NNOXX Data Interpretation Guide

Key Terms and Definitions

What IS Muscle Oxygeation (SmO2)?

Your muscle oxygenation (SmO2) level is the percentage of oxygenated blood in your muscles, and it reflects the balance of oxygen supply and demand during exercise. If your SmO2 level increases, your oxygen supply has exceeded your oxygen demand, and vice versa. Alternatively, if SmO2 is unchanging, oxygen supply and demand are in balance.

Under normal conditions, SmO2 increases when you transition from exercise to rest. The fitter you are, the higher your SmO2 level will get during recovery, and the faster it will reach its peak value. Average resting SmO2 levels before exercise range from 50-70%, and resting levels following intense exercise can reach as high as 85%.

During high-intensity exercise, SmO2 decreases, indicating that your muscles utilize oxygen faster than it can be supplied, and the harder you exert yourself, the lower your SmO2 level falls. An average SmO2 value after maximal effort exercise is 25-45%; however, it can get as low as 10% in exceptionally fit individuals.

You can gain additional insights from your SmO2 data by cross-referencing it with external load measurements, including acceleration, speed, and power. Fortunately, the NNOXX wearable measures acceleration, which NNOXX One Elite members can view in the High Performance Platform (HPP). Ordinarily, SmO2 and external load are negatively correlated, meaning SmO2 decreases as load increases and vice versa. However, there are circumstances where the above relationships do not hold. The observed data trends in these cases provide important clues about an athlete's internal physiologic state, which you can explore in the preceding data interpretation guide.

What Is Nitric Oxide (NO)?

Nitric oxide (NO), released from red blood cells, also known as SNO-Hb, is the body's natural regulator for blood flow and oxygen delivery to muscle tissue.

When oxygen levels in a tissue are low, as is often the case during intense exercise, NO is released from the red blood cells, causing the blood vessels to widen, which results in greater blood flow and oxygen delivery. Alternatively, when oxygen levels in a tissue are high, as is often the case during recovery, NO is not released, and blood flow is evenly maintained. This system makes sense when you consider the need to regulate blood flow at the level of individual tissues, resulting in increases and decreases in NO based on a tissue's needs.

How To Use NNOXX's Data Interpretation Guide

Using This Guide For Continous Cyclic Exercise:

Step 1 - Slice the workout into segments based on distinct patterns in your acceleration, muscle oxygenation (SmO2), and nitric oxide (NO) data. A segment consists of a period in the workout where the trends for all three measurements above are relatively unidirectional. For example, a period in which acceleration increases, SmO2 decreases, and NO increases is a segment. Then, let's say acceleration becomes constant, SmO2 continues to decrease, and NO continues increasing - that is another segment.

Step 2 - After breaking your workout into segments, you can interpret the data for each segment one by one using the look-up table provided in the guide below. The guide is broken into three parts based on whether acceleration is increasing, decreasing, or constant. Within each of those three parts, you'll find all possible combinations of SmO2 and NO trends with interpretations for what each of them means for you.

Step 3 - After analyzing each segment of your workout, you can order the interpretations sequentially, resulting in a time-series analysis of what happened during the workout (i.e., how acceleration, speed, or power changed as a function of time), how your body responded, and what this means.

Using This Guide For Interval Cyclic Exercise:

Step 1 - Each interval during an interval training session is a discrete and continuous exercise bout. As a result, you can use steps 1-3 in the continuous exercise guide above to analyze the intra-interval trends and derive their meaning.

Step 2 - After analyzing each interval in isolation, you can order the interpretations sequentially. This results in a time-series analysis of what happened during any given interval.

Step 3- Next, you can view the big-picture changes in your data from one interval to another using the look-up table below. For example, did acceleration, SmO2, and NO increase, decrease, or remain constant from one interval to the next?

Step 4 - Finally, after analyzing the changes in measurements from each interval to the next, you can order the interpretations sequentially, resulting in a time-series analysis of what happened from interval to interval (i.e., how acceleration, speed, or power changed as a function of time), how your body responded, and what this means for you.

I *increased* my acceleration, speed, or power... now, what does my data mean?

