Energy Mobility Testing

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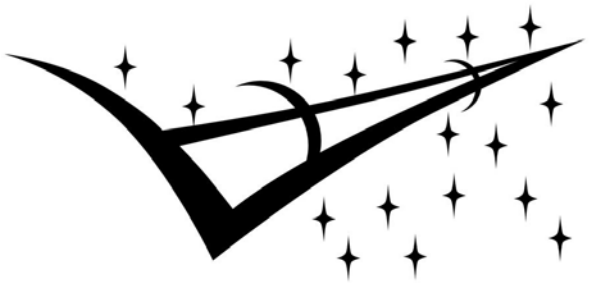
SPACE LIFE SCIENCES
SUMMER INSTITUTE



Introduction

- Education
  - Rice University, M.B.E. in Bioengineering
  - University of Missouri, B.S. in Biomedical Engineering

- Why NASA?
  - Curiosity
  - Interested in astronaut exercise training pre-, post- and in-flight

- Career/Interests
  - Sports Medicine and Exercise Physiology
  - Own/coach my own CrossFit box

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Internship Objectives

- Original Objectives
  - To evaluate alternative methods of securing CO_2 sensing locations on the face for suited CO_2 washout testing
  - To improve the current CO_2 washout system by adding drying lines to the oronasal sampling locations
  - To characterize some of the error sources associated with CO_2 washout testing in an EVA suit

- Actual Objectives
  - Evaluated the feasibility of characterizing suited mobility as a function of metabolic cost to the occupant
  - Helped with energy mobility test monitoring
  - Analyzed data obtained from testing to provide recommendations for future work

Background

- Extravehicular Activity (EVA)
  - Provide service, maintenance, repair, or replacement of space equipment without need to remove it to a pressurized environment, return to Earth, or abandon it
    - Examples: support/assembly, inspection/maintenance, transfers
  - Risks/dangers
    - Radiation
    - Suit malfunctions
    - Environment
    - Workload, metabolic rate, fatigue

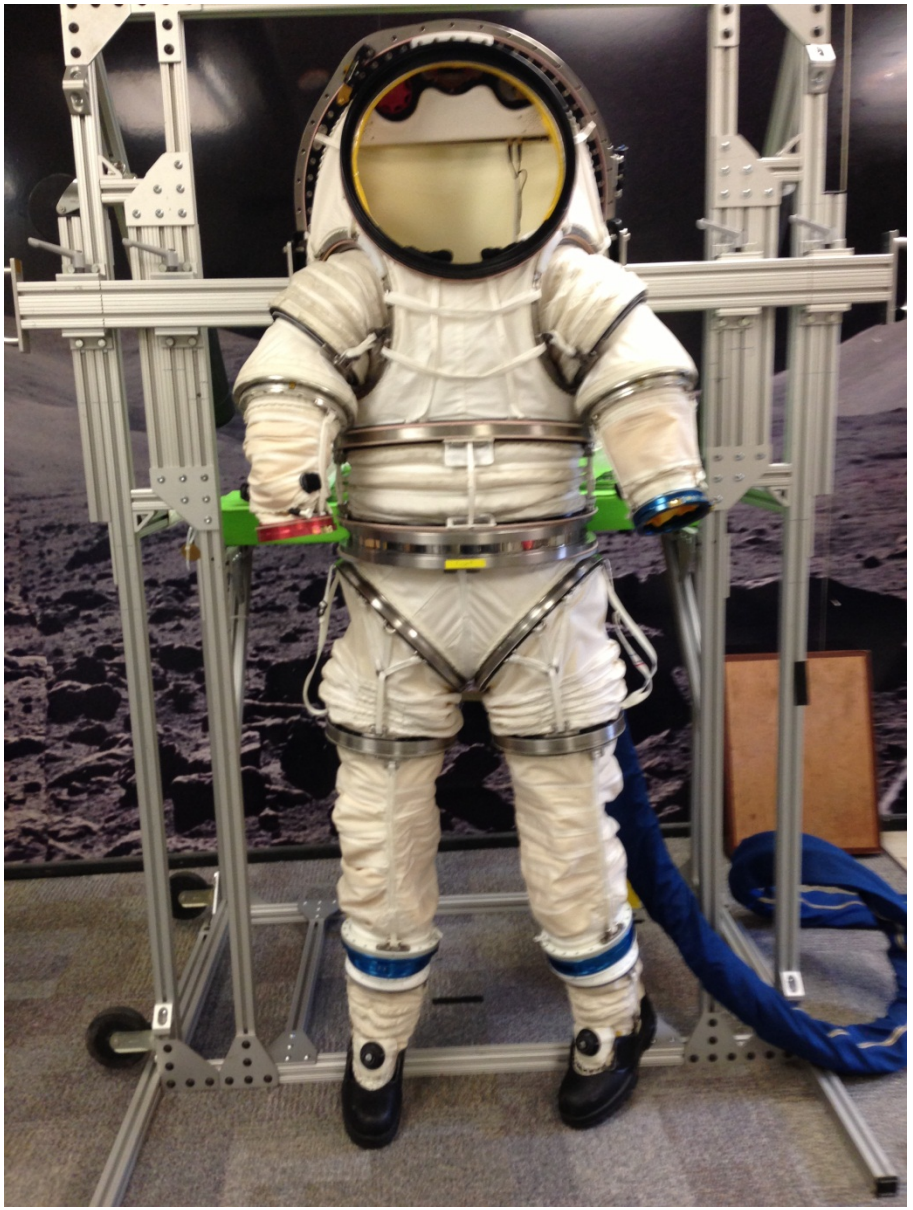
- What is the relevance/NASA interest?
  - Use functional tasks to evaluate suit mobility requirements rather than isolated movements (single joint range of motion)
  - Use data from this test to figure out what measurements and methods are most promising for future tests
  - Eventually may be used for designing improvements for future space suits
  - May be a quick and easy way to show efficacy of new space suit designs

Mark III (MKIII) Suit

- ~120 lb (sans PLSS)
- 0 – 8.3 psid
- Hybrid suit
  - Hard upper torso and brief
  - Soft components (i.e., elbows, knees)
- Rear entry
- Bearings
  - Shoulder, upper arm, waist, upper hip, mid hip, upper leg, ankle
  - More hip bearings for dynamic joint mobility

Z-1 Suit

- ~130 lb (sans PLSS)
- 0 – 8.3 psid
- “Soft” EVA suit
  - Texture of soft components allows more flexion mobility
- Rear entry
- Bearings
  - Mid shoulder, upper arm, waist, hip, upper thigh, ankle

