Association of Near-Infrared Spectroscopy Assessed Muscle Oxidative Capacity Between Collegiate Cross-Country Athletes and College Students

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Abstract

Muscle oxidative capacity (MOC) is the maximum rate at which the muscle can utilize oxygen to meet the energy demand of exercise. Near-infrared spectroscopy (NIRS) measurement of muscle oxygen uptake (mVO_2) during brief arterial occlusions has shown to be a valid, reliable indicator of MOC, but is affected by aerobic fitness. It is unclear if the NIRS measurement can detect a difference in MOC in populations of varying aerobic fitness. The purpose was to compare MOC between collegiate cross-country runners and age-matched college students. Maximal oxygen uptake was measured from an individualized treadmill test to characterize aerobic fitness. MOC was determined from a series of 20 short (5-10 sec) arterial occlusions interspersed with short recoveries. Rapid inflation cuffs placed on the distal portion of the thigh were inflated to 300 mmHg during occlusions and released during recovery. Deoxyhemoglobin (HHb), collected at 10 Hz, was measured at the gastrocnemius. To calibrate the signal to individuals, a 5-min arterial occlusion determined maximal deoxygenation (highest HHb) and the hyperemic response after cuff release determined minimum HHb (maximal oxygenation). The slope of change in HHb during the first 3-5 seconds of each occlusion was considered mVO_2. Each mVO_2 was plotted and a mono-exponential decay curve was fitted to determine the time constant, indicative of MOC. A t-test was conducted to compare MOC between groups. It was hypothesized that collegiate cross-country runners would exhibit a faster time constant which would indicate greater MOC.

Background

- Mitochondria serve an important role in the production of ATP through oxidative phosphorylation, as the demand for ATP substantially increases during endurance exercise and endurance performance is largely dependent on the ability of mitochondria to produce ATP.
- Endurance athletes primarily rely on skeletal muscles that have a high mitochondrial capacity, which can readily produce ATP oxidatively and limit fatigue.
- Muscle oxidative capacity (MOC) is the maximal rate at which the muscle can extract and utilize oxygen to create ATP through oxidative phosphorylation.
- Traditionally, muscle biopsies have evaluated mitochondrial density and oxidative enzyme activity to quantify MOC. Biopsy studies have shown that MOC is an important aspect of endurance performance and increases with endurance training, even in highly trained athletes.
- However, muscle biopsies are an invasive technique and may not be practical for many endurance athletes.
- Recently, non-invasive near-infrared spectroscopy (NIRS) measurement of muscle oxygen uptake (mVO_2) during brief arterial occlusions has shown to be a valid, reliable indicator of MOC.
- Changes in deoxyhemoglobin (HHb) during a series of multiple, transient arterial occlusions following exercise measures muscle oxygen uptake (mVO_2). Recovery mVO_2 is related to phosphagen recovery kinetics and is an indirect measure of MOC, in that the faster muscle oxygen uptake returns to a resting level, the greater MOC.
- While previous investigations have compared MOC between subjects of high- and low-aerobic fitness, few studies have investigated the differences in MOC between competitive athletes (XC runners) and their trained, non-competitive counterparts.

Purpose

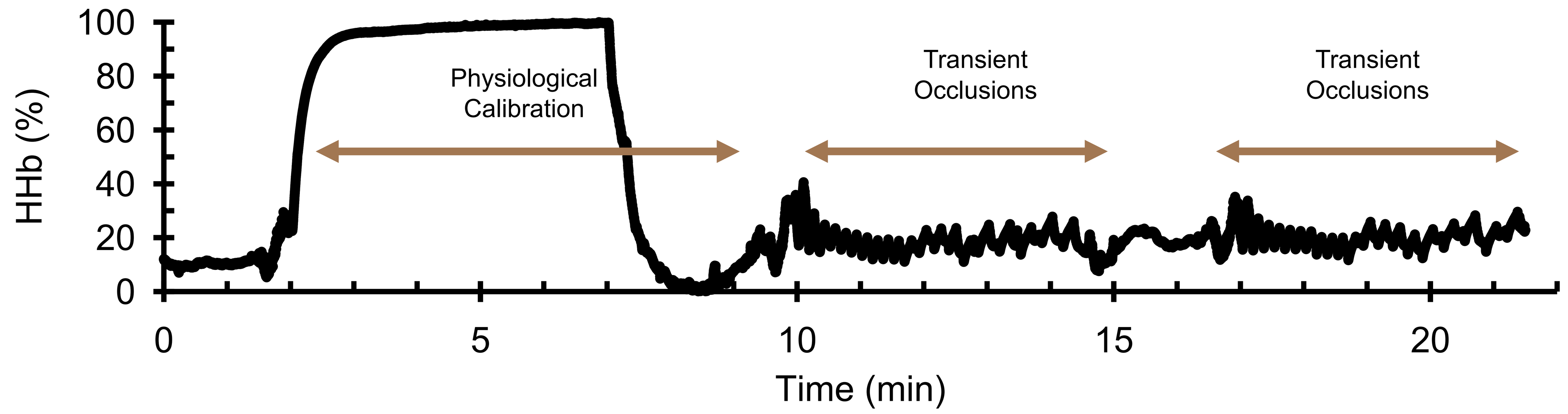
The purpose was to compare the muscle oxidative capacity, as assessed by NIRS, between collegiate cross-country athletes and recreationally-trained, age-matched college students.