How Did You Body Respond?		What Does It Mean?
Decreased Muscle Oxygenation (SmO2)	Increased Nitric Oxide (NO)	You increased your speed, and your body responded by utilizing a greater % of the oxygen available to your muscles to power activity, resulting in a decreased muscle oxygen saturation (SmO2) level. Thus, oxygen demand in your exercising muscles is greater than oxygen supply, and we can infer that your level of exertion is unsustainable for an extended duration. Furthermore, nitric oxide (NO) levels increased, resulting in greater blood flow and oxygen delivery to tissues. The combination of increased NO and decreased SmO2 means that you utilized an increased fraction of an increased oxygen supply to power activity as intensity increases. This is a typical physiological response during high-intensity exercise.
Decreased Muscle Oxygenation (SmO2)	Decreased Nitric Oxide (NO)	You increased your speed, and your body responded by utilizing a greater % of the oxygen available to your muscles to power activity, resulting in a decreased muscle oxygen saturation (SmO2) level. Thus, oxygen demand in your exercising muscles is greater than oxygen supply, and we can infer that your level of exertion is unsustainable for an extended duration. Furthermore, nitric oxide (NO) levels decreased, resulting in diminished blood flow and oxygen delivery to tissues. The combination of decreased SmO2 and NO means you utilized an increased fraction of a decreasing oxygen supply to power activity as intensity increases, indicating you may benefit from training that improves your maximal cardiac output, blood flow, and oxygen supply to exercising muscles.
Decreased Muscle Oxygenation (SmO2)	Constant Nitric Oxide (NO)	You increased your speed, and your body responded by utilizing a greater % of the oxygen available to your muscles to power activity, resulting in a decreased muscle oxygen saturation (SmO2) level. Thus, oxygen demand in your exercising muscles is greater than oxygen supply, and we can infer that your level of exertion is unsustainable for an extended duration. Furthermore, nitric oxide (NO) levels were stable, indicating a constant supply of blood and oxygen to working muscles. The combination of decreased SmO2 and stable NO means you utilized an increased fraction of a constant oxygen supply to power activity as intensity increases, indicating you may benefit from training that improves your maximal cardiac output, blood flow, and oxygen supply to exercising muscles.
Increased Muscle Oxygenation (SmO2)	Increased Nitric Oxide (NO)	You increased your speed, and your body responded by utilizing less of the oxygen available to your muscles to power activity, resulting in an increased muscle oxygenation (SmO2) level. Thus, the oxygen supply to your muscles is greater than the oxygen demand in your muscles, and your power output is sustainable despite increasing. Furthermore, nitric oxide (NO) levels increased, resulting in greater blood flow and oxygen delivery to tissues. The combination of increased SmO2 and increased SmO2 means that you utilized a decreased fraction of an increased oxygen supply to power activity as intensity increases. These trends indicate that you may have altered your movement pattern to reduce local muscle fatigue. Alternativley, you may observe these trends during a warmup period.
Increased Muscle Oxygenation (SmO2)	Decreased Nitric Oxide (NO)	You increased your speed, and your body responded by utilizing less of the oxygen available to the muscles to power activity, resulting in an increased muscle oxygenation (SmO2) level. Thus, the oxygen supply to your muscles was greater than the oxygen demand in your muscles, and your power output was sustainable despite increasing. Furthermore, nitric oxide (NO) levels decreased, resulting in diminished blood flow and oxygen delivery to tissues. The combination of increased SmO2 and decreased NO means that you utilized a decreased fraction of a decreasing oxygen supply to power activity as intensity increases. These trends indicate that you may have altered your movement pattern over the course of the workout to reduce muscle fatigue.
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Constant Muscle Oxygenation (SmO2)	Increased Nitric Oxide (NO)	You increased your speed and your body responded by utilizing a constant % of the oxygen available to your muscles to power activity. This means the supply of oxygen to your muscles and your muscle's demand for oxygen are balanced, resulting in a steady state. Furthermore, nitric oxide (NO) levels increased, resulting in greater blood flow and oxygen delivery to tissues. The combination of stable SmO2 and increased NO means that you utilized a constant fraction of an increased oxygen supply to power activity as intensity increases. Thus, even though SmO2 is unchanging, we can infer that your total oxygen consumption still increased, which is a common physiological during moderate to high-intensity exercise.

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I *decreased* my acceleration, speed, or power... now, what does my data mean?