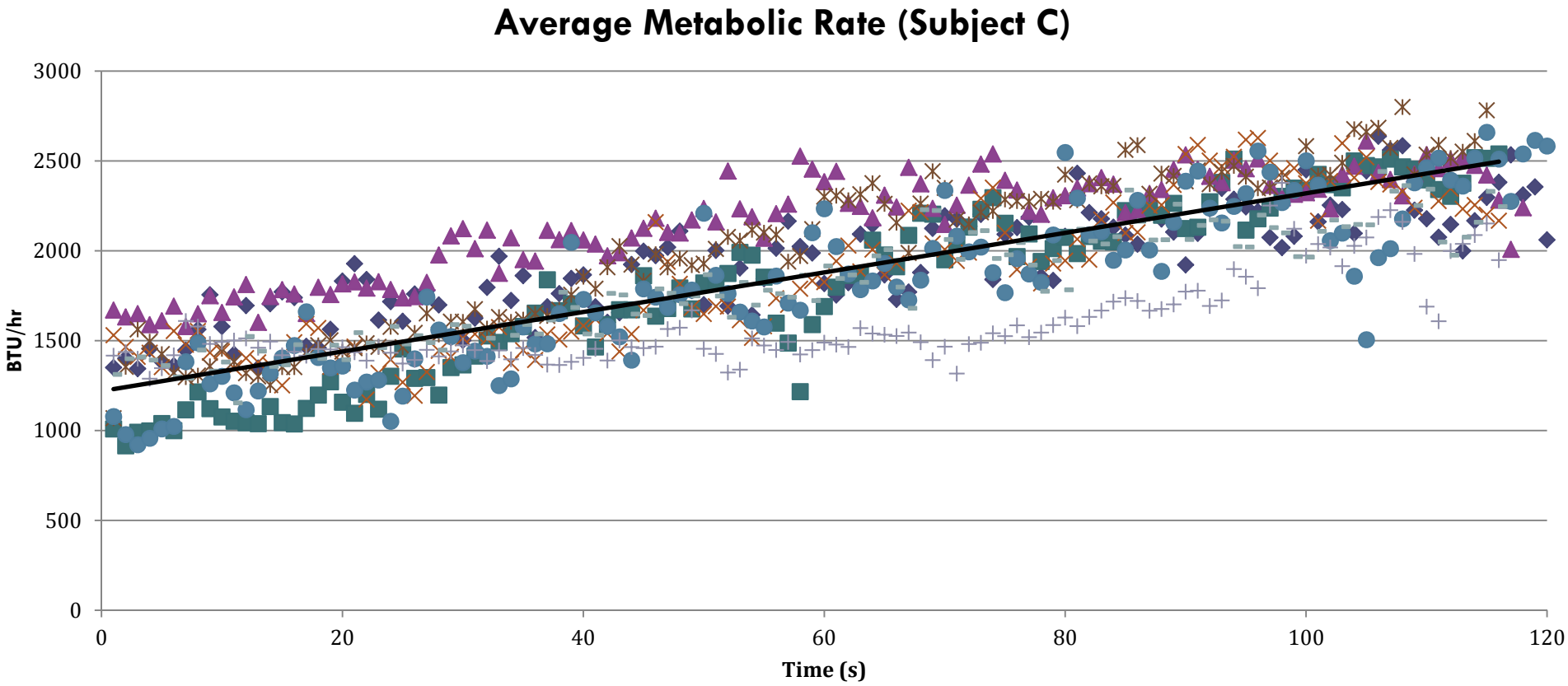


Methods and Materials

- Approach
  - 3 fit-checked and approved suit test candidates used
  - Performed various functional tasks 4 ways: MKIII, Z-1, unsuited natural, and unsuited cadenced
  - Pressure maintained at 4.3 psid for all suited runs
  - Tasks (2 min each): walking, sit/stand, stair climb, prone/recover, shoveling, hammering, object relocation, side step
  - Minimum of 2-min break between each task to return to resting met rate
  - Number of reps completed in the 1st suited run was used for 2nd suited run
  - Number of reps completed in MKIII was used for unsuited cadenced run

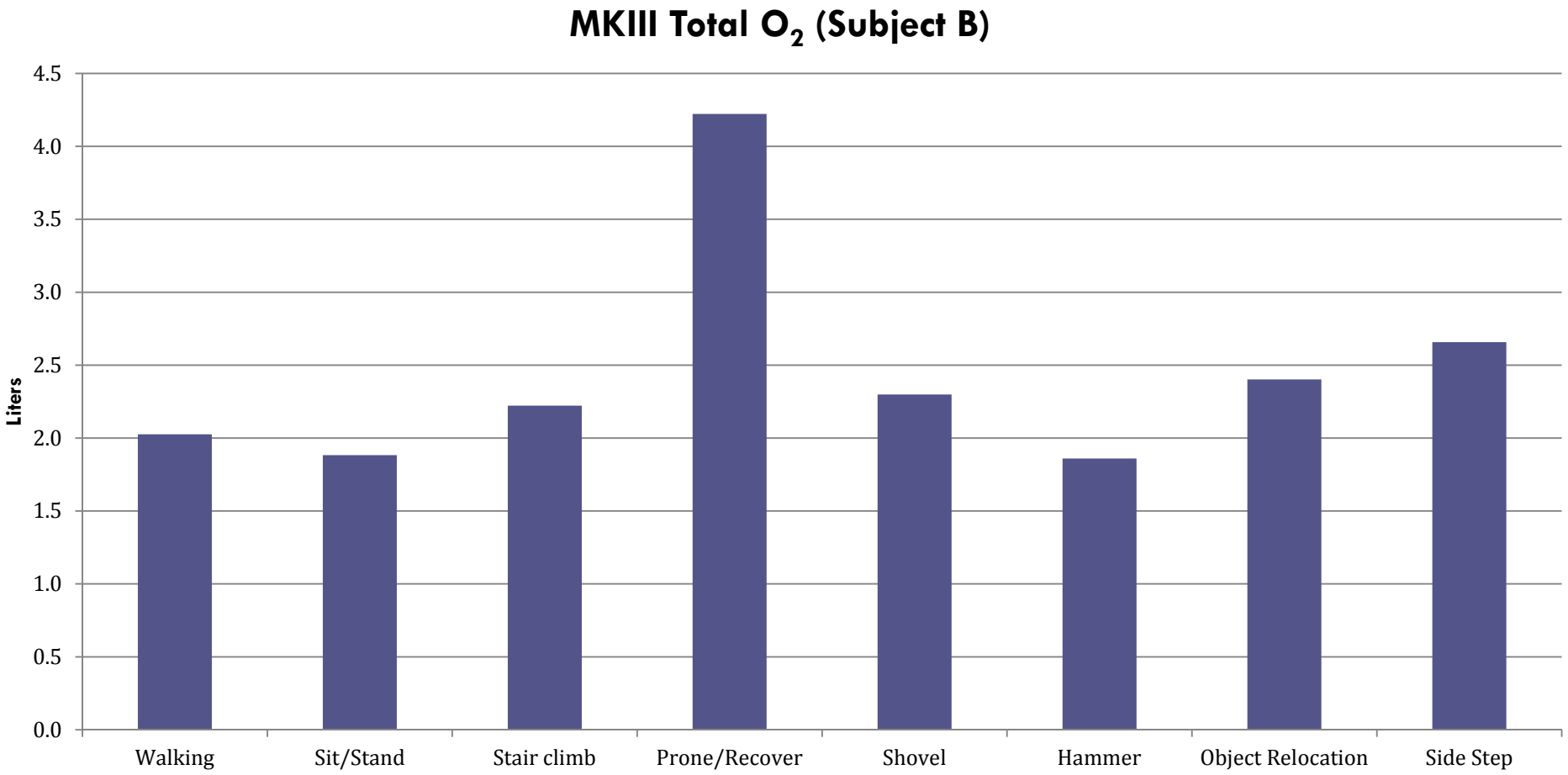
- Hardware
  - MKIII Suit
  - Z-1 Suit
  - Liquid cooling garment (LCG)
  - Donning stands (Z-1 and MKIII)
  - COSMED K4b2 Mobile Metabolic System
  - AEI Tech CD-3A Infrared CO_2 analyzer
  - Zephyr BioHarness heart rate monitor

