National Aeronautics and Space Administration

# Human performance in simulated reduced gravity environments

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1 Lockheed Martin

2 Covidien (former Lockheed Martin)

3 NASA, Johnson Space Center

# Background

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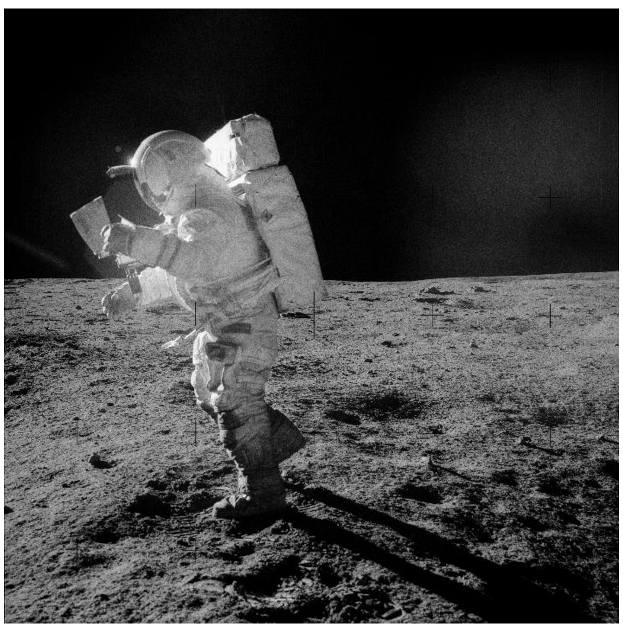
- Design of space suits is a balance of many trade-offs including:
  - Optimal human performance
  - Cost
  - Mass
  - Complexity
  - Prevention of injury
- Issues:
  - - Need to understand human performance in non-earth gravity levels

# 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



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Wider shot of POGO

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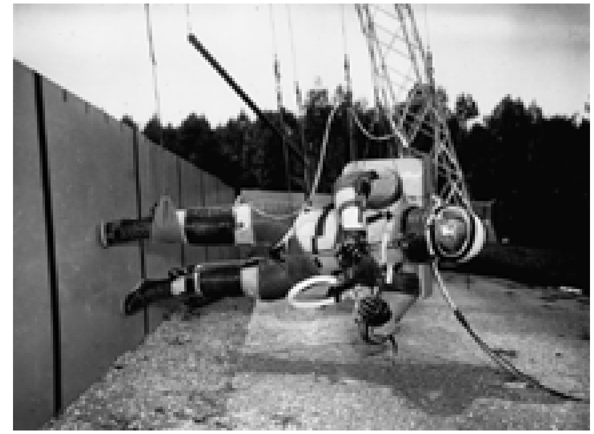

# Background

- 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)

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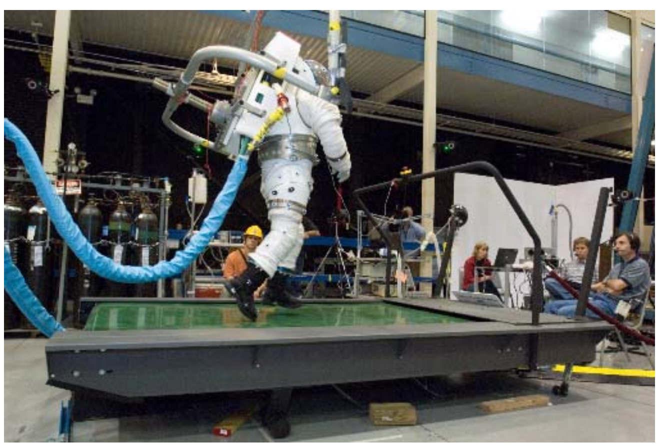
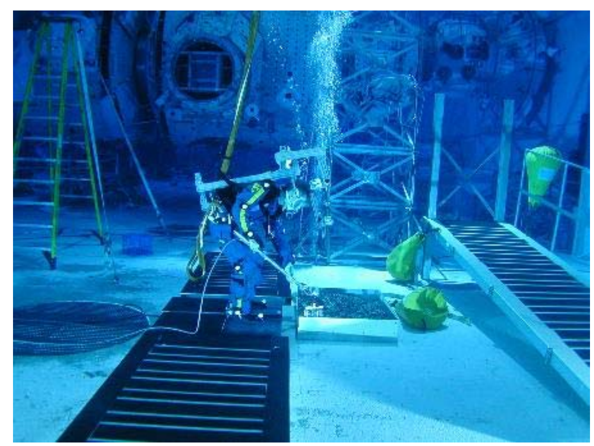