Experimental Protocol

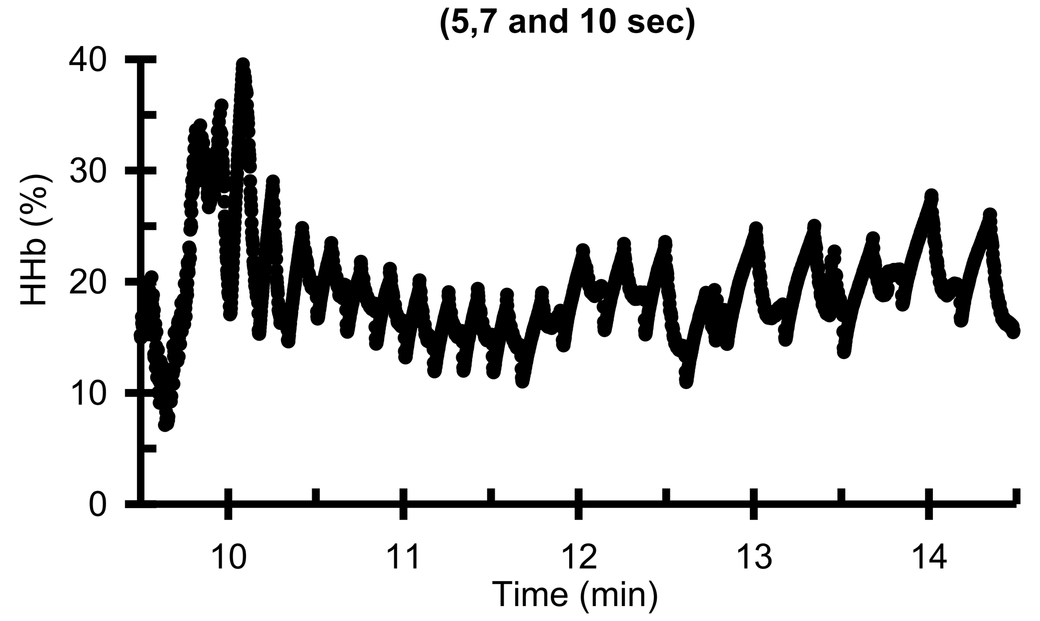
- Participants were recruited from the Coastal Carolina University men's and women's cross-country team and the Coastal Carolina University Student Population.
- Each participant was required to visit the lab for one visit. Cross-Country runners completed visits prior to their season, and age-matched college students completed the visit when they were best available. During each visit, participants completed two tests, a running graded exercise test followed by the muscle oxidative capacity protocol.
- An individualized graded exercise test on a treadmill to exhaustion was performed. The test began at a comfortable speed and 0% grade. Speed was increased by 0.5 mph every minute for 4 mins. Grade was then increased by 1% every minute for the remainder of the test. Breath-by-breath pulmonary gas exchange was sampled at the mouth and recorded continuously.
- Muscle oxidative capacity was assessed following the graded exercise tests similarly to a protocol described by Ryan et al. (2013).