How Did You Body Respond?		What Does It Mean?
Decreased Muscle Oxygenation (SmO2)	Increased Nitric Oxide (NO)	You decreased your speed, and your body responded by utilizing a greater % of the oxygen available to your muscles to power activity, resulting in a decreased muscle oxygen saturation (SmO2) level. Thus, oxygen demand in your exercising muscles is greater than oxygen supply, and we can infer that your level of exertion is unsustainable despite the intensity decreasing. Furthermore, nitric oxide (NO) levels increased, resulting in greater blood flow and oxygen delivery to tissues. The combination of decreased SmO2 and increased NO means you utilized an increased fraction of an increased oxygen supply to power activity, even as intensity decreases. This is a typical physiological response during high-intensity exercise.
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My acceleration, speed, or power were *constant*... now, what does my data mean?

How Did You Body Respond?		What Does It Mean?
Decreased Muscle Oxygenation (SmO2)	Increased Nitric Oxide (NO)	Your speed was constant, and your body responded by utilizing a greater % of the oxygen available to your muscles to power activity, resulting in a decreased muscle oxygen saturation (SmO2) level. Thus, oxygen demand in your exercising muscles is greater than oxygen supply, and we can infer that your level of exertion is unsustainable despite the intensity decreasing. Furthermore, nitric oxide (NO) levels increased, resulting in greater blood flow and oxygen delivery to tissues. The combination of decreased SmO2 and increased NO means you utilized an increased fraction of an increased oxygen supply to power activity, even as intensity decreases. This is a typical physiological response during high-intensity exercise.
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Constant Muscle Oxygenation (SmO2)	Constant Nitric Oxide (NO)	Your speed was constant, and your body responded by utilizing a constant % of the oxygen available to your muscles to power activity. This means the supply of oxygen to your muscles and your muscle's demand for oxygen are balanced, resulting in a steady state. Furthermore, nitric oxide (NO) levels were stable, indicating a constant supply of blood and oxygen to working muscles. The combination of stable SmO2 and NO means that you utilized a constant fraction of a constant oxygen supply to power activity as intensity is held constant. From these trends we can infer you are at a metabolic steady-state and that your current power output is sustainable.

NNOXX Advanced User Guide

How do I use my data to guide pacing in real-time?

Traditionally, systemic physiological responses such as VO2, heart rate, and blood lactate changes have been used to quantify exercise intensity and inform athletes' pacing strategies during training and racing. An alternative approach is to use local indicators of a working muscle's status, such as muscle oxygenation (SmO2) and nitric oxide (NO), which you can measure with your NNOXX wearable device.

With trial and error, you can determine your minimum and maximum SmO2 values and how they change based on how well-rested and recovered you are. Additionally, you can learn to identify what ranges of values are easy or challenging to maintain, which can be used as a real-time feedback tool to guide exercise intensity.

Once you understand how varying SmO2 levels relate to your effort, exertion, and fatigue, you can associate different bodily sensations with your SmO2 level. For example, I've found that when my SmO2 level gets below ~55%, my breathing starts to elevate ever so slightly. However, I can still converse and sustain this SmO2 level indefinitely without feeling like I'm exerting myself. Additionally, I commonly perform long-duration (>2 hours) cycling workouts in the 50-60% SmO2 range.

When my SmO2 level is between ~40-50%, my breathing starts to elevate, and I begin to feel a mild burning sensation in my muscles. This level of exertion is comfortably challenging, and I can maintain this SmO2 level for an extended duration. However, once my SmO2 is 30-40%, my breathing becomes labored, and my muscles have an uncomfortable continuous burning sensation. This level of exertion is unsustainable, and I have limited time I can spend in this intensity range before fatigue starts mounting.

Finally, if I push below 30% SmO2, I can no longer coordinate my breathing, and my muscles rapidly fatigue. Often, I'll see my SmO2 level in this range if I'm aggressively climbing a hill on my bike. Knowing that I have limited time I can spend at this oxygenation level, I'll use it as a sign that I need to reduce my power or speed to avoid 'spilling over' to the degree that I cannot recover.

Through trial and error, you can learn to manipulate your muscle oxygenation level during exercise by altering your power, cadence, breathing volume and frequency, and body position. For example, suppose you're cycling and are approaching your minimum SmO2 value. In that case, you can lower your power output to prevent your SmO2 from bottoming out. Alternatively, say you're in a race, and a competitor passes you. You may notice that your SmO2 value is relatively high, meaning you have sufficient energy reserves to increase your power output. In another instance, you may be on a long bike ride as part of your training, holding a submaximal power output and aiming to keep your muscle oxygenation level in a moderate intensity range. In this case, you could adjust your gears and cycling cadence to see if you could increase your SmO2 without changing your power. If so, you've improved your movement efficiency.

