Evaluation of Maximal Oxygen Uptake (VO$_{2}\text{max}$) and Submaximal Estimates of VO$_{2}\text{max}$ Before, During and After Long Duration ISS Missions

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Background

- NASA’s Human Research Program Integrated Research Plan (HRP-47065) serves as a road-map identifying critically needed information for future space flight operations (Lunar, Martian)
- VO$_2$max (often termed “aerobic capacity”) reflects the maximum rate at which oxygen can be taken up and utilized by the body during exercise
- Lack of in-flight and immediate postflight VO$_2$max measurements was one area identified as a concern
- The risk associated with not knowing this information is: “Unnecessary Operational Limitations due to Inaccurate Assessment of Cardiovascular Performance” (HRP-47065)
- Currently, VO$_2$max is estimated using HR response to submaximal exercise
- Assumes VO$_2$ at each exercise stage during flight same as preflight
- The validity of this technique has not been established during or after flight
Current data suggests a sharp decline in VO\textsubscript{2}max early in-flight and a slow recovery with participation in exercise countermeasures.

- Large decline at R+5, but recovered to preflight fitness by R+30.
- Do these changes in estimated VO\textsubscript{2}max reflect true changes?
  - Factors such as cycling efficiency can influence the HR and VO\textsubscript{2} response to exercise.
  - Anything affecting exercise HR response also affects the VO\textsubscript{2}max estimate.
Specific Aims

➢ To directly measure VO$_2$max during and following long duration missions

➢ To assess the validity of the current methods of estimating VO$_2$max change during and following ISS missions, and;

➢ To determine if the accuracy of estimating changes in VO$_2$max during and following ISS missions can be improved (e.g. addition of submaximal VO$_2$, cardiac output measures)
# Experiment Design

<table>
<thead>
<tr>
<th>Preflight</th>
<th>In-Flight</th>
<th>Postflight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Peak Cycle Exercise Test</strong>-</td>
<td><strong>VO₂max Cycle Exercise Tests</strong></td>
<td><strong>VO₂max Cycle Exercise Tests</strong></td>
</tr>
<tr>
<td>Nominal MEDB 4.1</td>
<td>FD 14 (± 2 days)</td>
<td>R+1</td>
</tr>
<tr>
<td>L-270 (± 3 weeks)</td>
<td>3.0 hours</td>
<td>1 hour</td>
</tr>
<tr>
<td>1 hour</td>
<td>(Repeated every 30 days)</td>
<td>R+10 (± 2 days)*</td>
</tr>
<tr>
<td><strong>VO₂max Cycle Exercise Test</strong></td>
<td></td>
<td>R+30 (± 2 days)</td>
</tr>
<tr>
<td>– Preflight Trial 1*</td>
<td></td>
<td>1 hour</td>
</tr>
<tr>
<td>L-60 (± 5 days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>VO₂max Cycle Exercise Test</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Preflight Trial 2§</td>
<td></td>
<td></td>
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<tr>
<td>L-30 (± 5 days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.5 hours</td>
<td></td>
<td></td>
</tr>
<tr>
<td>§If L-60 is technically sound,</td>
<td></td>
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</tr>
<tr>
<td>L-30 test will be waived.</td>
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</tbody>
</table>

*Represents test session not normally performed for MEDB 4.1
SESSION: Peak Cycle Exercise Test on L-270 (3 weeks)

Scenario: (1 hour)
- Measure VO$_2$max during a cycle protocol of increasing exercise intensity
- Heart rate, blood pressure, exercise workloads, and perception of effort will also be measured
- Data obtained from this test will be used to establish the protocol for the subsequent tests
- Session is identical to that performed by all crew members under MEDB 4.1
  - Data will be shared between PI and Med Ops to prevent necessity for redundant testing
Session Descriptions
Preflight/Postflight

SESSIONS: \textit{VO}_2\text{max Cycle Exercise Tests} on L-60, L-30, R+1, R+10 and R+30

Scenario: (1.5 hours/test preflight, 1 hour/test postflight)

- Measure \textit{VO}_2\text{max} using investigation specific protocol
- First 3 exercise stages are 5 min @ work rates eliciting \(\sim 25\), 50 and 75% of \textit{L}-270 \textit{VO}_2\text{max}, remaining stages increase 25 W/min to maximal levels
- First 3 stages are identical to those used in MEDB 4.1 testing
- Blood pressure, oxygen uptake, heart rate, workloads and perception of effort will be measured
- Cardiac output will be measured using a rebreathing technique during last minute of the first 3 exercise stages
- Data obtained from L-60, R+1, R+30 will fulfill MEDB 4.1 testing requirements.
Session Descriptions
Preflight/Postflight

Constraints:
• No max exercise 24 hrs prior to testing; no regular exercise 8 hrs prior to testing
• No food 2 hrs prior to test
• No caffeine, alcohol, or nicotine 8 hrs prior to test
• No Neutral Buoyancy training 48 hours prior to test; prefer 72 hours
• ECG monitoring (up to 3 Leads) is required for tests
• No physical testing or physical training will be conducted with the crewmembers within 72 hours of returning from overseas travel
• No physical testing or physical training will be conducted with the crewmembers within 48 hours of domestic travel unless approved by the Crew Surgeon
Session Descriptions
In-Flight