Muscle Oxidative Capacity

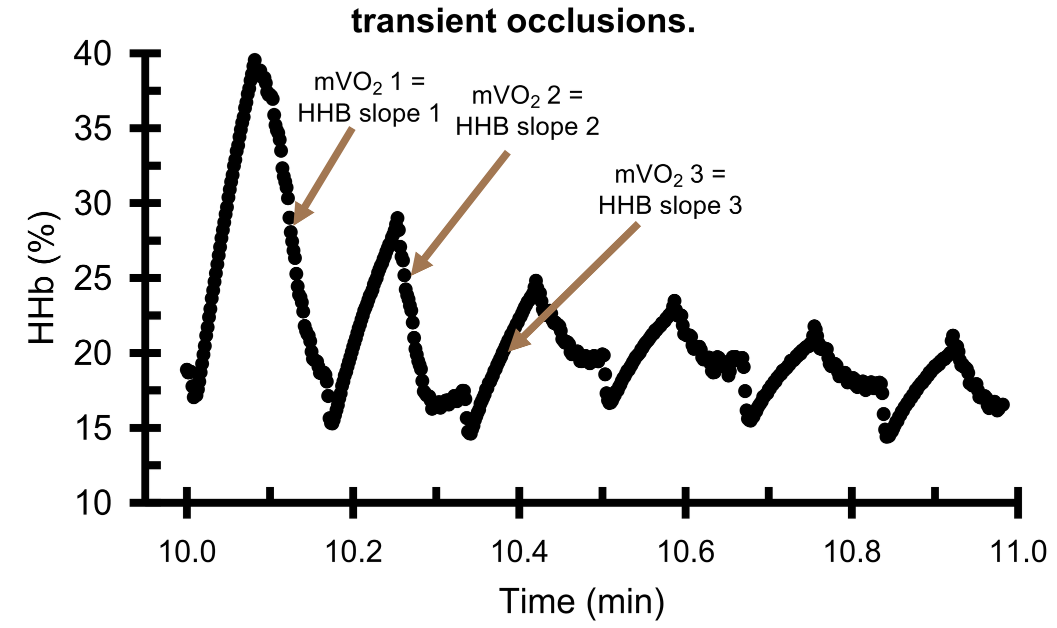
- A 2-dimensional ultrasound was used to determine subcutaneous adipose tissue thickness. The probe was placed horizontally on the medial head of the gastrocnemius at the thickest part of the calf. Subcutaneous adipose tissue was measured at three different sites within the probe and averaged. The measurement was repeated and duplicate measures were averaged.
- A continuous-wave NIRS system (Artinis, Portamon) was placed on the medial head of the gastrocnemius at the thickest part of the calf and tightly taped to the skin.
- HHb was collected continuously at 10 Hz using the 30, 35, and 40 mm channels using Oxysoft software.
- A Hokanson blood pressure cuff was placed immediately proximal to the patella and set to a pressure of 300 mm Hg.



Deoxygenated hemoglobin during all transient occlusions (5,7 and 10 sec)



Deoxygenated hemoglobin during 5-sec transient occlusions.

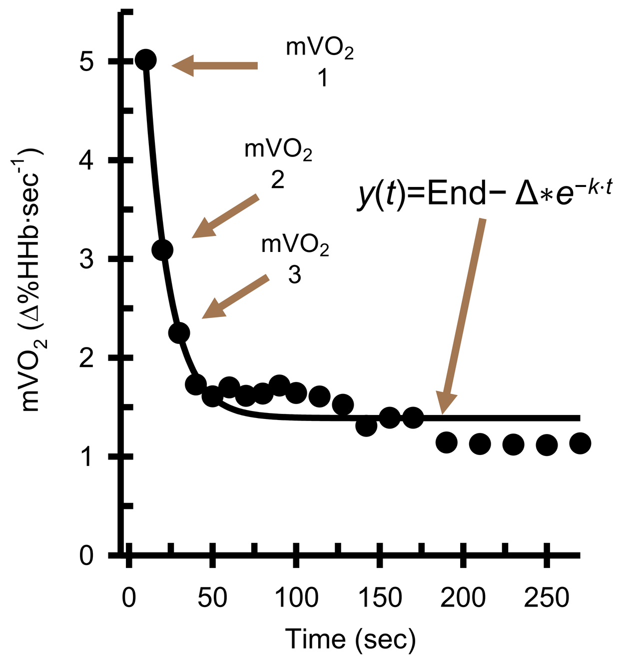


- A physiological calibration was done to normalize NIRS data. Participants used a resistance band to perform 30 seconds of plantar flexion followed by a 5-min arterial occlusion.
- The highest HHb was considered maximal deoxygenation and the minimum HHb during the hyperemic response after cuff release was considered the minimum deoxygenation.
- To determine recovery mVO_2, 30 seconds of plantar flexion exercise with a resistance band was completed following a series of transient arterial occlusions interspersed with short recoveries (5 × 5 s on/5 s off, 5 × 7 s on/7 s off, 10 × 10 s on/10 s off).
- The recovery mVO_2 measurements were duplicated after at a 2-minute rest.

