MOON GAIT:

FIRST PILOT EXPERIMENT RESULTS

Presenter: Prof. Bernard Foing
International Lunar Exploration Working Group & ESA ESTEC (NL) (bernard.foing@esa.int)

Authors: Mouzzam Mehmood Mukadama(a), Dr. Irene Lia Schlacht(b), Prof. Jörn Rittweger (c), Prof. Melchiorre Masali (e), Antonio Del Mastro(f), Prof. Bernard Foing(g)

a Karlsruhe Institute of Technology, Germany, mouzzam.mehmood@gmail.com
b International Association for the Advancement of Space Safety (IAASS), The Netherlands. (iaass.space-safety.org & www.extreme-design.eu), irene.schlacht@mail.polimi.it
c Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Germany, Joern.Rittweger@dlr.de
d Department of Pediatrics and Adolescent Medicine, University of Cologne, Germany
e Università degli Studi di Torino, Italy, Melchiorre.Masali@gmail.com
f Mars Planet, Italy, segreteria@marssociety.it
g ESA/ESTEC, ILEWG & VU Amsterdam, The Netherlands, Bernard.Foing@esa.int
Index:
1. Human Factors
2. Moon Gait
3. Balance
4. Experiment
5. Conclusion
Human Factors = Usability = safety, performance, comfort

For successful long duration & long distance mission we must understand human factors, such as human behavior and interaction during the mission.

LONG MISSION DURATION/DISTANCE = HIGH HUMAN FACTORS RELEVANCE

**MISSION DURATION**

- **Long** > 2 weeks
- **Short** <2 weeks

**MISSION DISTANCE**

- **Close** 400 km (ISS)
- **Far** 380,000 km (Moon)

International Space Station in low orbit 400 Km from Earth

“I don’t believe any pair of people had been more removed physically from the rest of the world than we were.” Buzz Aldrin, Apollo 11 MISSION

Apollo 14 longest distance traversed & stay time: 33 h
Human Factors on Moon gravity

Human system interaction in Moon $g$

• has advantages:
  - Lifting
  - Jumping and Climbing

• has disadvantages:
  - Pushing and Pulling
  - Torquing Down

• has a strong influence on system design:
  - Ceiling height, door dimensions
  - View angle & interface position
  - Gait pattern & interior interaction

Image: Advantages and Disadvantages in Moon gravity (c) SICSA
Moon Gait

Human biomechanics and kinematics interaction need to be assessed to correctly design habitat to support safety, performance and comfort.

E.G. Walking pattern & sight line tentative study (Prof. Masali)
SAFETY: How is balance affected on the Moon?

An analysis of mobility showed that the crewmen used three basic mobility patterns (modified walk, hop, side step) while on the lunar surface. Kurbis et al., 1972, p.V—apollo 15-Apollo 15 - Time and Motion Study (2.2 MB) by J.F. Kubis, J.T. Elrod, R. Rusnak, and J.E. Barnes, NASA Manned Spacecraft Center, January 1972, NASA M72-4. PDF document courtesy NASA Technical Reports Server (http://ntrs.nasa.gov/).
SAFETY: Causes for loss of balance

Cardiovascular System changes (Fluid shifts ↑)

Sensorimotor System changes (mechanical and proprioceptive)

Bones and Muscles (loss 20% per week)

Vestibular System (Changed otolith signals of movement)

Generate stiff movements and less balance, like with bed-rest (1)

Generate Visual signal (conflict) temporary (2-7 days) motion sickness

Poor frame of visual references

On the Moon the desert environment has not so many references to build up the visual perception of your own vertical (2)

The Gap

The difference in gravity affects: Posture, Visual field, Movement, Physical interaction (e.g. Oxygen consumption) etc. (Kanas & Manzey, 2008; Clément, 2005; Schlacht et al. 2016)

- Apollo missions and further experiments investigated mainly: speed and metabolism of Moon walk.
- Small number of subjects (e.g. Apollo: 2 subj.)
- Detailed biomechanical and anthropometrical data on walk are missing!
- Missing a reduced gravity experiment on Moon gait after bedrest.

- RISK OF AN INCOMPATIBLE HABITAT DESIGN, LOW SAFETY, MISSION FAIL

Solution: MOON GAIT experiment

MOON GAIT possible experiments set up

To better understand how hypogravity and neuromuscular de-conditioning may affect the walking gate and balance impacting: crew safety & countermeasure requirements, lunar architectural & design constraints we need to find Kinematic variables of joints or body segments on: extent, speed, and direction of movement in “Moon condition”.

http://moon.ouhsc.edu/dthompso/gait/knmatics/gait.htm More reference on final slide
MOON GAIT possible experiments set up

To simulate the “Moon condition“ we need to achieve the same physical state:

FIRST -> neuromuscular de-conditioning with Bedrest

SECOND -> Gait analysis in simulated hypogravity

http://moon.ouhsc.edu/dthompso/gait/knmatics/gait.htm More reference on final slide
Main Objective: To better understand how hypogravity and neuromuscular de-conditioning may affect the walking gate and balance impacting: crew safety & countermeasure requirements, lunar architectural & design constraints.