SESSIONS: **VO₂max Cycle Exercise Tests** on FD 14 and every 30 FDs subsequent (same schedule as MEDB 4.1)

Scenario: (3.0 hours/test, includes equipment and subject preparation, exercise and stowage time)

- Same test protocol as performed preflight
- ECG is down-linked real time during test (Ku coverage necessary during exercise) and viewed by Surgeon for medical monitoring purposes only
- Cardiac output will be measured using a rebreathing technique during last minute of the first 3 exercise stages
- Data other than ECG will be down-linked following session
Session Descriptions

In-Flight

Constraints:

- No max exercise 24 hrs prior to testing; no regular exercise 8 hrs prior to testing
- No food 2 hrs prior to test
- No caffeine, alcohol, or nicotine 8 hrs prior to test
# Experiment Training

<table>
<thead>
<tr>
<th>Session Title</th>
<th>Schedule</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEC OV*</td>
<td>L-1 year</td>
<td>1 hour</td>
</tr>
<tr>
<td>CMS Ops 1*</td>
<td>L-1 year</td>
<td>1.5 hours</td>
</tr>
<tr>
<td>PPFS Hardware Overview</td>
<td>L-365/180 days</td>
<td>2 hours</td>
</tr>
<tr>
<td>VO$_2$max Integrated Training</td>
<td>L-160/120 days</td>
<td>2 hours</td>
</tr>
<tr>
<td>VO$_2$max Refresher Training</td>
<td>L-90/45 days</td>
<td>1.5 hours</td>
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</tbody>
</table>

MEC OV – Medical Equipment Computer Overview  
CMS Ops – Countermeasure Systems Operations  
PPFS – Portable Pulmonary Function System  

* Scheduled training is performed as outlined in MEDB 4.1
Data Distribution

• In-flight real time data (ECG, HR, etc.) will be viewed by hardware support team to verify proper hardware configuration

• Experimental data will not be used to assess crew health

• Any data sharing will be captured in the Data Sharing Plan specific to that subject’s flight
Possible Risks or Discomforts

- Study designated as “Reasonable Risk” by NASA CPHS
- Many of these are already associated with MEDB 4.1
  - Muscle cramping, fatigue or soreness
    - Cycling rarely produces soreness
    - Warm-up and cool-down procedure mitigates risk
    - Subjects encouraged to stretch following the activity
  - Rash or irritation of the skin
    - Due to adhesive sensitivity (electrode site)
    - Request that electrode sites be washed/wiped following test
  - Saddle Soreness (pre/post only)
    - Padded gel seat used to minimize discomfort
  - Mouth/throat dryness
    - Drink water prior to and following test
Possible Risks or Discomforts

- **Electrical shock**
  - All testing equipment has passed both NASA safety inspections and manufacturing electrical tests.

- **Heart problems**
  - Vigorous exercise always carries this risk
  - Sudden death ~ 1:15,000 per year in recreational joggers, ~1:50,000 per year in marathon participants (majority are medically unscreened individuals)
  - Risk is mitigated by the amount of screening/testing astronauts receive
  - Medical monitoring will be used (pre/post flight, flight surgeon will be present; inflight ECG monitoring/downlink will be used)
Possible Risks or Discomforts

• **Dizziness Following Exercise**
  • Most likely to occur on R+1, potential to occur during other ground tests
  • May be due to blood pooling in legs, active cool down helps mitigate this
  • Will monitor blood pressure and symptoms
  • If necessary, subject will be moved to supine position for recovery

• **Perception of “air hunger”**
  • Cardiac output measure done with rebreathing technique
  • Elevation in bag CO₂ may cause “air hunger” symptoms
  • Mitigated by elevation of oxygen concentration in rebreathing gas
  • Rebreathing period is short: ≤ 30 seconds; may be aborted safely if discomfort is extreme

• **Accident Due to Improper Handling of Compressed Gas**
  • Crew and investigators will be trained on handling of compressed gas
VO$_2$max

Experiment Success

Defined by:

- Direct and accurate measures of VO$_2$max during and following long duration missions accomplished
- Determination of the accuracy of estimating VO$_2$max using submaximal test results (workload vs. HR; VO$_2$ vs. HR)
- Determination of added benefit of cardiac output to estimates of VO$_2$max from submaximal test results
Experiment Benefits

- Direct measures of VO₂max will establish the “space normal” response of VO₂max to long duration space flight. This will aid in future mission planning and act as a baseline for countermeasures assessment.
- Data will allow NASA to determine if submaximal tests provide accurate information to assess VO₂max. This may have implications on the future of routine tests conducted on the ISS and interpretation of data previously collected during long duration missions.
- Will determine if the addition of the non-invasive measurement of cardiac output improves the estimate of VO₂max derived from submaximal test results.