Time Constraint



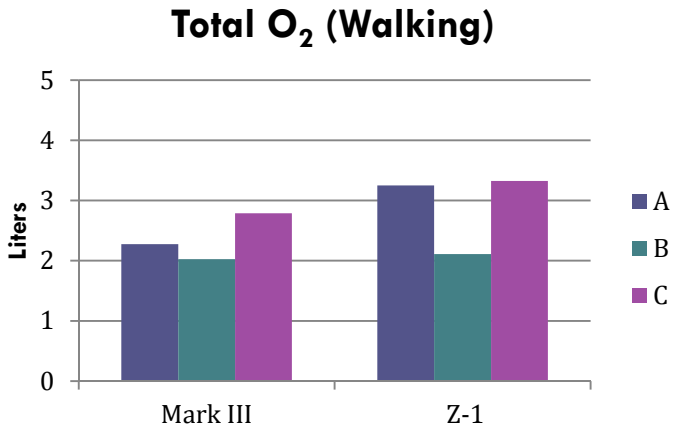
- Is 2 minutes per task enough time to reach steady state?
  - Longer time is needed to reach steady state

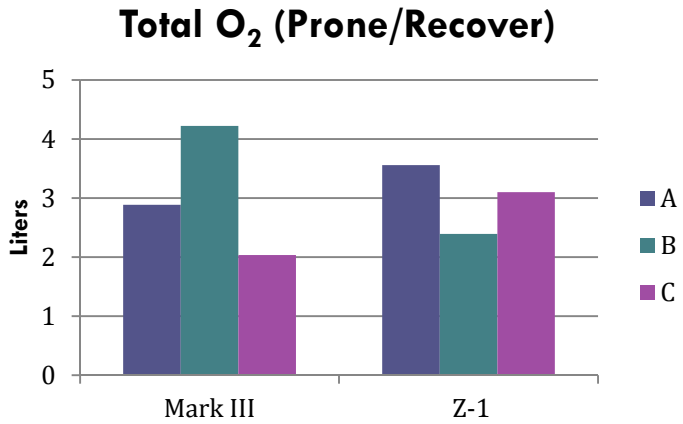
Task Order

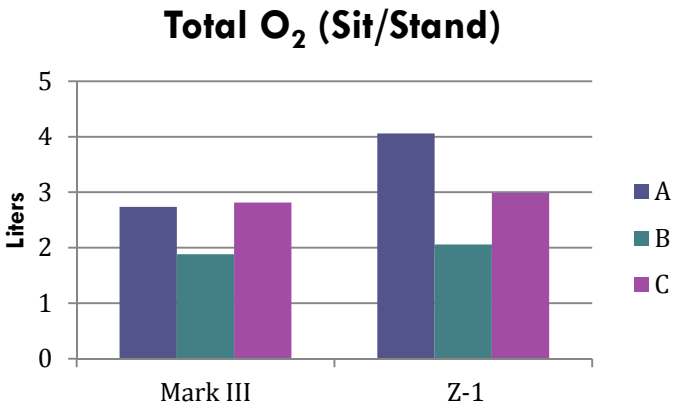


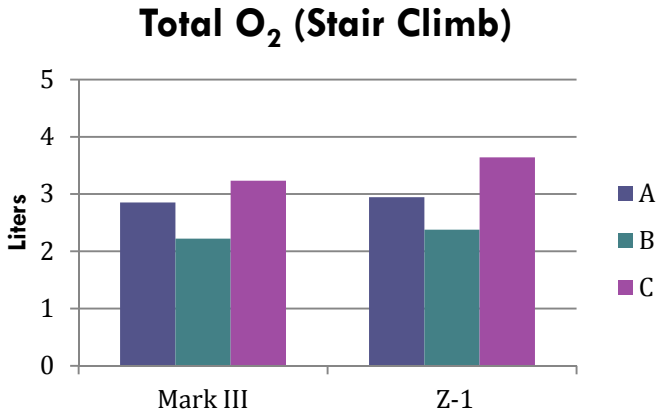
- Could move the hardest tasks to the end for future tests so fatigue isn't a confounding factor
- Move tasks that put wear and tear on suit last (prone/recover)
- Split up forearm intensive tasks (shovel and hammer)

