Integrated Resistance and Aerobic Exercise Mitigates Multi-System Deconditioning: Results from the NASA 70 Day Bed Rest Study

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No Disclosures
Spaceflight: A “Multiple-Hit”

**Baseline risk factors**
- Obesity, hypertension, age

**‘Direct’ injury**
- Microgravity

**‘Indirect’ Injury**
- Secondary to microgravity (deconditioning)

**Injury**
- Cognitive Impairments
- Sleep Deficiency
- Immune Dysfunction
- Cardiovascular Dysfunction
- Anemia
- Gastrointestinal Events
- Exercise Intolerance
- Skeletal Muscle Dysfunction
- Bone Demineralization

**Secondary to microgravity (deconditioning)**
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- Gastrointestinal Events
- Immune Dysfunction
- Cardiovascular Dysfunction
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- Exercise Intolerance
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- Sleep Deficiency
- Cognitive Impairments
Multisystem Deconditioning

Symptom limited cardiopulmonary exercise test
Cardiorespiratory fitness (VO$_{2peak}$ – mL·kg$^{-1}$·min$^{-1}$)

Cardiopulmonary exercise test

Endurance trained
Active
Sedentary

10 years Healthy aging
14 days Spaceflight (1965)
Cardiac Atrophy
Muscle Atrophy

Actual measurement

Derived measurement

Circumference = 2π \times \text{radius}

Vol = \frac{\pi}{3} \left( R_1^3 + R_1 R_2 + R_2^3 \right)

where \( R = \frac{\text{circumference}}{2\pi} \)
How to Prevent / Treat Multisystem Deconditioning?

EXERCISE

- **Pulmonary diffusion**
  - no change

- **Cardiac function**
  - stroke volume $\uparrow$
  - heart rate $\downarrow$
  - cardiac output $\uparrow$

- **Arterial/endothelial function**
  - nitric oxide $\uparrow$
  - angiogenic factors $\uparrow$

- **Skeletal muscle function**
  - mitochondrial size & number $\uparrow$
  - capillarization $\uparrow$

Whole-body cardiovascular performance
- Cardiac
- Blood / peripheral resistance
- Muscle oxidative capacity

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Whole-body cardiovascular performance
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Early Exercise Countermeasures

Project Gemini: 1964-1966
(4-14 day missions)
“Rather than seeking permission to exercise, you should have to get permission to be sedentary”
Exercise: Mandatory on ISS Missions

Exercise on the ISS: 2001-2009
(~6 month missions)
Exercise: Mandatory on ISS Missions

Exercise scheduled for 2h/day
- **Includes set-up time
- ~30-60min/day, 6 days/week, moderate intensity

Historical Practice
- One size fits all: ~30-60min/day, 6 days/week, moderate intensity
ISS Standard Exercise Countermeasures

- **Standard exercise countermeasures still associated with accelerated decline**

  - 10 years Healthy aging
  - 14 days Spaceflight (1965)
  - 14 days Spaceflight + Ex (1965)
  - 6 Months Spaceflight + Ex (2001-2009)

Nasa is paying a man £11,000 to stay in bed for 70 days

by Nancy Atkinson on nov

Would you lay in bed for 70 days for £11,000? (model used in picture) (Picture: Getty Images)
10 Weeks of Head Down Tilt Bed Rest

ARM A
Diet (n=9)

ARM B
Diet + traditional exercise (n=9)

ARM C
Diet + exercise + testosterone (n=8)

ARM D
Diet + flywheel exercise (n=8)

‘Astronaut-like cohort’

Randomize

10 weeks

10 Weeks of Bed Rest: Spaceflight Analog

- Subjects monitored 24 hours/day
- Toileting and showering performed in the head down tilt position
- Standard wake/sleep schedule
- 3 meals/day controlled diet with adjusted energy intake
  - 55% CHO, 30% fat, 15% protein
- Monitoring of fluid intake/output
- Resting metabolic rate measured every 2 weeks
- Exercise energy expenditure measured every week
- Individualized exercise prescriptions based on peak tests
- Each exercise session conducted by two exercise physiologists
Bed Rest Resistance Exercise

ISS

Bed Rest
Bed Rest Aerobic Exercise

ISS

Bed Rest
Bed Rest Flywheel Aerobic and Resistance Exercise

Future Missions

Bed Rest

Resistance

Aerobic
## SPRINT Exercise Schedule

<table>
<thead>
<tr>
<th></th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
<th>Day 5</th>
<th>Day 6</th>
<th>Day 7</th>
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<tbody>
<tr>
<td>Resistance</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
<td>35-60 min</td>
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<tr>
<td>Aerobic Interval</td>
<td>32 min</td>
<td></td>
<td>15 min</td>
<td></td>
<td>35 min</td>
<td></td>
<td></td>
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<tr>
<td>Aerobic Continuous</td>
<td>30 min</td>
<td>30 min</td>
<td>30 min</td>
<td></td>
<td></td>
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<td></td>
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</tbody>
</table>

### Aerobic Intervals:
- 4x4-min @ 85% max
- 6x2-min @ 70%, 80%, 90%, 100%, 90%, 80% max
- 8x30-sec @100% max, 15 sec rest

### Resistance exercise:
- 3 x 5-10 RM
- Leg press, squat, leg curl, calf extension
Bed Rest Outcomes

- Brain
- Cardiac
- Vascular
- Body Composition
- Skeletal Muscle
- Exercise Tolerance
Results: Cardiorespiratory Fitness

2 decades of aging in 10 weeks

-23%

-1%

Results: Cardiac Mass

Exercise: no change in cardiac size
Results: Leg Muscle Mass

Exercise: no change in upper leg size

Exercise: abrogated decline in lower leg size

Scott et al. *Journal of Cachexia, Sarcopenia and Muscle*, 2017
Summary I

1. SPRINT exercise with traditional exercise equipment alone and with the addition of low dose testosterone supplementation is safe and abrogates multi-system deconditioning

2. SPRINT exercise with FLY effective in mitigating multi-system deconditioning relative to exercise performed on traditional exercise equipment
HUMAN EXPLORATION
NASA’s Path to Mars

EARTH RELIANT
MISSION: 6 TO 12 MONTHS
RETURN TO EARTH: HOURS

PROVING GROUND
MISSION: 1 TO 12 MONTHS
RETURN TO EARTH: DAYS

MARS READY
MISSION: 2 TO 3 YEARS
RETURN TO EARTH: MONTHS

4 Key Challenges

Mastering fundamentals aboard the International Space Station

U.S. companies provide access to low-Earth orbit

Expanding capabilities by visiting an asteroid redirected to a lunar distant retrograde orbit
Challenge 1: Look Beyond the Mean
Challenge 2: Look Beyond Single Systems

Bed Rest Subject

<table>
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<tr>
<th>Fitness</th>
<th>Thigh size</th>
<th>Calf size</th>
<th>Heart size</th>
</tr>
</thead>
</table>

- Exercise not effective
- Exercise effective

- Worsening
- No change
- Improvement
Challenge 3: Risk Stratification

Unsupervised Machine Learning

Challenge 4: Precision Exercise Prescription

Optimize:
1. Safety
2. Efficacy
3. Resource utilization
Summary II

1. One size of exercise does not fit all
2. Critical to understand individual multisystem variability prior to exploration missions
• Look beyond ‘research silo’
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