# Goals and Objectives

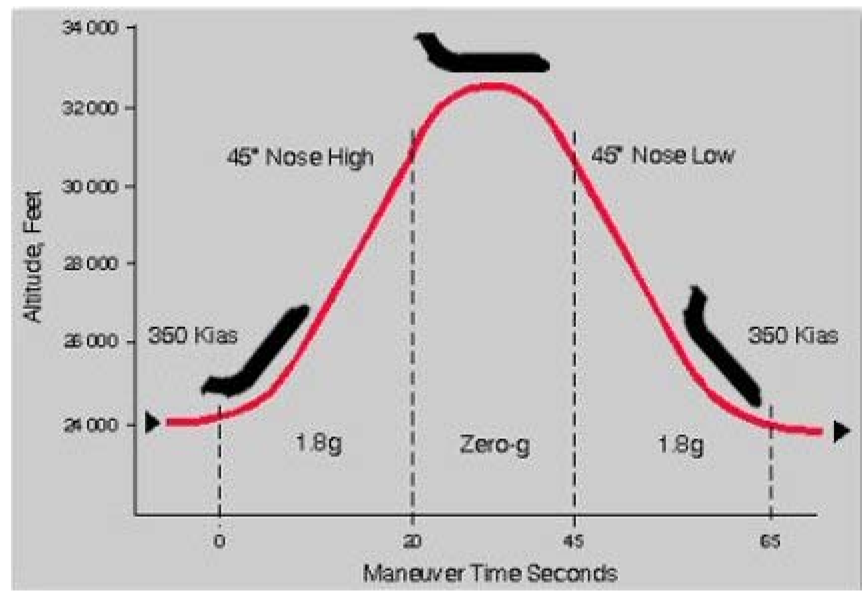
- Goal: Consolidate previous over-ground ambulation data from testing using NASA's most recent gravity simulators
  - Baseline over-ground at Earth gravity (9.8 $m/s^2$)
  - C-9 reduced gravity plane at lunar gravity (1.6 $m/s^2$)
  - Active Response Gravity Offload Simulator (ARGOS) at lunar gravity (1.6 $m/s^2$)

- 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

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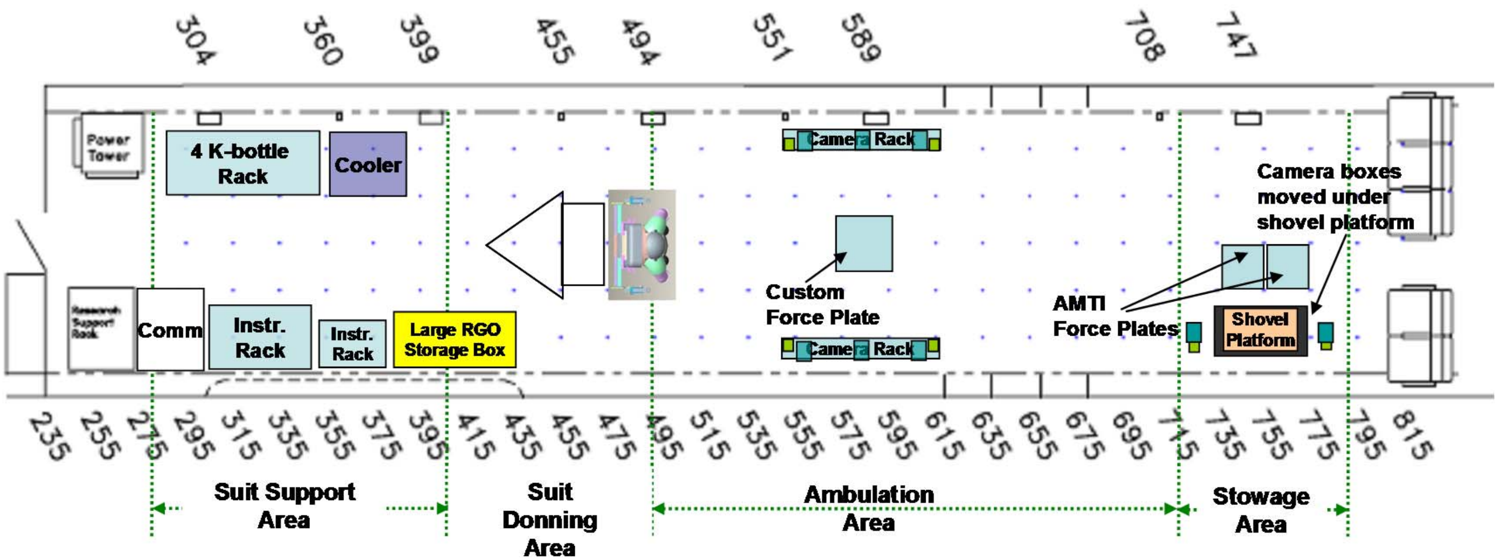
C-9 Flight Trajectory

# 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

Length of force plate

# 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 $\pm$ 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

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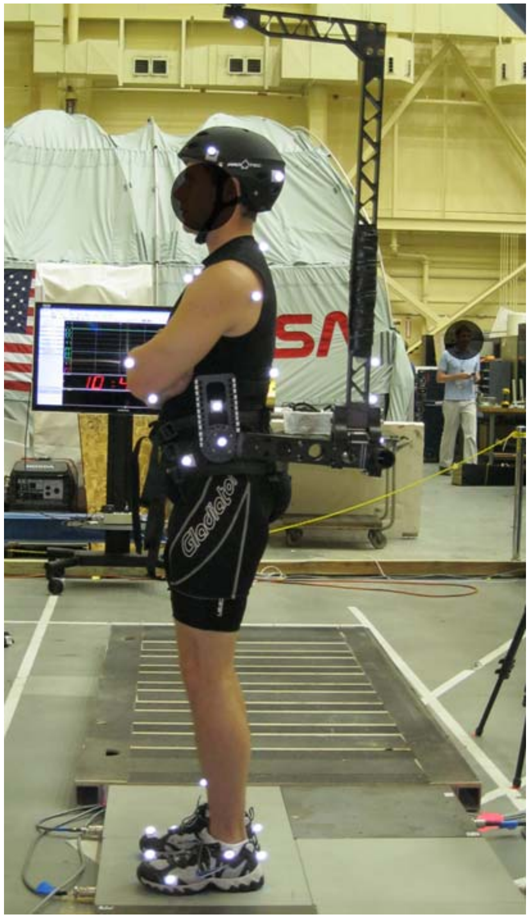
# Methodology – Testing Environments