Task Variability



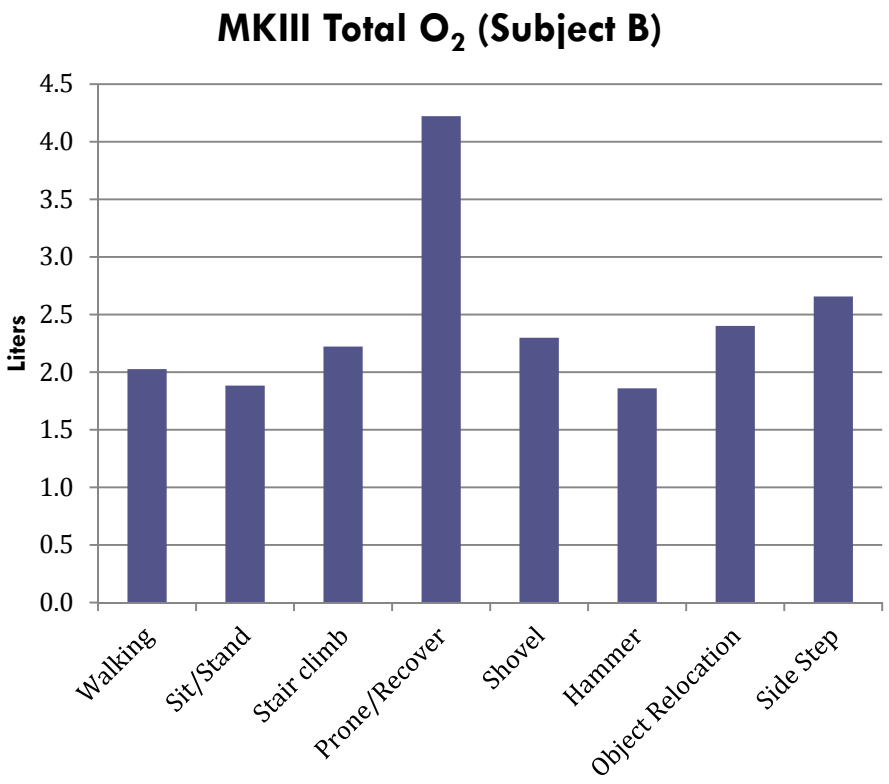


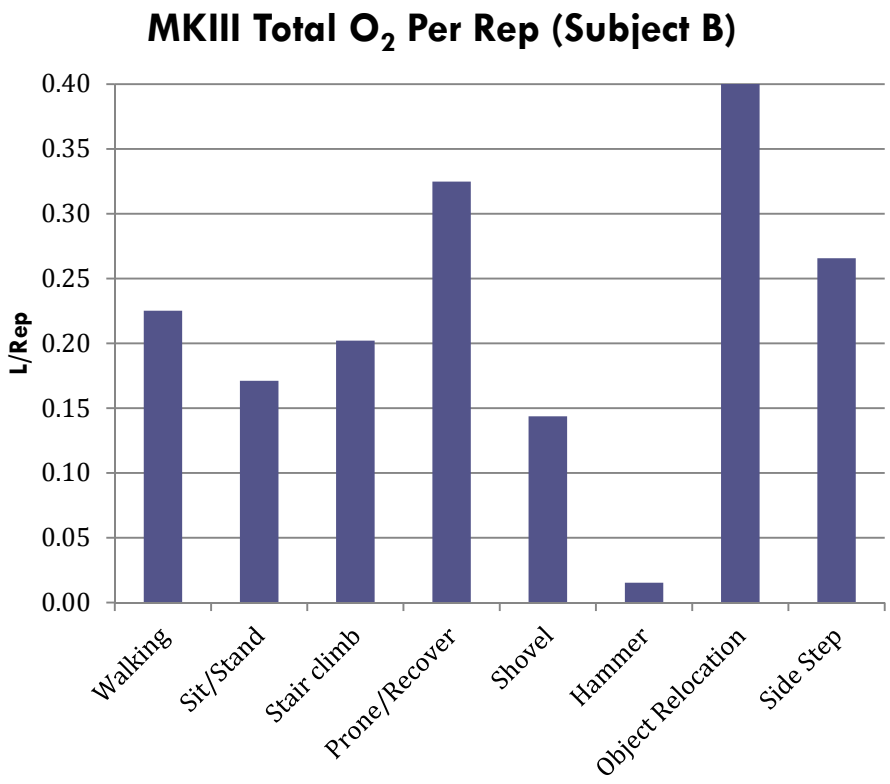




- No trends in the differences seen in total O_2 used between the MKIII and Z-1 over the tasks
- No tasks were consistently different between suits
  - Possibly due to subject variability or suit test order
  - May be better to use similar size/fitness subjects in future tests

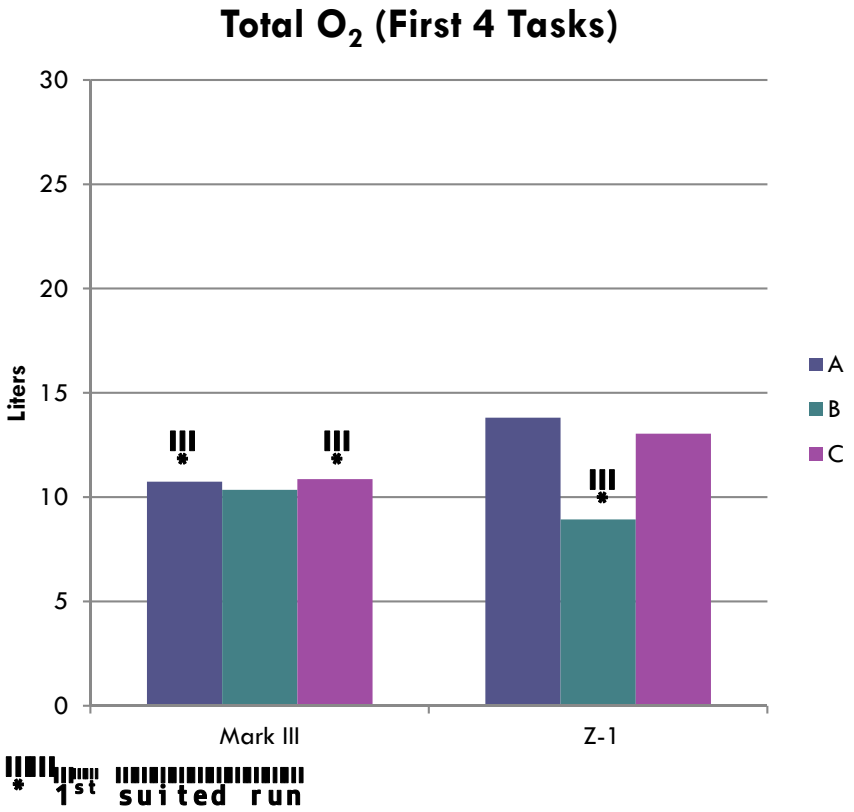
Remove Hammer Task

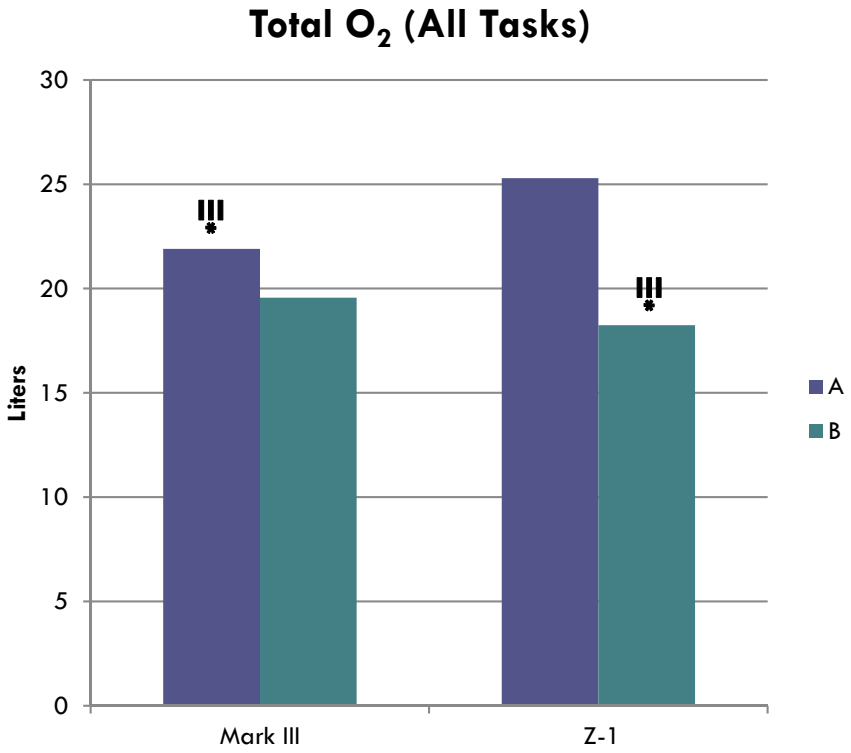




- Too much variability in hammer task execution
  - Force per hit
  - Number of hits
  - Strike pattern
  - Number of pads destroyed
  - Right, left, or two-handed

