acyclic, and Strength Sport training.

Assessments, Workouts and Competition

Assessments

Moxy requires some type of exercise protocol to be run in order to assess the athlete. Measurements at rest can easily range from 40% to 80% SmO2 and provide very little useful information. The real value of Moxy is in seeing how the athlete's body responds to loads and changes in loads. These assessments allow trainers to identify:

- What are the optimum training intensity zones?
- Which physiologic systems are limiting performance and which are compensating?
- How fast does the athlete recover after load?
- What is the athlete's recovery state from previous workouts?
- What is the level of mitochondrial function in the muscle?

A common type of assessment is a graded exercise test, where the exercise intensity is increased in small steps at fixed time increments. Information on training intensity zones can be derived from a test like this.

However, more sophisticated analysis is possible with more sophisticated tests. For example, when short periods of rest are introduced in between the steps, additional information can be obtained about recovery and limiting systems.

Workouts

In general, a training bout is defined by just a few parameters:

- **The Type of exercise**
  (run with a short stride, cycle with a cadence of 80 rpm, do bicep curls)

- **The Intensity of the exercise**
  (8 min/mile pace, 250 watts, 25 lb weights)

- **The Duration of the exercise**
  (5 minutes, 3 miles, 10 reps, until you can't maintain the pace)

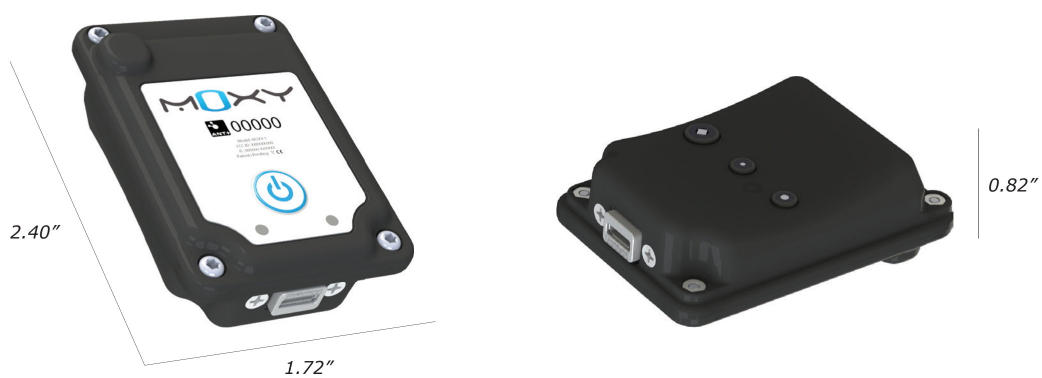
- **The Recovery between sets of exercise**
  (2 minutes, until your Heart Rate gets below 120 bpm)

These parameters will be selected by the trainer based on an individual assessment of the athlete. Moxy can be used to help guide training intensity, duration, and recovery.

Intensity - Moxy offers a better gauge of physiologic training intensity for an athlete than external measurements like pace or power because Moxy measures the intensity that the body is actually experiencing rather than just the mechanical output intensity. The trainer could instruct a runner to run at a pace that keeps their SmO2 around 65%. This could accommodate external factors such as heat and the athlete's level of recovery better than having the athlete simply run at an 8 min/mile pace.

Duration - Moxy guides training duration more accurately than just relying on a fixed time. A weight lifter could continue doing reps until their SmO2 reaches a low plateau and then stop for recovery. In this way, Moxy can help inform the optimal amount of reps that should be performed at different points in a work out.

Recovery - Moxy guides recovery during a workout. A hockey player could perform an interval training-like drill where they waited after each interval until their SmO2 recovered to a certain level before starting the next interval. If they fail to recover to the target level than the interval session could be over.



Competition

Moxy also optimizes performance and informs coaching decisions during competition. For instance, the device can be used to optimize the pace of a race based on an athlete's actual physiologic parameters measured in real time. It can identify when an athlete has fatigued to a point that their performance is suffering, or when they have sufficiently recovered on the bench to return to play.

