Human performance in simulated reduced gravity environments

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Background

- Design of space suits is a balance of many trade-offs including:
  - Optimal human performance
  - Cost
  - Mass
  - Complexity
  - Prevention of injury

- Issues:
  - Need to understand human performance in non-earth gravity levels
Background

- Design of space suits for planetary EVAs is based on limited knowledge of reduced gravity environments
  - Lunar Missions observations
  - Studies during the Apollo program
  - Current reduced gravity analogs
Background

- Microgravity simulators
  - Lunar Landing Research Facility
  - Manned Spacecraft Simulator
  - Partial Gravity Simulator (POGO)
  - Reduced Gravity Aircraft (C-9)
  - Neutral Buoyancy Lab (NBL)
  - Active Response Gravity Offload System (ARGOS)
Goals and Objectives

- **Goal:** Consolidate previous over-ground ambulation data from testing using NASA’s most recent gravity simulators
  - Baseline over-ground at Earth gravity (9.8 m/s²)
  - C-9 reduced gravity plane at lunar gravity (1.6 m/s²)
  - Active Response Gravity Offload Simulator (ARGOS) at lunar gravity (1.6 m/s²)

- **Objectives:**
  - Characterize lunar gravity ambulation
  - Compare reduced gravity analogs
Methodology – Testing Environments

C-9 Reduced Gravity Plane

- Inflight time is 2-3 hours consisting of about 50 parabolas of predetermined gravity levels
- Small test window (30-40 seconds) of lunar to Martian gravity
- Equipment must be secured for landing loads of up to 9-g horizontal and 2-g vertical
Methodology – Testing Environments

C-9 Reduced Gravity Plane

- Limited real estate for equipment storage and capture volume
  - Cargo bay is approximately 14 m long, 2.5 m wide and 2 m high

C-9 Plane Layout
Methodology – Testing Environments

C-9 Reduced Gravity Plane

- Subjects ambulated down fuselage at lunar gravity
- Four trials per subject of lunar unsuited ambulation, 2-5 passes during each parabola
- Self-prescribed walking speed (0.34-1.22 m/s)
  - Average 0.81 ± 0.20 m/s
- Custom-built force plate designed to be flush with floor padding
  - ~ 1 m in length
Methodology – Testing Environments

- Active Response Gravity Offload System (ARGOS)
  - Steel frame 12.5 m x 7.3 m x 7.6 m tall
  - Computer driven electric motors and in-line sensors
  - Maintains a constant offload force while the subject moves in all directions
Methodology – Testing Environments

- Active Response Gravity Offload System
  - Elevated ramp with six flush-mounted AMTI force plates
    - Overall platform 15 m in length
  - Over-ground ambulation
    - Earth gravity
    - Lunar gravity with gimbal
  - Ambulation speed set to 0.85 ± 0.05 m/s
    - Repeated trial until achieved desired speed
## Methodology – Subjects

<table>
<thead>
<tr>
<th>Earth and ARGOS (n = 9)</th>
<th>Height (cm)</th>
<th>Body Mass (kg)</th>
<th>Age (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>178.1</td>
<td>79.5</td>
<td>38</td>
</tr>
<tr>
<td><strong>Std. Dev.</strong></td>
<td>10.3</td>
<td>15.7</td>
<td>9.3</td>
</tr>
<tr>
<td><strong>Max</strong></td>
<td>190.5</td>
<td>106.8</td>
<td>54</td>
</tr>
<tr>
<td><strong>Min</strong></td>
<td>160</td>
<td>57</td>
<td>26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>C-9 (IST-X) (n = 6)</th>
<th>Height (cm)</th>
<th>Body Mass (kg)</th>
<th>Age (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong></td>
<td>181.4</td>
<td>78.8</td>
<td>45</td>
</tr>
<tr>
<td><strong>Std. Dev.</strong></td>
<td>6.8</td>
<td>11.2</td>
<td>4</td>
</tr>
<tr>
<td><strong>Max</strong></td>
<td>189.2</td>
<td>97.5</td>
<td>52</td>
</tr>
<tr>
<td><strong>Min</strong></td>
<td>175.3</td>
<td>67.1</td>
<td>41</td>
</tr>
</tbody>
</table>
Methodology

- Custom Vicon BodyBuilder model and MATLAB processing code
- Collected variables
  - Torso, hip, knee, and ankle joint angles
  - Normalized ground reaction forces
  - Gait kinematics
    - Stance Time, Stride Length, Step Width, Cadence
Results

![Normalized Peak GRF comparison between Earth, Lunar - C9, and Lunar - ARGOS environments](image)
Results

Stance Time (% Gait Cycle)

Earth  Lunar - C9  Lunar - ARGOS
Results

![Box plots comparing step width in various gravity environments](image)

- **Earth**
- **Lunar - C9**
- **Lunar - ARGOS**
Results

![Box plot of stride length in simulated reduced gravity environments.](image-url)
Results

![Box plot showing cadence comparison between Earth, Lunar - C9, and Lunar - ARGOS.](image-url)
Results

Hip Flexion/Extension (deg)

Earth, 1-g

C9, lunar

ARGOS, lunar

Knee Flexion/Extension (deg)

Earth, 1-g

C9, lunar

ARGOS, lunar

Ankle Dorsi/Plantar Flexion (deg)

Earth, 1-g

C9, lunar

ARGOS, lunar

Gait Cycle (%)
Results
Discussion

• Lunar gravity analogs:
  • Variation increased, both between subjects and within
    • Greatest variation seen in C-9 data
  • Increased swing time
• Various styles of gait adapted when learning to ambulate in a new gravity environment
• ARGOS more closely resembled Earth gravity ambulation than on the C-9 reduced gravity plane
Limitations

- Preconceived idea of lunar ambulation style
  - No one has experienced true lunar gravity since the Apollo era
  - Subjects with varying levels of experience on gravity simulators
- Limited walkway length for C-9 trials
Summary

• The C-9 is considered the gold-standard for gravity analogs

• There is a need to maintain integrity of conclusions from studies while also reducing costs

• There are different challenges with each analog
  
  • ARGOS: subject limited by a gimbal
  
  • C-9: minimal time to complete tasks, costly, small test volume

• Need to further benchmark the differences between the ARGOS system (and other analogs) and the C-9 reduced gravity plane
Contact Information

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