MKIII vs. Z-1 Energy Expenditure

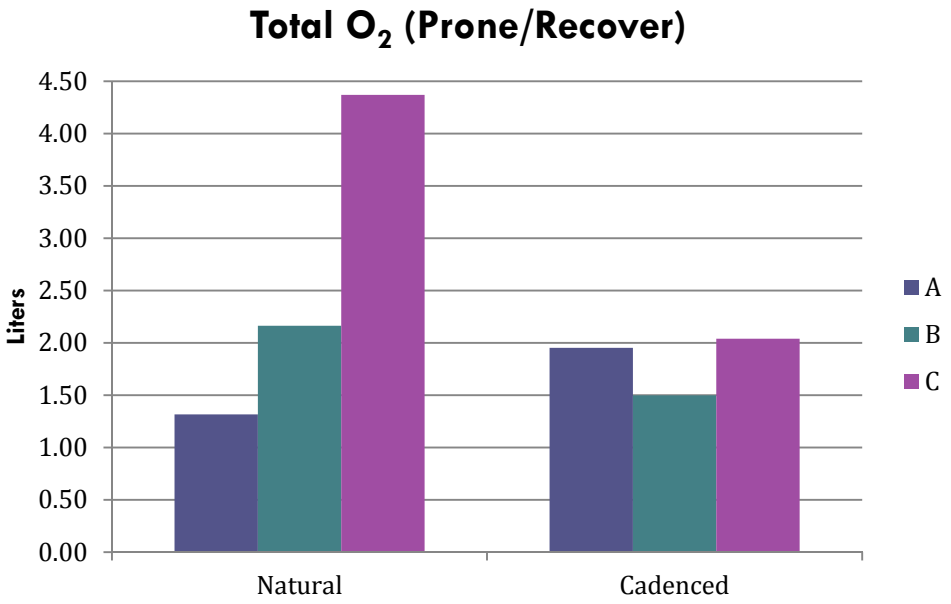


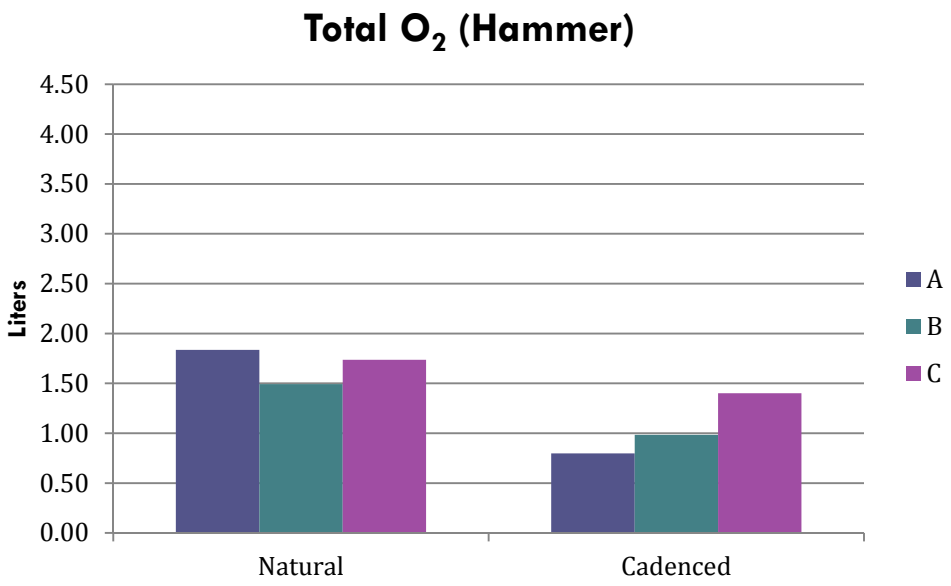


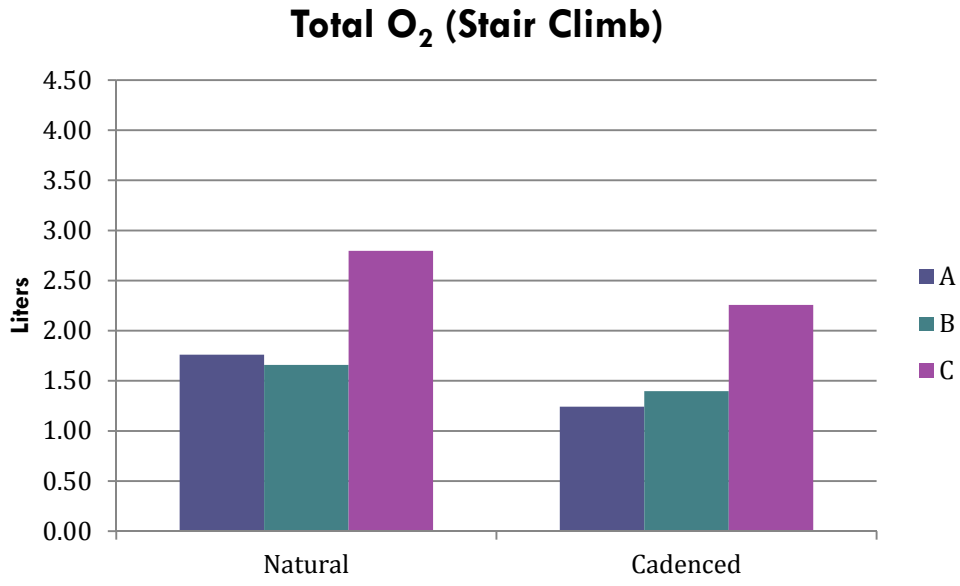
- Does suit order affect performance?
  - 2nd suited run required more work than 1st run in all subjects
    - May be due to more familiarity with movements in a suit during 2nd run. Might need full familiarization run prior to data collection

Unsuited data (Shirtsleeve)

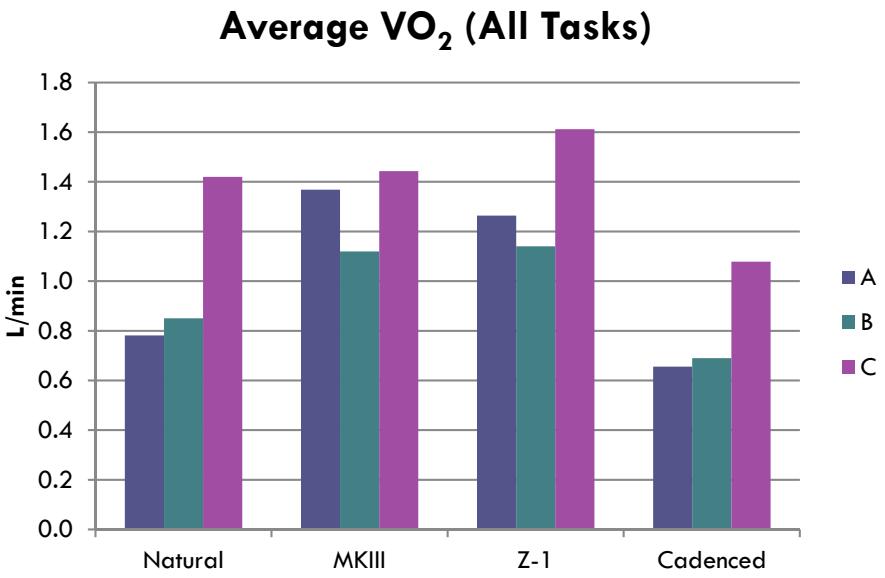
- Natural vs. Cadenced
  - Cadenced shirtsleeve (SS) runs were typically lower than natural SS runs
- Clearly define what a natural pace is in the future (Subject A) →