- 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

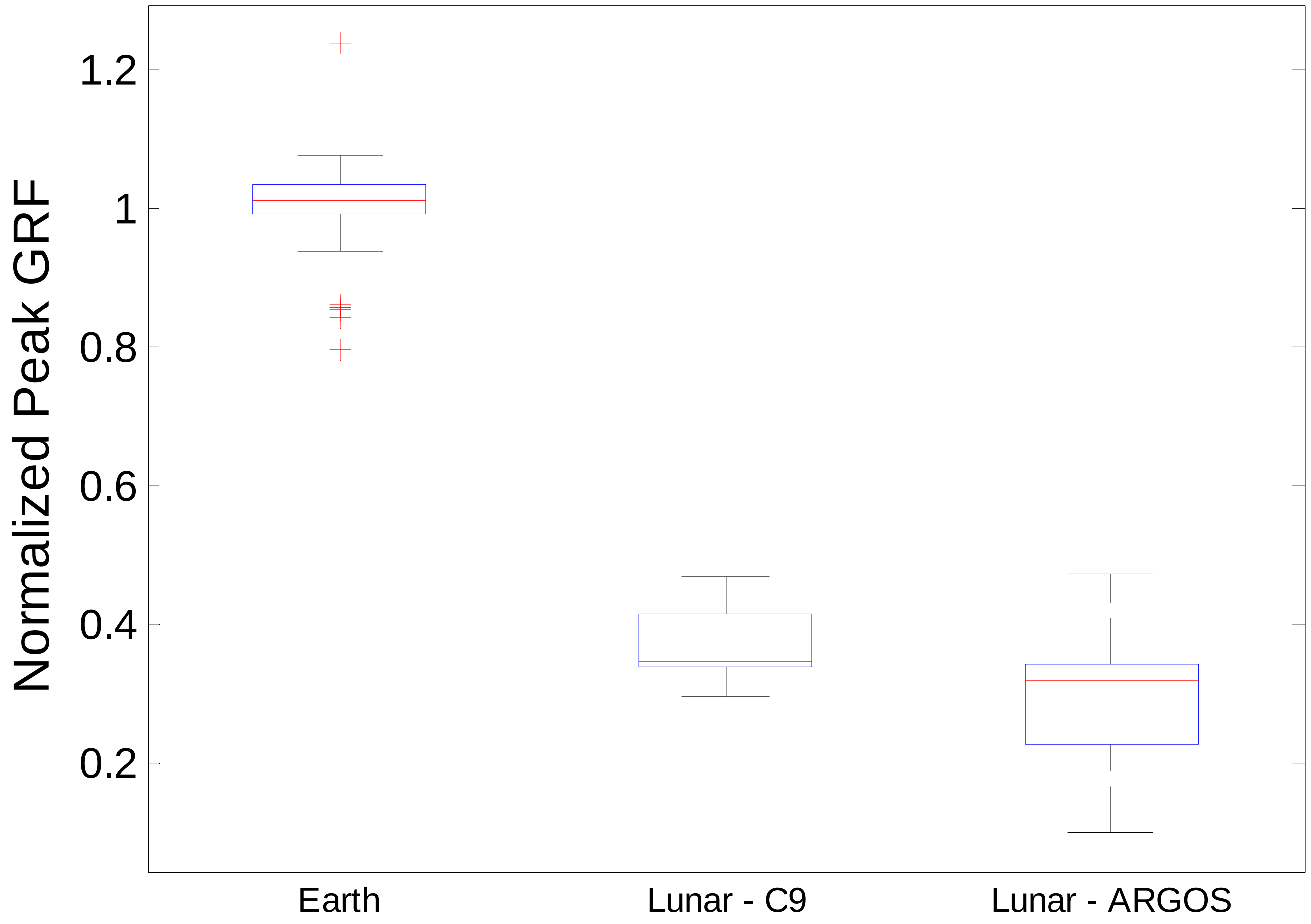
| Earth and ARGOS (n = 9) | Height (cm) | Body Mass (kg) | Age (years) |
|---|---|---|---|
| **Average** | 178.1 | 79.5 | 38 |
| **Std. Dev.** | 10.3 | 15.7 | 9.3 |
| **Max** | 190.5 | 106.8 | 54 |
| **Min** | 160 | 57 | 26 |

| C-9 (IST-X) (n = 6) | Height (cm) | Body Mass (kg) | Age (years) |
|---|---|---|---|
| **Average** | 181.4 | 78.8 | 45 |
| **Std. Dev.** | 6.8 | 11.2 | 4 |
| **Max** | 189.2 | 97.5 | 52 |
| **Min** | 175.3 | 67.1 | 41 |