You can even work on manipulating your movement cadence, breathing volume and frequency, and body posture to increase your pace at a given SmO2 level. For example, I'm running one-mile repeats with my SmO2 at 35-45%. From set to set, I could try running with a different cadence, increasing my breathing frequency while maintaining my volume, or altering the position of my torso to see if I can increase my speed without my SmO2 level going below my target range.

How can I use my data for physiologically guided training?

How hard should you push yourself during training? How many intervals should you do, and how long should each be? Is active or passive recovery better for you? Until now, there haven't been easy answers to these questions. But, with NNOXX, you can get real-time feedback during exercise, allowing you to fine-tune your training.

The idea behind physiologically guided training is to do your own workout with your goals and training plan in mind. At the same time, NNOXX's mobile app displays your data in real-time, helping you auto-regulate your exercise intensity, volume, or recovery.

Select the unguided workout mode in your NNOXX mobile app to perform physiologically guided training, then attach your NNOXX wearable to the primary locomotor muscle for your chosen activity. Once you've selected your exercise modality and sensor placement, performing physiologically guided training can be as simple as exercising within your desired muscle oxygenation training zone, as explained in the previous section. However, more advanced users may wish to use their muscle oxygenation (SmO2) and nitric oxide (NO) levels and trends to perform physiologically guided training designed to target specific training adaptations, as explained in the following sections.

Maximum Steady State (MSS):

Training The easiest type of physiologically guided training to perform is maximal steady-state (MSS) training. You can do MSS training with any cyclic exercise modality, including cycling, running, rowing, or cross-country skiing.

You should begin exercising at a low to moderate intensity to find your maximal steady-state intensity. After an initial drop in your SmO2 level, it will stabilize. You should then increase your intensity ever so slightly. After seeing another drop in your SmO2, it should stabilize again, indicating that your body's oxygen supply systems can match your muscle's demand for oxygen.

After repeating this process, you will eventually find a power output where your SmO2 level does not stabilize after the initial drop and continues to decline steadily, indicating your working muscles are extracting oxygen faster than it can be supplied. At that point, you have overshot your MSS and should reduce your power or speed until your SmO2 level stabilizes. They should then aim to hold that approximate power output for the duration of the exercise bout, making minor modifications to avoid your SmO2 level declining. As your fitness improves, you should be able to hold progressively higher power outputs at your maximal steady state.

Rapid Desaturation Training:

Mitochondria are best known as the powerhouse of cells due to their ability to generate chemical energy in the form of ATP. As a result, Mitochondria play a crucial role in cellular function and exercise performance, and athletes across various sports require time-efficient training methods to improve their mitochondrial density and muscle oxidative capacity.

Rapid desaturation training is designed to increase tissue capillarization, mitochondrial density, and an athlete's maximal rate of oxygen utilization. This training method must be performed at a near-maximal intensity with an interval long enough for muscle oxygen saturation to reach a minimum value.

Additionally, the total number of sets for this workout style should be individualized based on an athlete's real-time physiologic response. For example, we want an athlete to perform as many sets of rapid desaturation training as possible until they can no longer deoxygenate the working muscle to the same nadir as previous sets or they cannot recover their muscle oxygenation back to the same baseline level during fixed-duration rest periods. Below is a sample rapid desaturation training session for a competitive CrossFit athlete during their offseason:

Accumulate as many rounds as possible: 10-second Echo Bike (70-75% of maximum wattage), Rest 1:00 b/w sets. The session ends when SmO2 cannot reach the same minimum value as previous sets during your sprint or you cannot reoxygenate back to the same SmO2 value as previous sets during your recovery. Additionally, you should terminate the workout if you can no longer hit the prescribed wattage, you begin to compensate biomechanically to reach your target power, or your RPE increases exponentially from set to set.

This type of workout can also be completed with a concept-2 rower at 80-85% max watts or a skierg at 90-95% max watts. The target wattages are a starting point, and an individual may need to raise or lower them to achieve the target response. Additionally, I recommend putting a thirty to forty-five-minute time cap on this style workout to limit total training volume.

