Biosensors for EVA: Muscle Oxygen and pH During Walking, Running and Simulated Reduced Gravity

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During lunar excursions in the EVA suit, real-time measurement of metabolic rate is required to manage consumables and guide activities to ensure safe return to the base. Metabolic rate, or oxygen consumption (VO_2), is normally measured from pulmonary parameters but cannot be determined with standard techniques in the oxygen-rich environment of a spacesuit. Our group developed novel near infrared spectroscopic (NIRS) methods to calculate muscle oxygen saturation (SmO_2), hematocrit, and pH, and we recently demonstrated that we can use our NIRS sensor to measure VO_2 on the leg during cycling. Our NSBRI-funded project is looking to extend this methodology to examine activities which more appropriately represent EVA activities, such as walking and running and to better understand factors that determine the metabolic cost of exercise in both normal and lunar gravity. Our 4 year project specifically addresses risk: ExMC 4.18: Lack of adequate biomedical monitoring capability for Constellation EVA Suits and EPSP risk: Risk of compromised EVA performance and crew health due to inadequate EVA suit systems.

Lunar and planetary exploration space suit design can be enhanced by considering the physiologic responses of individual muscles during locomotion in reduced gravity. We investigated calf SmO_2 and pH during reduced gravity walking at varying treadmill inclines and added mass conditions using NIRS. Four male subjects aged 42.3±1.7 years (mean ± SE) and weighing 77.9±2.4 kg walked at a moderate speed (3.2±0.2 $km \cdot h^{-1}$) on a treadmill at inclines of 0, 10, 20, and 30%. Unsuited subjects were attached to a partial gravity simulator which unloaded the subject to simulate body weight plus the additional weight of a space suit (121 kg) in lunar gravity (0.17G). Masses of 0, 11, 23, and 34 kg were added to the subject and then unloaded to maintain constant weight. Spectra were collected from the lateral gastrocnemius (LG), and SmO_2 and pH were calculated. The effects of incline and added mass on SmO_2 and pH were analyzed through repeated measures ANOVA. SmO_2 and pH were both unchanged by added mass ($p>0.05$), so data from trials at the same incline were averaged. LG SmO_2 decreased significantly with increasing incline ($p=0.003$) from 61.1±2.0% at 0% incline to 48.7±2.6% at 30% incline, while pH was unchanged by incline ($p=0.12$). Increasing the incline (and thus work performed) during walking causes the LG to extract more oxygen from the blood, presumably to support the increased metabolic cost of uphill walking. The lack of an effect of incline on pH may indicate that, while the intensity of exercise has increased, the LG has not reached a level of work above the anaerobic threshold. In these preliminary studies, 30% incline walking at reduced gravity may not require anaerobic LG activity due to the low exercise intensity (42.8±1.6% of VO_{2max}).

In a separate study we examined the exercise-induced hydrogen ion (H^+) threshold, which can be detected in the *vastus lateralis* (VL) using NIRS and has been found to be correlated with lactate threshold. Different levels of upper and lower leg muscle work during locomotion may result in dissimilar rates of H^+ accumulation and perhaps influence onset of local fatigue. We hypothesized that the H^+ threshold in the LG would precede the H^+ threshold in the VL because of the predominant role of the LG in stance and propulsion during locomotion,. Nine healthy subjects exercised on a motorized treadmill at 3.2 $km \cdot h^{-1}$ for 3 min, increasing each 3 min in 1.6 $km \cdot h^{-1}$ increments until reaching 85% of predicted maximal heart rate. NIRS sensors were secured over the VL and LG. Whole-body oxygen consumption (VO_2) was measured using a standard metabolic cart. H^+ threshold was defined as the VO_2 at which the slope of [H+] increased with work rate as determined by a simultaneous bilinear regression ($R^2>0.68$). Paired t-tests were used to detect differences in H^+ threshold between muscles. The H^+ threshold occurred at a lower VO_2 in the LG (1.00±0.26 l·min-1; mean (±SD) than in the VL (1.26±0.40 $l \cdot min^{-1}$, p=.003), corresponding to a lower treadmill speed (LG: 5.6±0.9; VL: 6.6±1.3 $km \cdot h^{-1}$, p=.01). The lower H+ threshold of the LG, compared to the VL, may lead to an earlier onset of LG fatigue during higher treadmill walking speeds, potentially influencing the walk-to-run transition.