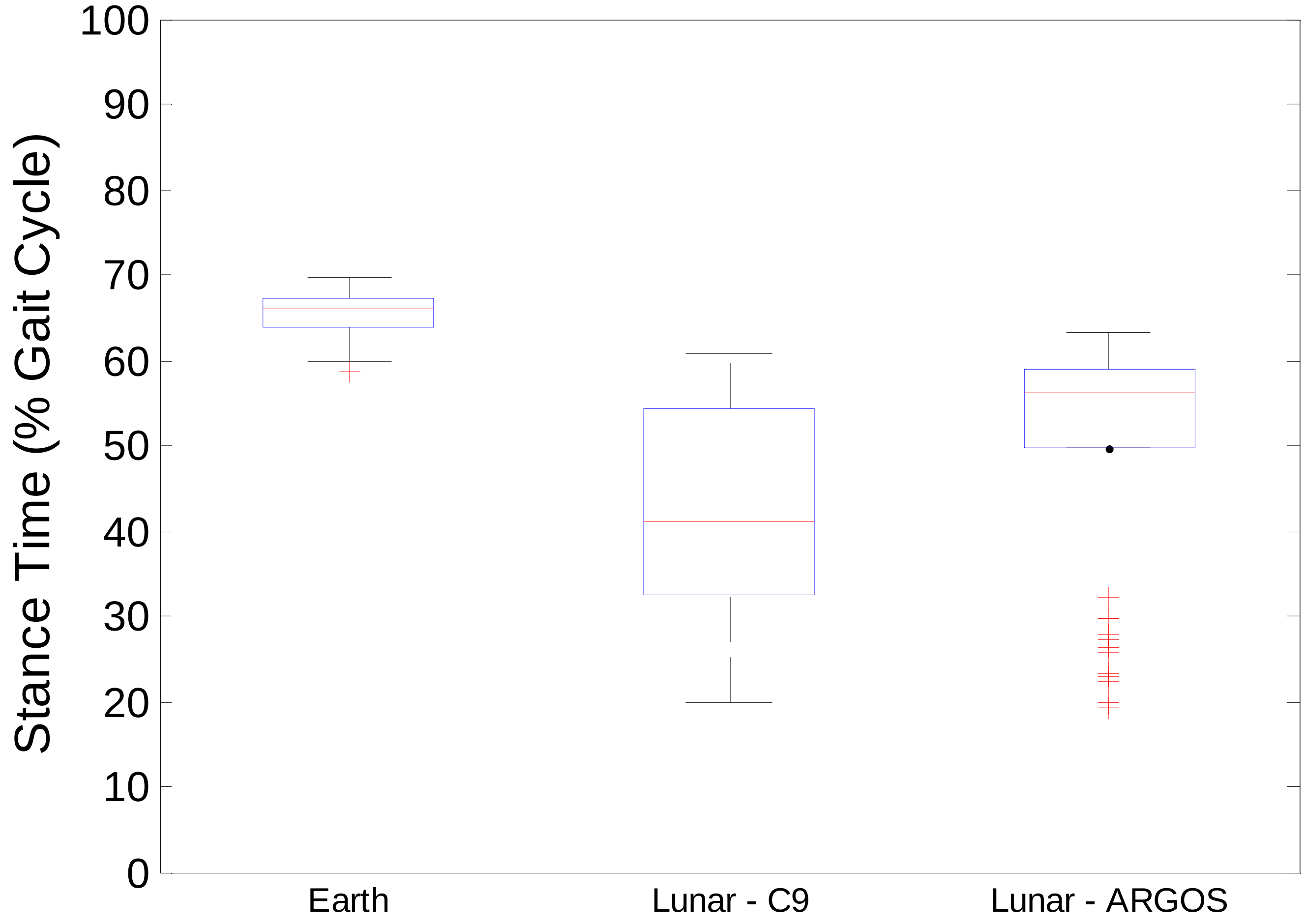
# Methodology

- 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

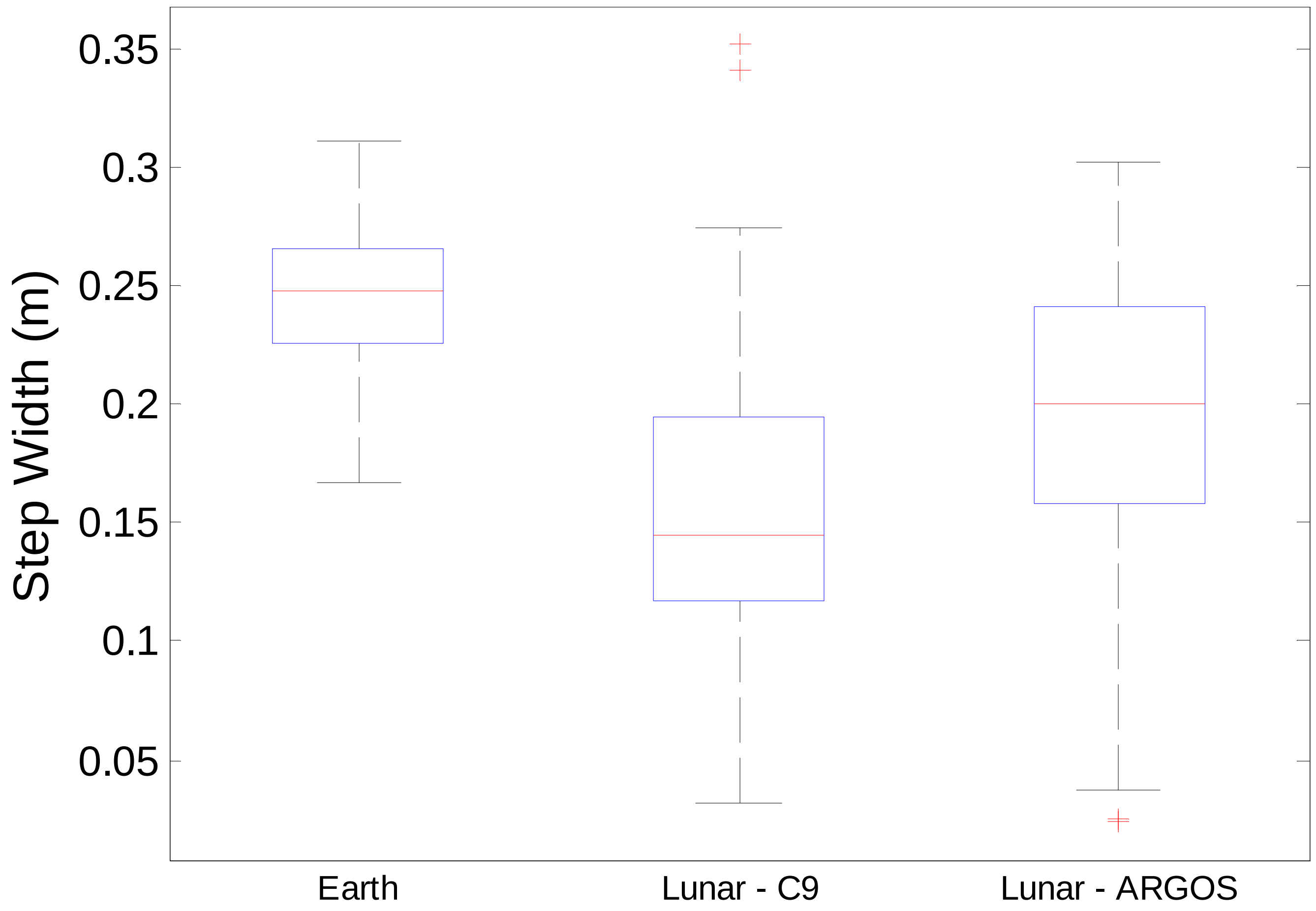
# Results


Normalized Peak GRF
1.2
1