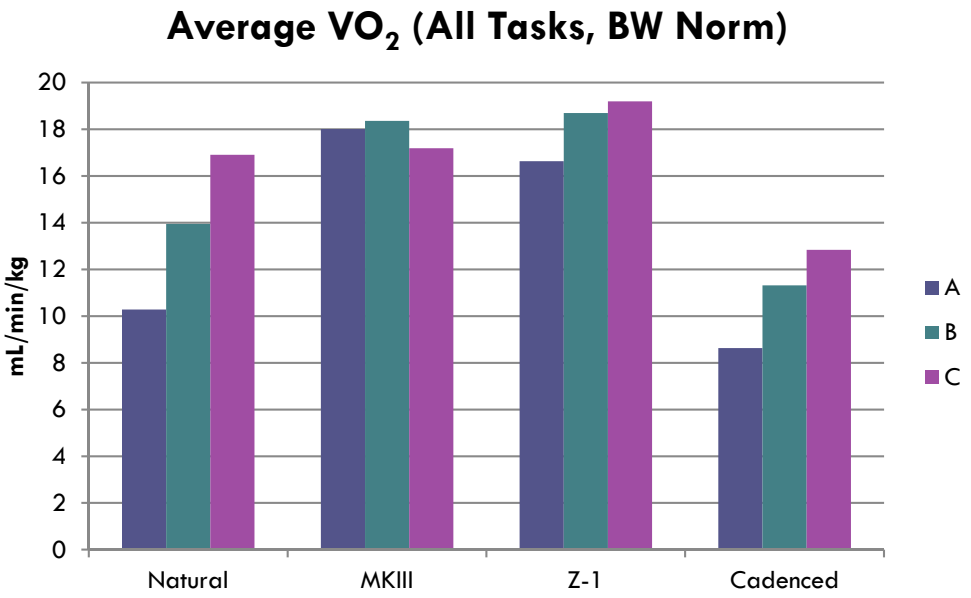


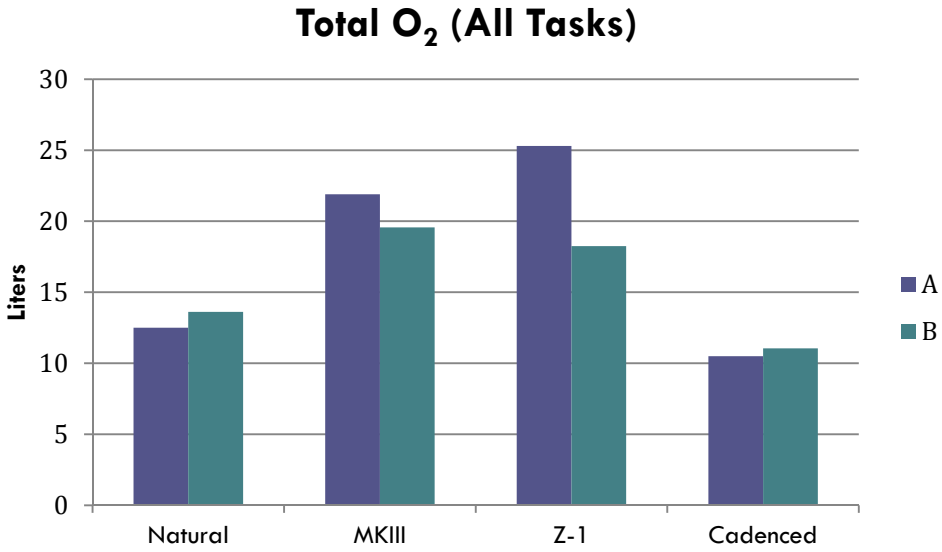




Suited vs. SS

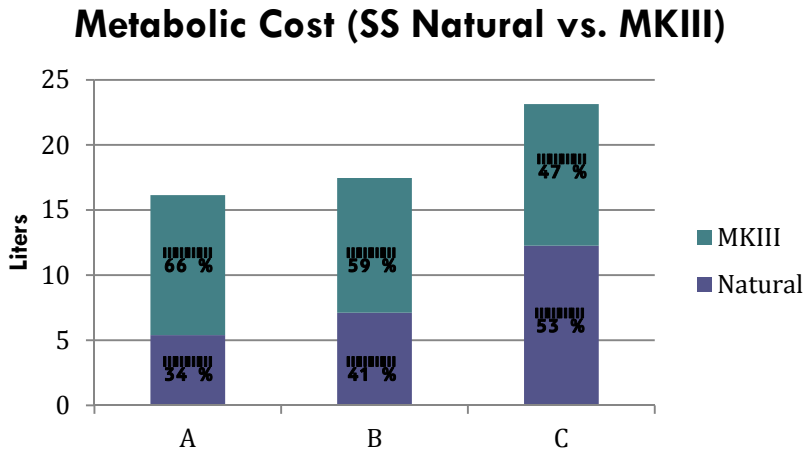


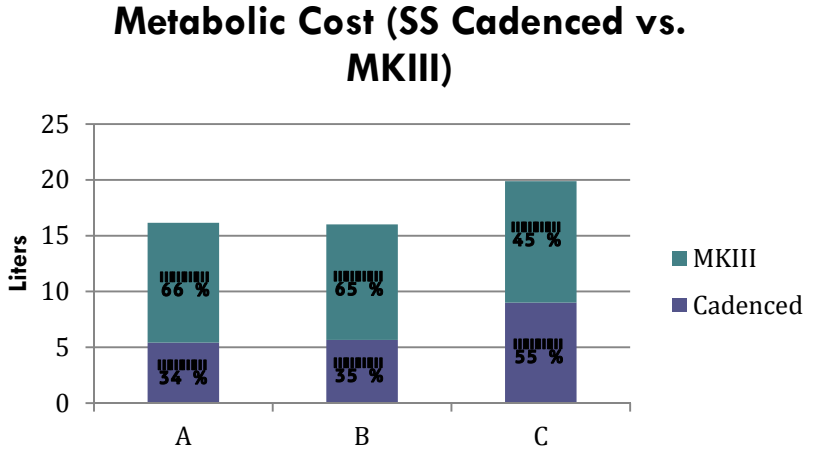


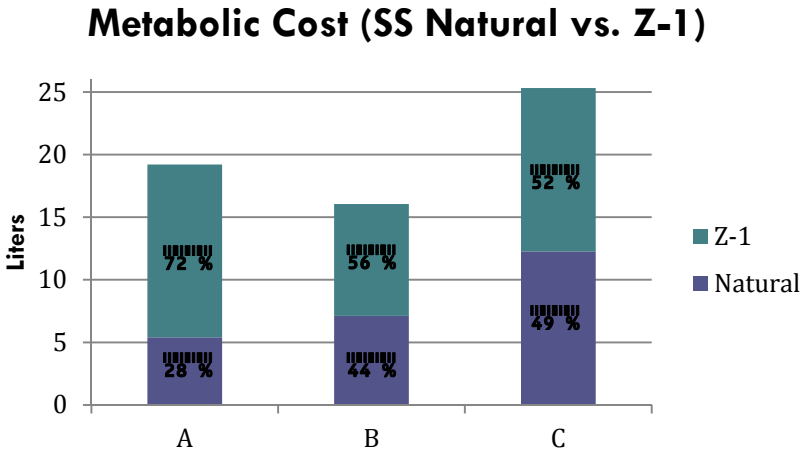


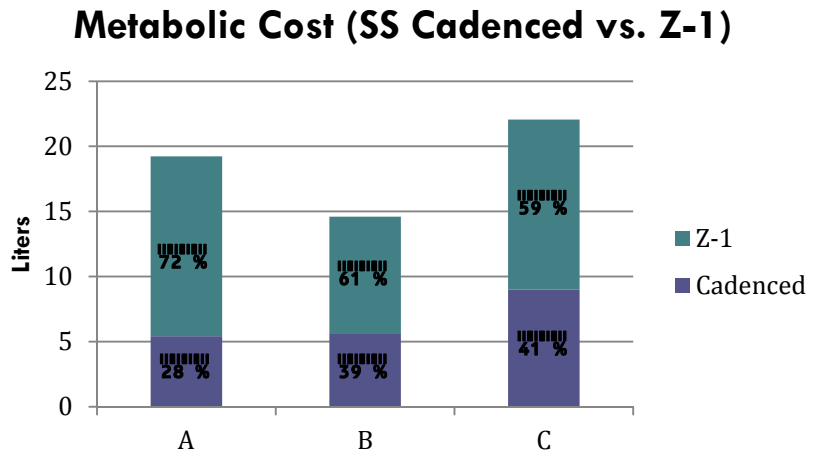
- Suited work was notably more demanding than unsuited
- Cadenced runs may be a better control than natural runs for suited vs. SS comparison since number of repetitions will be the same

