Peripheral skin temperature effects on muscle oxygen levels

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Abstract

In both hot and cold environments, tissue oxygen saturation levels may affect muscle performance. Using near-infrared spectroscopy, muscle oxygen saturation (StO2) and total hemoglobin levels were measured during exercise. Lowering skin temperature caused a greater StO2 and total hemoglobin decrease by 16% and 15.9%, respectively, compared to controls. Increasing skin temperature resulted in a smaller decrease in both StO2 and total hemoglobin by 12.2% and 8.2%, respectively, compared to controls. These data indicate that warming the skin will cause less of a decrease in StO2 and total hemoglobin, while cooling the skin has the opposite effect.

Keywords: Near-infrared spectroscopy (NIRS); Oxygen saturation; Skin (peripheral); Total hemoglobin; Temperature; Exercise; Muscle metabolism

1. Introduction

Oxygen saturation (StO2) is the percent amount of oxygen that is bound to hemoglobin in tissue. Oxygen saturation decreases during exercise, since working muscles require oxygen to produce energy in the form of adenosine tri-phosphate. As a result of this demand, oxygen saturation and consumption have an inverse relationship with one another. Numerous studies have measured oxygen saturation and consumption before, after, and during exercise (Bangsbo et al., 2003; Bouckaert et al., 2002; Calbet and Gonzalez-Alonso, 2003). However, invasive techniques had to be used, in order to measure these parameters, such as drawing blood samples or inserting catheters into blood vessels during exercise to measure lactic acid concentration.

Near-infrared spectroscopy (NIRS) provides a new approach of measuring tissue oxygen saturation levels non-invasively. This is accomplished by exploiting the absorption properties of hemoglobin at specific wavelengths (Bolinger et al., 1994). NIRS technology has been applied in numerous diagnostic studies regarding septic shock, compartment syndrome, and other disease states (Boushel et al., 2001; Busani et al., 2003; Van den Brand et al., 2004). It has also been used in studies regarding exercising muscle and observing how oxygen saturation changes during exercise (Boushel and Piantadosi, 2000; Colier et al., 1995; Ferrari et al., 2003).

Exercise under various temperature conditions has been the focus of numerous studies (Batterham et al., 2002; Binzoni and Delpy, 2001; Bruck and Olschewski, 1998; Bruck and Schmidt, 1981; Costill et al., 1975; Ferretti, 1992; Marsh and Sleivert, 1999) investigating what role temperature plays in muscle metabolism and assessing which conditions are favorable for prolonging exercise. Marsh and Sleivert (1999) reported that pre-cooling improves short-term cycling performance by possibly increasing blood availability to the muscles. Batterham et al. (2002) suggested that pre-warming caused a reduction in muscle endurance because of high internal body temperatures and changes to the heat...
storage capacity of the body. The majority of these studies however, deal with leg muscles exercising during cycling or performing a treadmill exercise (Batterham et al., 2002; Marsh and Sleivert, 1999).

Studies on exercising the forearm muscles and measuring oxygen consumption using NIRS have also been performed (Astrup et al., 1988; Colier et al., 2001; Conti et al., 1994; Hicks et al., 1999). Colier et al. (2001) noted that oxygen consumption in flexor digitorum superficialis and brachioradialis muscles increased dramatically after the onset of exercise. However, all previous studies focused on isometric contraction of the forearm muscles. Our study focused on cooling and warming the skin surface of the forearm before performing a moderate isotonic hand exercise. We monitored oxygen saturation of a forearm muscle group during exercise using NIRS. Our hypothesis is that warming the skin surface of the forearm extensor region prior to exercise will result in less of a decrease in oxygen saturation during exercise compared to controls. Conversely, cooling the skin surface of the forearm extensor region prior to exercise will result in more of a decrease in oxygen saturation during exercise compared to controls. Measuring both temperature and oxygen saturation levels may have applications in determining optimal temperature conditions for prolonging the duration of exercise performed by the upper limbs.

2. Materials and methods

2.1. Protocol

The study protocol was approved by the Institutional Review Board of San Diego State University and all subjects gave written informed consent. All subjects had no prior history of repetitive stress injuries such as carpal tunnel syndrome. The average subjects' age was 24.7 ± 3.5 years (range: 18–30 years). Each subject underwent four separate trials over a two-day span: warm, cold, two controls (one for warm and cold). A total of eight subjects (six men, two women) were used for this study.

The room where all experiments were conducted had a room temperature between 18 and 21 °C. The time when the trials were performed each day was between 8 and 11 a.m. All subjects were dressed in short-sleeved shirts. For all four trials, subjects were seated in front of a Royal manual typewriter and asked to type for 2 min with their dominant hand, excluding the thumb in a sequential manner (index to pinky). The typing pace was 180 beats per minute (BPM) set by a metronome. The StO2, total hemoglobin, and other metabolic parameters of the forearm extensor muscle were continuously monitored throughout typing with an InSpectra™ tissue spectrometer, Model 325 (Hutchinson Technology Inc., Hutchinson, Minnesota). A 15-mm probe connected to the tissue spectrometer was placed on the surface of the forearm extensor region and held in place by an InSpectra™ shield that blocked any ambient light that might interfere with the signal. This NIRS probe measures muscle oxygen saturation 15 mm below the skin surface of the forearm extensor region. A 1 min oxygen saturation baseline and recovery were taken before and after exercise, respectively.