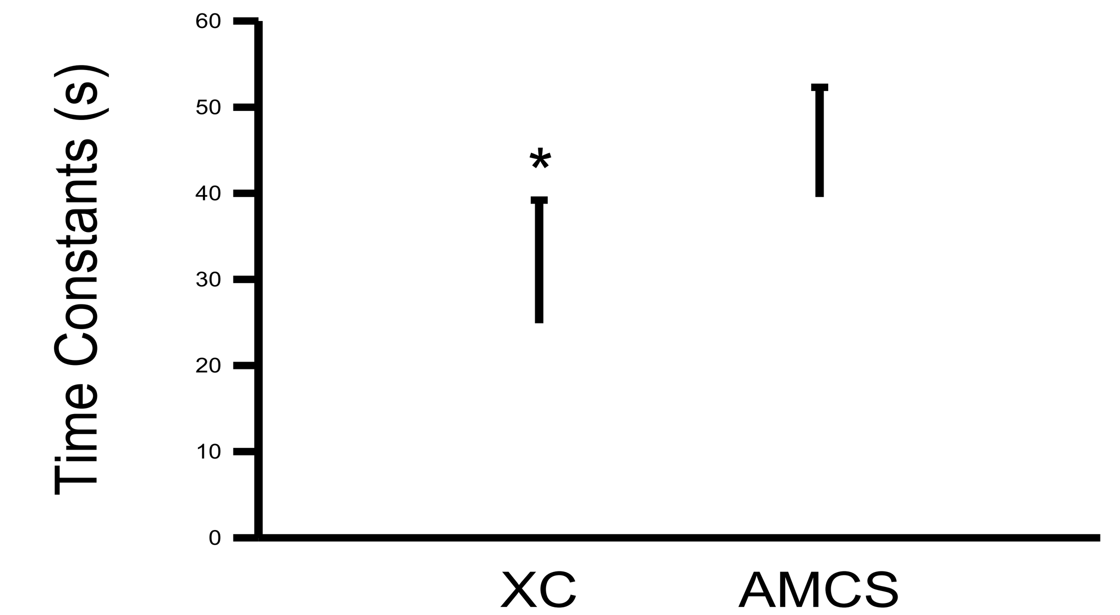
Data Analysis

- 7 female and 8 male cross-country runners, and 2 male and 5 female age-matched college students completed this study.
- HHb was corrected for changes in blood volume using methods described by Ryan et al (2012) and normalized to the minimum and maximum deoxygenation.
- In each channel, the slope of change in HHb during the first 3-5 seconds of each transient occlusion is the mVO_2.
- Duplicate mVO_2 were averaged and were plotted against time. A mono exponential curve using the following equation: $y(t)=\text{End}-\Delta * e^{-k \cdot t}$ was fitted and the time constant (k) was calculated.
- The time constant found in each channel was averaged to determine MOC.

mVO_2 (Δ HHb during transient occlusions) for 35 mm channel



Data



* - significantly difference between XC and AMCS

Results

There was a significant difference in MOC between cross-country runners and their age-matched counterparts (24.9 ± 14.3 s vs. 39.6 ± 12.7 s; $t(20) = -2.308$; $p = 0.03$).

Therefore, these results provide evidence that non-invasive assessment of muscle oxidative capacity using NIRS is robust enough to detect differences in MOC between competitive athletes and their non-competitive, recreationally-trained counterparts.

References

1. Brizendine JT, Ryan TE, Larson RD, McCully KK. Skeletal muscle metabolism in endurance athletes with near-infrared spectroscopy. *Med Sci Sports Exerc*. 2013;45(5):869-75.
2. Lagerwaard B, Janssen JJE, Cuijpers I, Keijer J, de Boer VCJ, Nieuwenhuizen AG. Muscle mitochondrial capacity in high- and low-fitness females using near-infrared spectroscopy. *Physiol Rep*. 2021;9(9):e14838.
3. Lagerwaard B, Keijer J, McCully KK, de Boer VCJ, Nieuwenhuizen AG. In vivo assessment of muscle mitochondrial function in healthy, young males in relation to parameters of aerobic fitness. *Eur J Appl Physiol*. 2019;119(8):1799-808.
4. Ryan TE, Erickson ML, Brizendine JT, Young HJ, McCully KK. Noninvasive evaluation of skeletal muscle mitochondrial capacity with near-infrared spectroscopy: correcting for blood volume changes. *J Appl Physiol (1985)*. 2012;113(2):175-83.
5. Ryan TE, Southern WM, Reynolds MA, McCully KK. A cross-validation of near-infrared spectroscopy measurements of skeletal muscle oxidative capacity with phosphorus magnetic resonance spectroscopy. *J Appl Physiol (1985)*. 2013;115(12):1757-66.
6. Southern WM, Ryan TE, Reynolds MA, McCully K. Reproducibility of near-infrared spectroscopy measurements of oxidative function and postexercise recovery kinetics in the medial gastrocnemius muscle. *Appl Physiol Nutr Metab*. 2014;39(5):521-9.