Metabolic Cost of the Suit



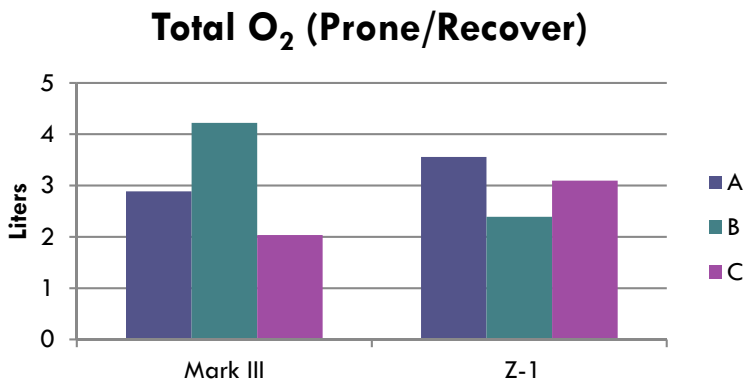


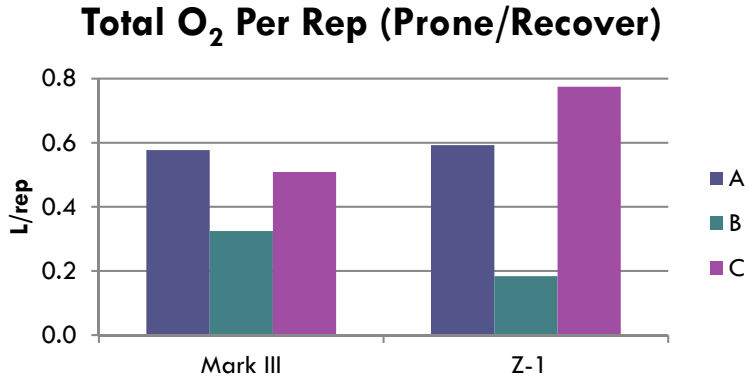


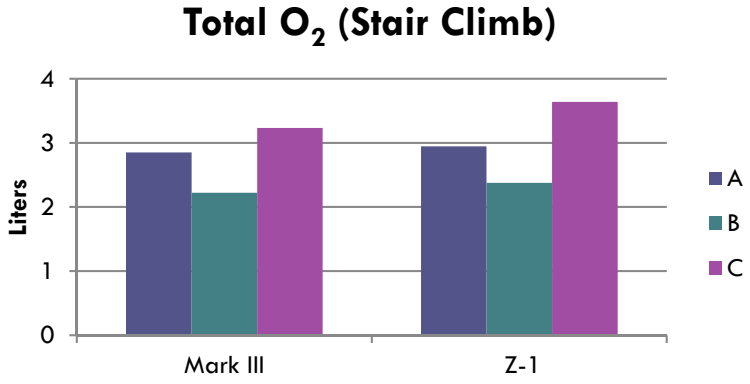


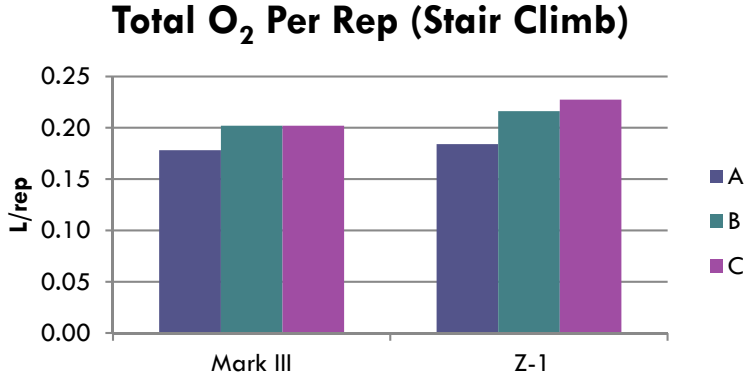
- Metabolic cost of suit ranged from 45-72%