0.8
0.6
0.4
0.2
Earth
Lunar - C9
Lunar - ARGOS

# Results

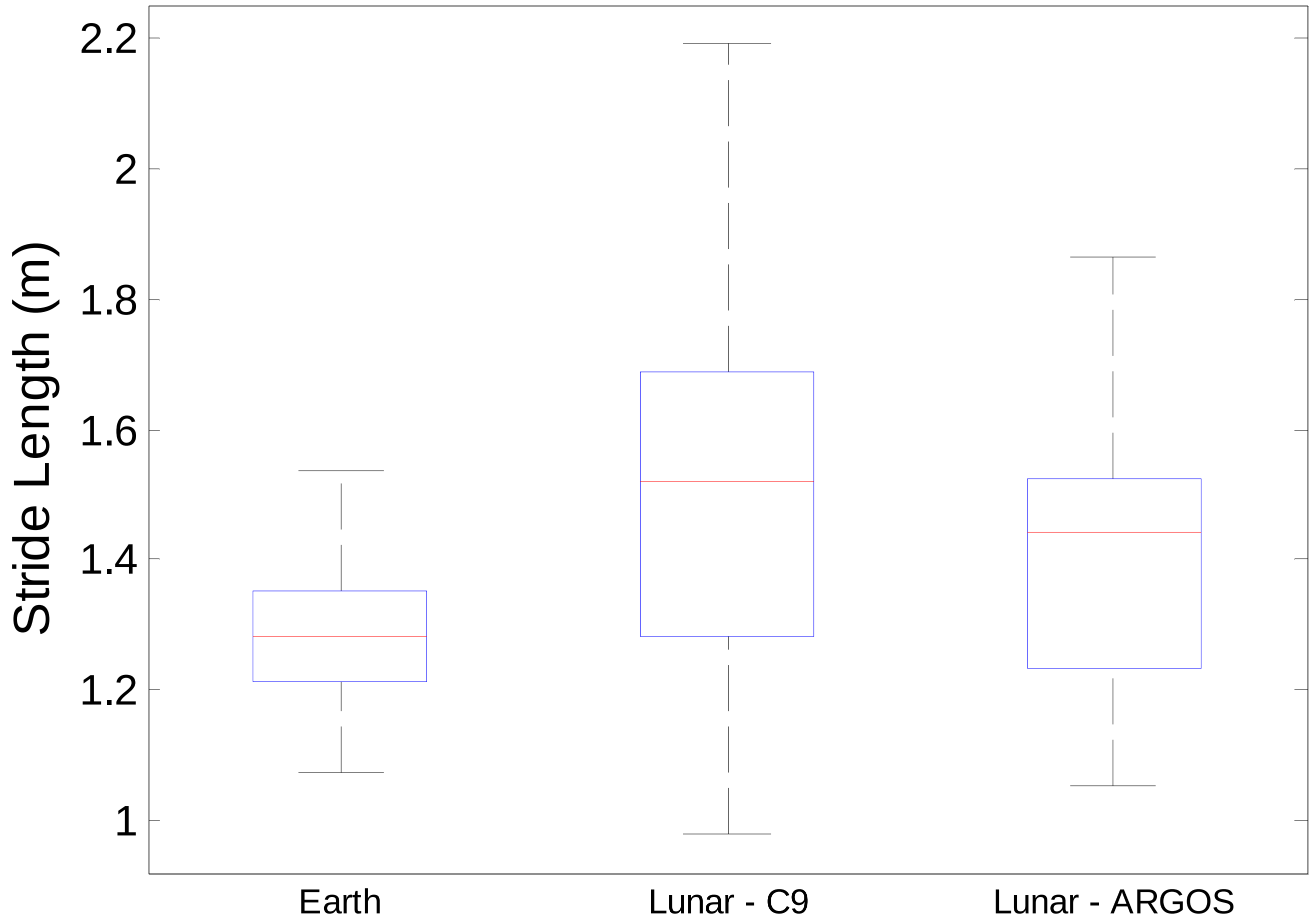

Stance Time (% Gait Cycle)
100
90
80
70
60
50
40
30
20
10
0
Earth
Lunar - C9
Lunar - ARGOS