Extended Desaturation Training:

One of the most important considerations when training respiratory-limited athletes is that the amount of work accumulated at a high percentage of their peak oxygen consumption is a primary determinant of performance. However, the amount of training volume an athlete's muscles, bones, and joints can tolerate week after week is finite, limiting how much work they can conceivably do at a high percentage of their peak oxygen consumption.

One way to circumvent the issues above is to perform extended desaturation intervals. Extended desaturation intervals induce higher mean oxygen consumption levels than traditional interval training methods, making them ideal for accumulating more time at a high percentage of an athlete's VO2 peak with less wear and tear.

Extended desaturation intervals aim to have an athlete exercise at a high intensity, with a fixed power output, that causes them to utilize oxygen in the working muscles at a greater rate than it can be supplied, resulting in rapidly declining muscle oxygenation levels. Once muscle oxygenation stops declining and plateaus at a nadir, the athlete should stop exercising and begin their rest period. They should then rest until SmO2 stops increasing and levels off at a peak value, then repeat this process for two to six total sets. Below is a sample extended desaturation training session for a competitive rower. You can try this workout style with any cyclic exercise modality and should aim to use a power output, or pace, that allows you to sustain each effort for two to six minutes.

Row at 1:30/500m (5s/500m faster than 2k PR pace) until SmO2 stops declining and levels off at the same % for 5-10 seconds. Rest until SmO2 stops increasing and reaches a recovery baseline. Repeat for 2-6 total sets.

Gradual Desaturation Training:

When you exercise, oxygen levels in the working muscles decline, causing nitric oxide (NO) to be released from red blood cells and signaling for small blood vessels to dilate. When small blood vessels dilate, the heart must stretch and pump harder and faster to maintain blood pressure. When done frequently enough, this type of training causes your heart to adapt, resulting in increased cardiac output.

To maximize your cardiac output, you can perform workouts that progressively deoxygenate your exercising muscles to a minimum oxygenation (SmO2) level, resulting in NO levels reaching their peak concentration. During these workouts, your heart will progressively pump harder and faster, up to its tolerable limits. At that point, you'll achieve peak cardiac output levels. Once your muscle oxygenation (SmO2) is no longer declining and nitric oxide (NO) levels are no longer increasing, you should cut your work interval short.

I recommend that athletes performing gradual desaturation training aim for 2:00-6:00 of work per interval. You can repeat this process 3-6 times in a workout, resting 3:00-5:00 between sets. Below is a sample gradual desaturation training session for a competitive Crossfit athlete. You can test this type of workout with any cyclic exercise modality, such as running, rowing, or cycling.

6:00 Echo Bike, Rest 4:00 x4 sets. Start each set at 150 watts (easy pace) and gradually increase your speed across the interval to finish within 5-10% of your minimum SmO2 value. Some gamification is needed to get the pacing just right, so you can experiment with different strategies for increasing your pace set to set.

Active Recovery:

During active recovery training, the goal is to increase an athlete's SmO2 as much as possible, which will help aid in recovery. Because every athlete's physiology and response to exercise are unique, their active recovery sessions will also need to be. For example, many strong and muscular athletes have trouble doing true low-intensity work. In these groups, heart rate is not a reliable indicator of how much stress they impose on a given activity. When SmO2 is low, oxidative metabolism is compromised, which leads to an increased reliance on glycolysis to replenish phosphocreatine and, subsequently, ATP.

Athletes will find certain modalities where they cannot exercise without rapidly deoxygenating the working muscles. For example, many athletes cannot run with a stable or increasing SmO2 level and will have to walk to achieve that goal. So, the goal for each athlete is to find the right combination of modality, intensity, and cadence that allows them to maximize their SmO2 level over time during active recovery workouts.

You can select a cyclic exercise modality, such as walking, running, cycling, or rowing, to perform active recovery training. Now, begin exercising at a very low intensity. Initially, you may see a slight decrease in SmO2, followed by a stabilization and slow rise. If SmO2 plateaus for more than three minutes, you can try modulating your power or speed to see if you can drive it up further. Counterintuitively, you may be able to drive your SmO2 value up by increasing your speed every so slightly and then taking a brief rest period before continuing to exercise. You can also try increasing or decreasing your cadence without changing your power output. Over time, you'll identify patterns and learn how to best increase your SmO2 value during active recovery sessions by choosing the correct exercise modality, intensity level, and cadence.