Normalization per Repetition



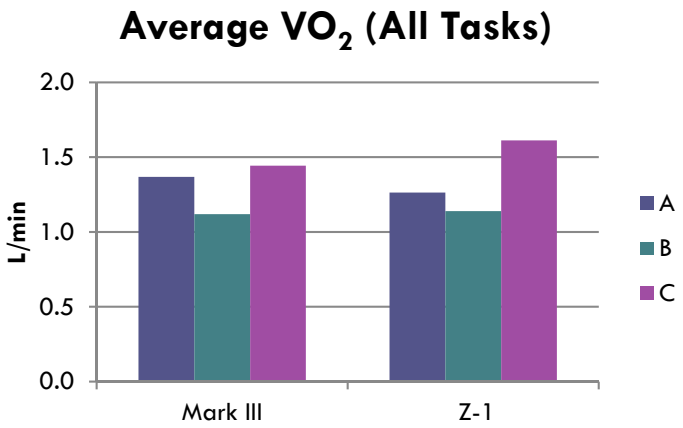


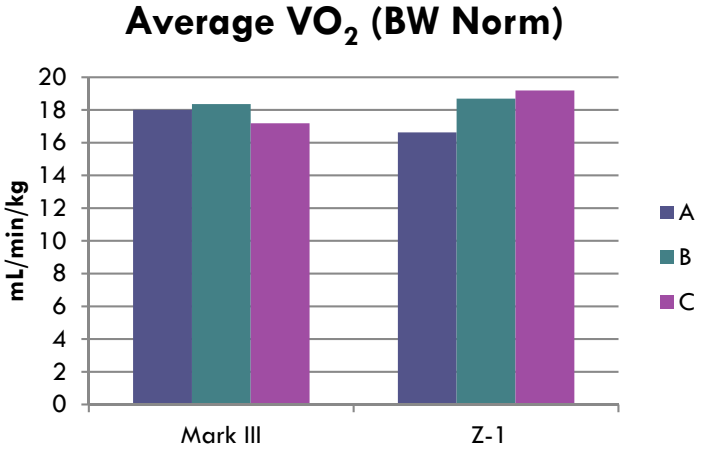


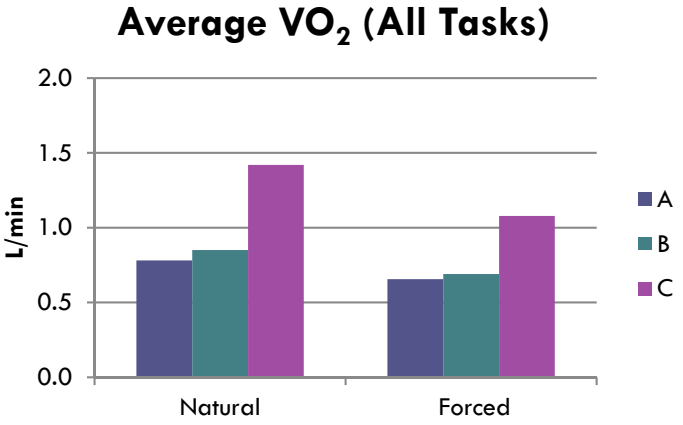


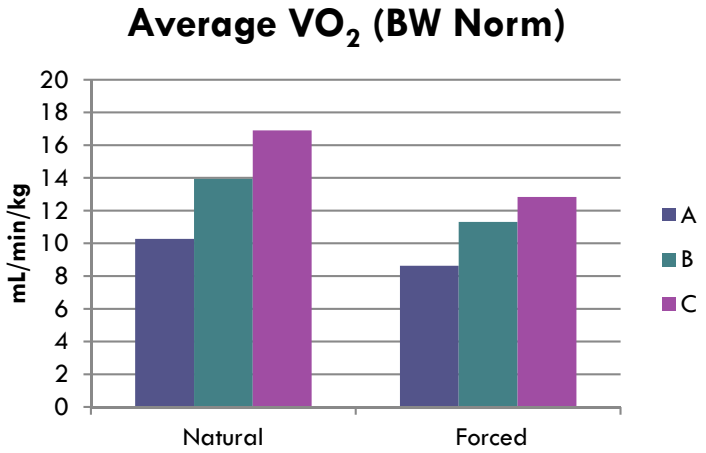
- Shows differences in how the tasks were executed
  - Prone/Recover: Subject B only went to a kneeling position and had a pole for assistance
- Takes into account for the different number of repetitions performed by each subject (i.e., stair climb)

Normalization to Bodyweight



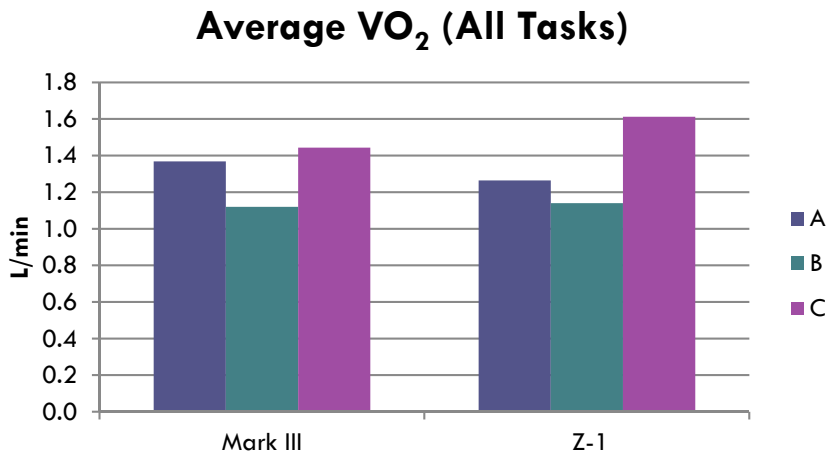


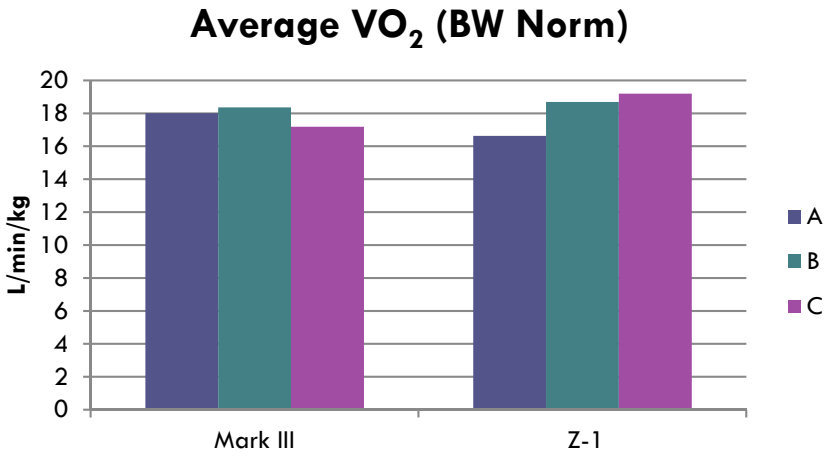


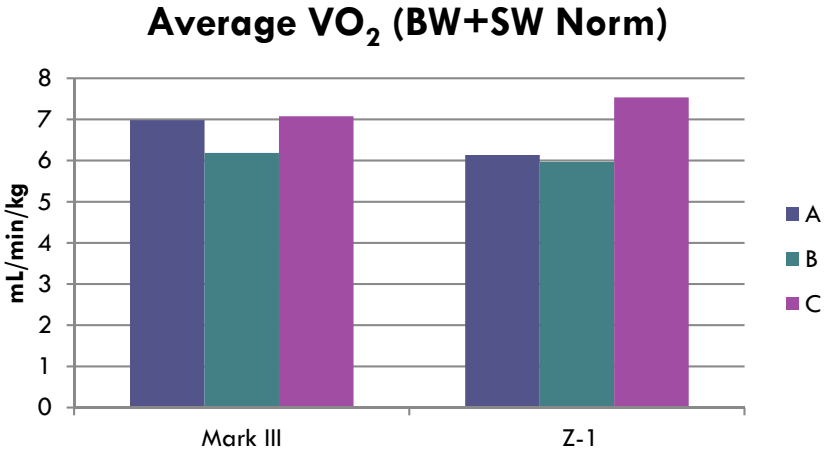


- Brought subject B (light weight) up and subject C (heavy weight) down
- Subjects tended to work at similar average metabolic rates
  - Does not account for differences in total work completed by each individual subject or show consistent differences between suits

Normalization to BW + Suit Weight







- Could be used to account for total weight in suit for future tests

*Suit weights were approximated for these normalizations

Conclusions

1. Increase amount of time for each task so steady state is reached
2. Try to normalize the amount of work completed for each task

Method changes for future tests

- Have set number of repetitions to complete per task (2) and make sure number of repetitions will take enough time to reach steady state (1)
  - Ex: If on average, subjects completed 10 prone/recover full repetitions in 2 min, increase the target number of repetitions to complete the task to 20
    - Eliminates the need to normalize to O_2 per rep
    - Shows subject to subject differences (Sub B might take 4 min to complete 20 reps and use more energy than subject C who might complete 20 reps in 3 min)
    - Eliminates the need for a natural and cadenced run and just gives the unsuited subject an exact total work target that they can complete at a comfortable pace
- Remove hammer task and possibly shoveling task as these are the most difficult tasks to normalize to a total amount of work done

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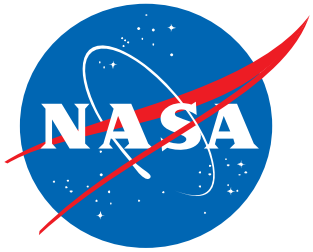
NASA