A surface thermocouple was placed on the skin surface of the forearm extensor region to measure skin temperature before and after exercise. The surface thermocouple consisted of one wire (2 mm thick) that was locally constructed using copper-constantan wire and calibrated against industrial models. The surface thermocouple was held in place using the same InSpectra™ shield, which held the NIRS probe in place. Temperature values were recorded as an output of a Sensortek Inc. temperature monitor system (Model TH-8) that was connected to the surface thermocouple.

In the warm trial, the above-mentioned protocol was repeated, applying a Thermacare™ heat wrap to the surface of the forearm extensor muscle for 1 h prior to exercise. After 1 h, the heat wrap was removed, the NIRS probe and surface thermocouple were immediately placed over the surface of the forearm extensor region, baseline measurements were taken, and typing commenced. In the cold trial, a cold bag filled with crushed ice was applied to the surface of the forearm extensor region for 1 h prior to typing. After 1 h the cold bag was removed and the protocol was repeated.

2.2. Analysis methods

The InSpectra™ tissue spectrometer has a data acquisition rate of 3.5 s for both StO2 and total hemoglobin. The StO2 value for the InSpectra™ tissue spectrometer is a quantification of the ratio of oxygenated hemoglobin to total hemoglobin within the measured volume of tissue. Total hemoglobin is a quantification of total hemoglobin within the measured volume of tissue. StO2 and total hemoglobin were expressed in terms of percentage units. StO2 and total hemoglobin data were recorded into a data file using the InSpectra™ software program. Each data file contained marks that indicate the end of baseline, start and stop of typing, and the end of the post-typing rest period. The StO2 data file for each subject was processed to obtain baseline, exercise, and percentage change values for both StO2 and total hemoglobin. The definitions of these values, which have been previously used in other studies using the same InSpectra™ tissue spectrometer (Van den Brand et al., 2004), are listed in Table 1. Skin temperatures were recorded manually into a spreadsheet. We used ANOVA analysis to determine if there was a statistical difference of StO2 and total hemoglobin
averages between the warm and cold trials and their respective controls. \( P \) values were compared to the alpha value of 0.05 to assess statistical significance.

### 3. Results

Average skin temperatures before and after typing for each trial are listed in Table 2. These results show that warming the skin prior to exercise increased the skin temperature on average by 3.7 °C compared to its control, whereas skin temperature was decreased on average by 7.4 °C in the cold trial compared to its control.

Table 3 lists the average StO2 and total hemoglobin baseline, exercise, and percentage change values for each trial performed by the subjects. For the warm trial and its control, there was a smaller percentage decrease in StO2 and total hemoglobin during the warm trial (Figs. 1A and B). For the cold trial and its control, there was a greater StO2 and total hemoglobin percentage decrease (Figs. 1C and D). The mean percentage decreases of StO2 and total hemoglobin during exercise in the warm and warm control trials were statistically different (\( P < 0.05 \)). The mean percentage decreases of StO2 and total hemoglobin during exercises were also statistically different for the cold trial and its control (\( P < 0.05 \)).

### 4. Discussion

The objective of this study was to quantify the effects of altering the skin temperature of a particular muscle group during exercise. This study suggests that cooling or warming the forearm skin surface will significantly change oxygen dissociation in muscle tissue during exercise.

There were no significant differences in baseline StO2 and total hemoglobin values before exercise in any of the trials. This indicates that skin temperature of non-isotonically contracting muscles has no effect on muscle oxygen saturation or total hemoglobin. However, in the cold trial, subjects had on average a greater percentage decrease of both StO2 and total hemoglobin than during
Fig. 1. (A) Warm control trial (no warm pre-treatment). (B) Warm trial (after 1 h of warm pre-treatment), (C) Cold control trial (no cold pre-treatment), (D) Cold trial (1 h of cold pre-treatment). Upper line = oxygen saturation, lower line = total hemoglobin.
the cold control trial. These data suggest that the muscles extracted more oxygen due to a decrease in total hemoglobin induced by the cold pre-treatment. Conversely, in the warm trial, subjects had on average a smaller percentage decrease in both StO2 and total hemoglobin values than during the warm control trial. In this case, the muscles extracted less oxygen due to less of a decrease in total hemoglobin induced by the warm pre-treatment.

These data support the concept that warming the skin surface prior to exercise is beneficial. The reasons are that by pre-warming the skin surface, muscle oxygen saturation and total hemoglobin will not decrease as much, making muscles less vulnerable to fatigue and enabling them to perform work for a longer period of time. However, further study into this area with the inclusion of electromyography and intra-muscular temperature measurements is required to verify this notion.

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