# Results

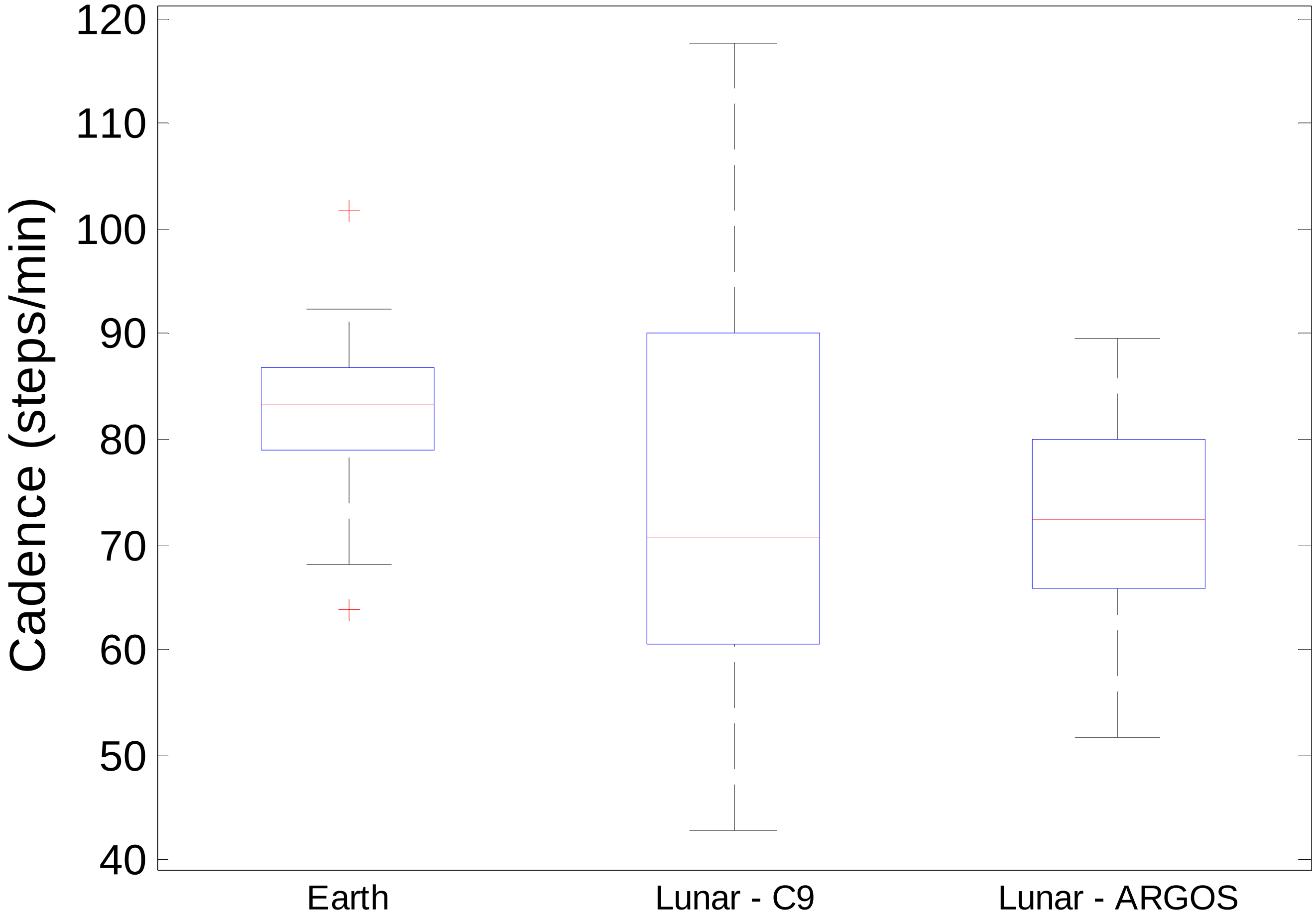


0.35
0.3
0.25
0.2
0.15
0.1
0.05
Step Width (m)
Earth
Lunar - C9
Lunar - ARGOS

# Results

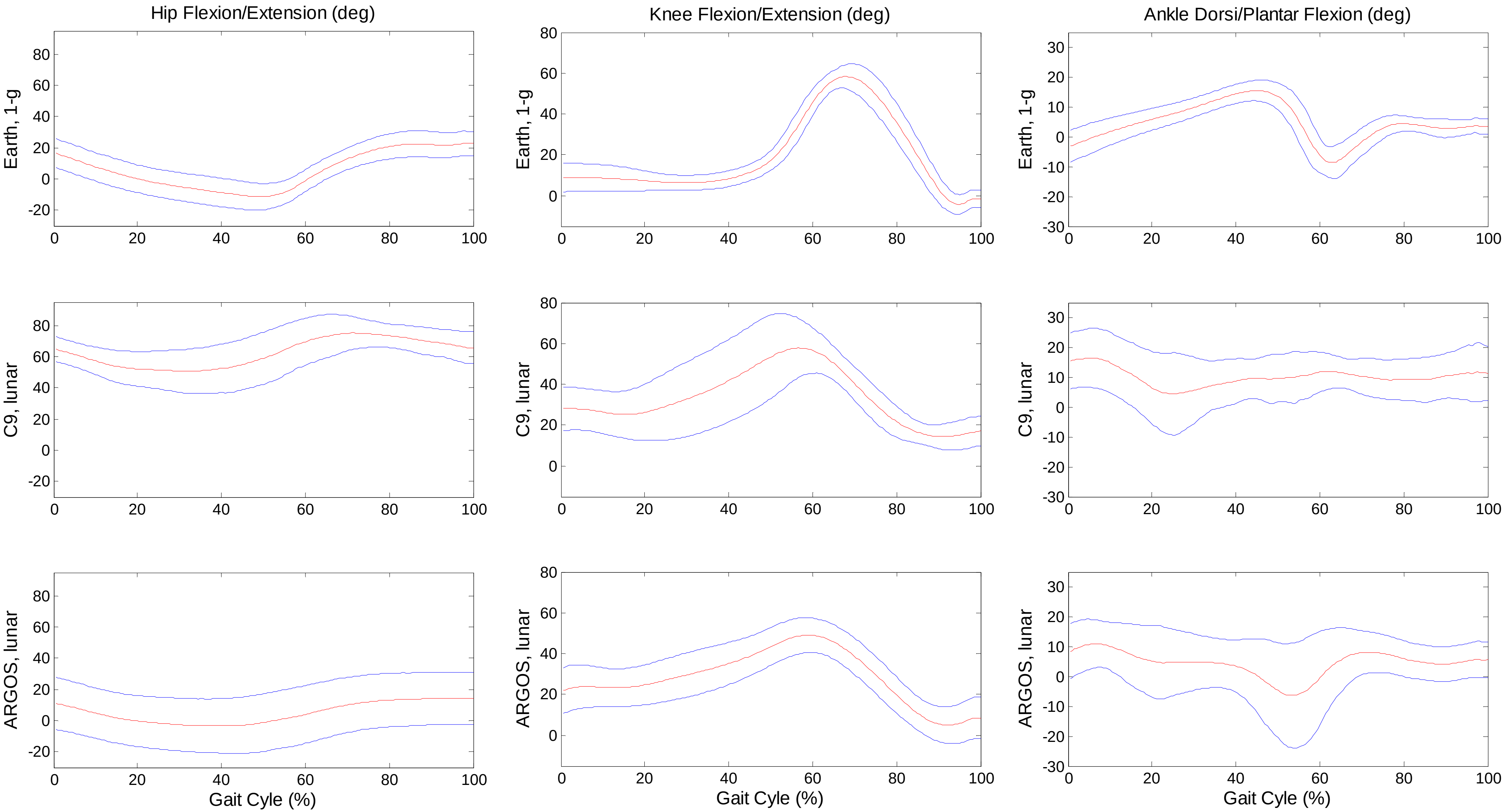


# Results

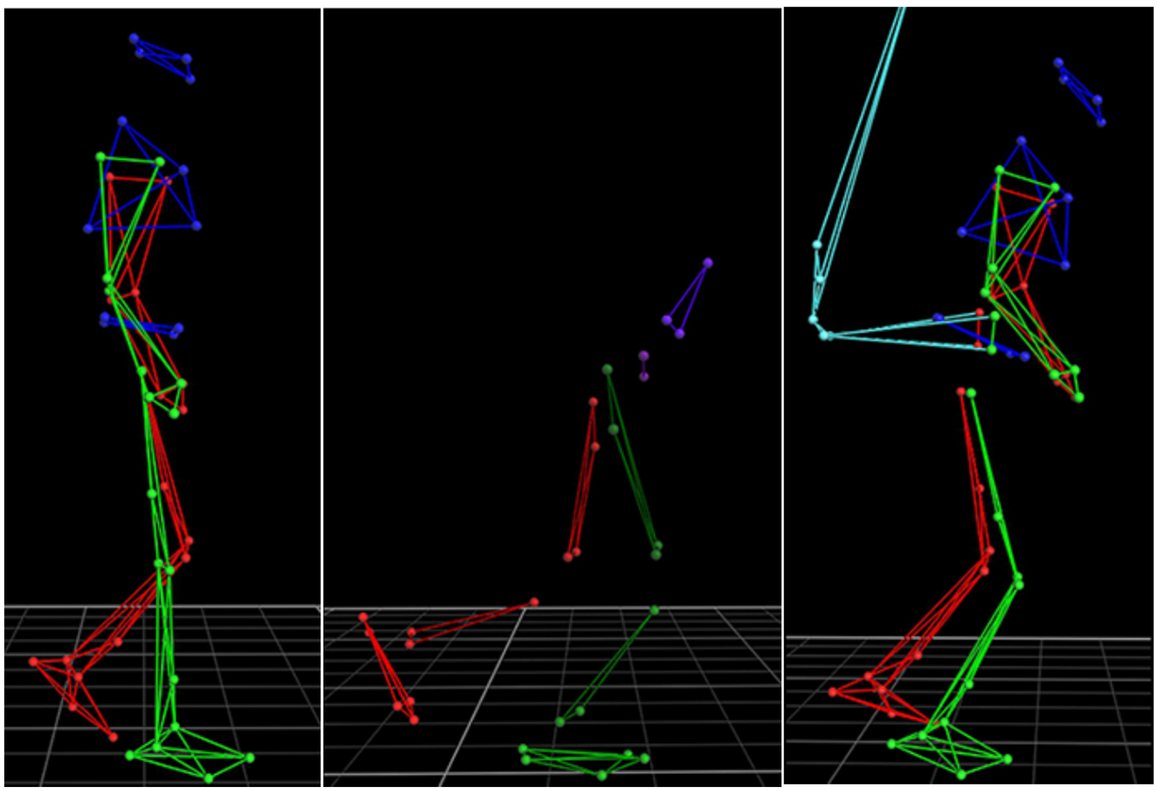


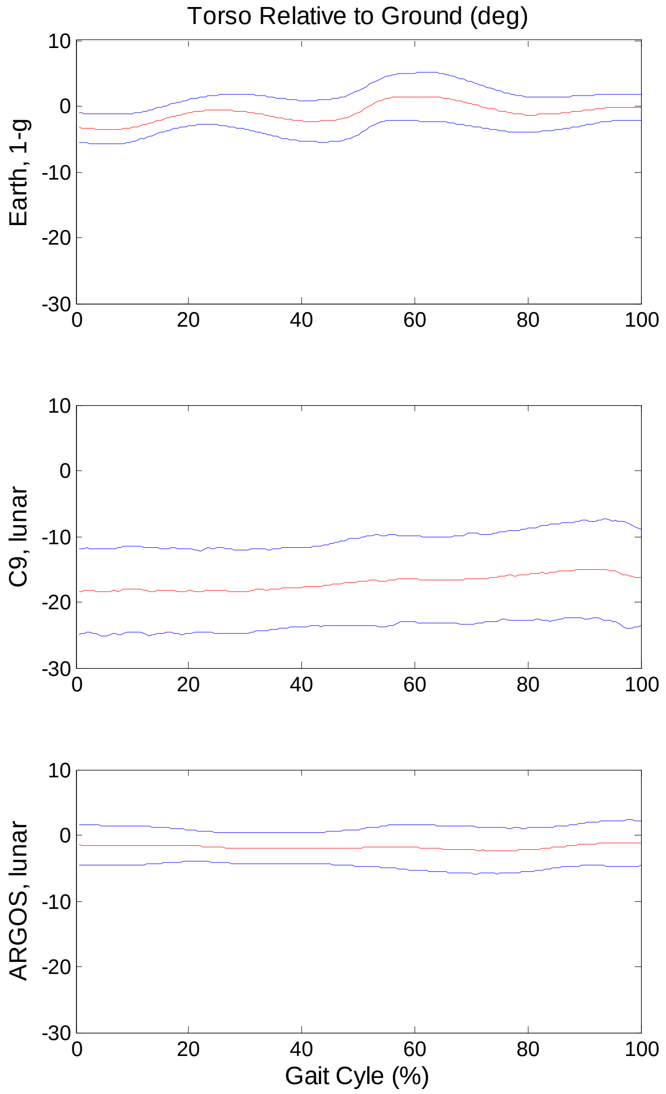
Cadence (steps/min)
120
110
100
90
80
70
60
50
40
Earth
Lunar - C9
Lunar - ARGOS

# Results


Hip Flexion/Extension (deg)
Knee Flexion/Extension (deg)
Ankle Dorsi/Plantar Flexion (deg)
Earth, 1-g
C9, lunar
ARGOS, lunar
Gait Cyle (%)

# Results





Torso Relative to Ground (deg)
Earth, 1-g
C9, lunar
ARGOS, lunar
10
0
-10
-20
-30
0
20
40
60
80
100
Gait Cyle (%)

# 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

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# 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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