Types of Sports

Endurance Sports

Endurance sports are sports like long distance cycling, running or swimming, where the athlete puts out a continuous effort for a period of many minutes or hours. Several assessment protocols have been developed for Moxy relative to endurance sports. Data from the Moxy device can be used by itself or complement the information trainers currently use.

Moxy is ideal for guiding intensity and monitoring recovery in endurance sports. Muscle oxygen can be an especially effective tool for monitoring physiologic intensity because it accommodates external factors such as temperature or recovery state of the athlete in a way that external measures like pace or wattage cannot.

Acyclic Sports

Acyclic sports are sports like soccer, hockey or football, where athletes start and stop frequently. The assessments for acyclic sports generally consist of having athletes perform an all-out effort in drills that are meant to mimic the typical movements of their sport. A huge benefit of Moxy is that these assessments can be done while the athlete is on their own field (or court, or pool) performing their own sport.

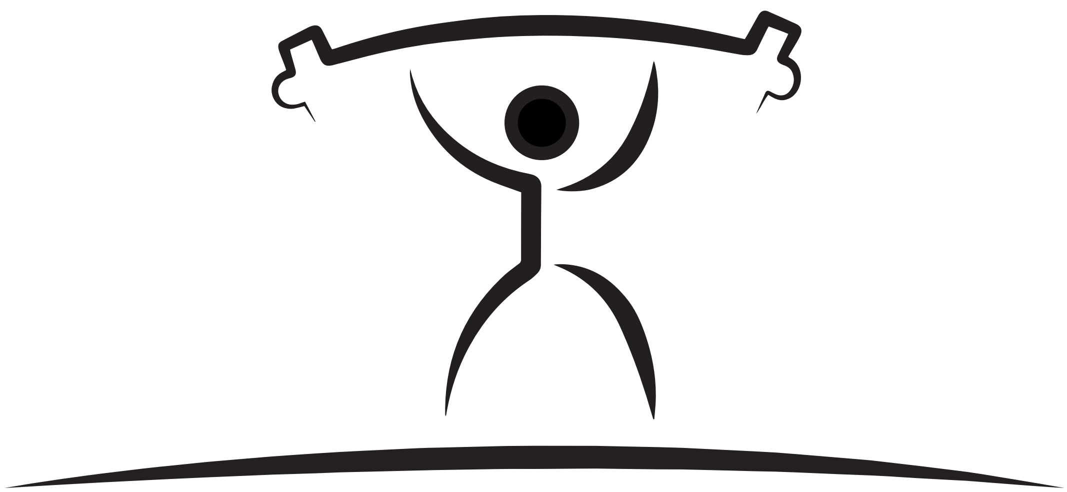
These drills are further tailored for the type of efforts required of the athlete's position or role in a given sport: linebackers can push sleds or wide receivers can run patterns. The assessments allow trainers to identify which physiologic systems limit performance, allowing trainers to more accurately measure progress in training and help athletes learn to recover more quickly.

In the future, athletes in acyclic sports will use Moxy during competition. By doing so, the coaching staff will know when a player needs to come out of the game and when he's recovered and ready to go back in.

Strength Training

Moxy can be used as an assessment tool in strength training to help determine which fiber system is being loaded. The SmO2 trends displayed by Moxy during strength training can help identify how the systems in the body are adapting to differing loads.

Moxy is also useful for guiding duration and recovery in strength training workouts. For instance, the ideal number of reps can be determined by monitoring the level of deoxygenation, and the recovery time between sets can be optimized based on the level of reoxygenation.



Summary

Muscle Oxygen Monitoring with Moxy allows trainers to see what is going on inside the athlete's muscle in real time. They can use this information to better assess their athletes and design more effective workouts. Moxy can also be used to guide the workouts to achieve more optimal results.

Once again, we invite you to refer to our sport-specific eBooks at www.moxymonitor.com for practical information on how to Train with Moxy.

MUSCLE OXYGEN MONITOR

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 Sm02 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 industrail 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.