Characterization of Carbon Dioxide Washout Measurement Techniques in the Mark-III Space Suit

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Providing adequate carbon dioxide (CO_2) washout is essential to the reduction of risk in performing suited operations. Long term CO2 exposure can lead to symptoms such as headache, lethargy, dizziness, and in severe cases can lead to unconsciousness and death. Thus maintaining adequate CO2 washout in both ground testing and during in flight EVAs is a requirement of current and future suit designs. It is necessary to understand the inspired CO2 of suit wearers such that future requirements for space suits appropriately address the risk of inadequate washout. Testing conducted by the EVA Physiology Laboratory at the NASA Johnson Space Center aimed to characterize a method for noninvasively measuring inspired oronasal CO2 under pressurized suited conditions in order to better inform requirements definition and verification techniques for future CO2 washout limits in space suits. Prior work conducted by the EPL examined several different wearable, respirator style, masks that could be used to sample air from the vicinity surround the nose and mouth of a suited test subject. Previously published studies utilized these masks, some being commercial products and some novel designs, to monitor CO2 under various exercise and flow conditions with mixed results for repeatability and/or consistency between subjects. Based on a meta-analysis of those studies it was decided to test a nasal cannula as it is a commercially available device that is placed directly in the flow path of the user as they breathe.

A nasal cannula was used to sample air inhaled by the test subjects during both rest and exercise conditions. Eight subjects were tasked with walking on a treadmill or operating an arm ergometer to reach target metabolic rates of 1000, 2000, and 3000 BTU/hr. Suit pressure was maintained at 4.3 psid for all tests, with supply flow rates of 6, 4, and 2 actual cubic feet per minute depending on the test condition. Each test configuration was conducted twice with subjects breathing either through their nose only, or however they felt comfortable. By restricting breathing through a single orifice, we are able to more accurately define exactly what flow stream the sampled CO2 is taken from. Oronasal CO2 was monitored using real time infrared gas analyzers fed via sample tubes connected to the nasal cannula within the suit. Two additional sampling tubes were placed at the head and chin of the test subject, in an effort to capture CO2 concentrations across the entire flow stream of the Mark-III vent system (flow path is head to neck). Metabolic rate was calculated via the exhaust CO2 concentration and used to adjust subject workload on either the treadmill or arm ergometer until the target was reached.

Forward work will aim to characterize the historically accepted minimum ppCO2 in suit during EVA by repeating this study in the Extravehicular Mobility Unit (EMU) space suit. This will help to define washout requirements for future suits, be they NASA (e.g. Z-2) or Commercial Crew designed. Additionally it is important to determine the functional consequences of CO2 exposure during EVA. Severe CO2 symptoms are a result of very high concentration, acute exposures. While long term, low concentration exposures have been shown to result in slight cognitive decline, symptoms resolve upon quickly returning to nominal concentrations and it remains unknown the impact that minor deficits in cognitive performance can have on EVA performance.