Specific aim: To obtain kinematographic and biomechanical data during simulated hypogravity walking and running at baseline and after 60d bed rest with and without Artificial gravity

Hypotheses:

H1) Physical deconditioning will lead to increases in effective leg stiffness during walking and running in normogravity and simulated microgravity.

H2) Increased effective leg stiffness after bed rest will lead to reduced ground contact times, greater vertical displacement and reduced regularity of gait and running patterns

H3) The latter effect (H2) will be more pronounced at lower levels of simulated gravity

H4) Artificial gravity will partly conserve neuromuscular performance and ameliorate effects under H1 to H3

Variables
1. Body mass
2. Gravity
3. Stiffness
MOON GAIT  first pilot experiment on 6 participants

- to simulate physical deconditioning: comparing older and younger person
- to simulate hypogravity: vertical treadmill

On the vertical treadmill the subject is able to walk vertically. In this position, gravity has no longer any influence on the subject’s vertical axis and hypogravity can be reproduced using a special type of software that calculates the tightness of the string where the subject is belted.
MOON GAIT aim

Experiment AIM: to research the effects of different weight loads on:

• Vertical oscillation (variation in the height given by the oscillation of the top of the head while walking)
• and OAE (Frankfurt Plane, a line from the tragus of the ear through the zygomatic bone on the middle of the ocular bulb) (Mukadam, et al., 2017).
MOON GAIT methodology

1. Record participants video with defined markers on the vertical treadmill
2. Data Selection
3. Extract data with the Tracker software.
4. Formulate a strong hypothesis on significant difference in:
   - Gait Vertical Oscillation
   - OAE angle
5. Statistical test of the hypothesis
1. Record participants video with defined markers on the vertical treadmill

- 50-60 older
- 20-30 younger
- different gender, mass, age

**Anthropometric Data**

<table>
<thead>
<tr>
<th>Participant n°</th>
<th>Gender</th>
<th>Age in years</th>
<th>Height in cm</th>
<th>Wight in kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>ava15</td>
<td>f</td>
<td>54</td>
<td>169</td>
<td>60</td>
</tr>
<tr>
<td>ava27</td>
<td>m</td>
<td>55</td>
<td>182</td>
<td>75</td>
</tr>
<tr>
<td>ava33</td>
<td>f</td>
<td>28</td>
<td>160</td>
<td>57</td>
</tr>
<tr>
<td>ava35</td>
<td>f</td>
<td>23</td>
<td>164</td>
<td>60</td>
</tr>
<tr>
<td>ava36</td>
<td>f</td>
<td>20</td>
<td>168</td>
<td>51</td>
</tr>
</tbody>
</table>

Considering the complexity of the procedure, a first pilot experiment has been realised on 6 selected participants.
MOON GAIT methodology

2. Data Selection

- Minimum and maximum gait speeds (4km/h & 11.5km/h)
- Weight loads (0.3g, 0.6g & 1g)
- Time length 10 seconds.

<table>
<thead>
<tr>
<th></th>
<th>1g</th>
<th>1g</th>
<th>0.6g</th>
<th>0.3g</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horizontal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treadmill</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vertical</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Treadmill</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25% VO2 Max</td>
<td>1</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>50% VO2 Max</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4km/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6.5km/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9km/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11.5km/h</td>
<td>6</td>
<td></td>
<td></td>
<td>48</td>
</tr>
<tr>
<td>14km/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16.5km/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19km/h</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Participants have been running for 60 minutes at different speeds, including the maximum subjective speed, only the most relevant and shared ones between all the participants have been analyzed for comparison.
MOON GAIT methodology

3. Extract data with the Tracker software of:
   - OAE inclination: by marking two mass point.
   - Vertical Oscillation by marking top of head.

Formula used was: \( \arctan \left( \frac{y_1-y_2}{x_1-x_2} \right) \); Calibration is done identically in all the videos.
MOON GAIT methodology

4. Formulate a strong hypothesis on difference in OAE & Vertical oscillation

In order to make a strong legitimate hypothesis video observations, literature research and data analysis was done. (Kanas & Manzey, 2008; Clément, 2005; Schlacht et al. 2016)

Graphs: video data analysis of participant 33 in hypogravity and in normal gravity

Amplitudes and the means were compared to hypothesize a significant change on OAL & Vertical osc. at:

- Different speeds and same weight load.
- Different weight loads and same speed.
5. Statistical test of the hypothesis

2 Groups = A & B consisting of same people.

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Control variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed</td>
<td>OAE angle</td>
<td>Age</td>
</tr>
<tr>
<td>Weight Load</td>
<td>Vertical Displacement</td>
<td>Height</td>
</tr>
<tr>
<td></td>
<td>Posture</td>
<td>Gender</td>
</tr>
<tr>
<td></td>
<td>Step Extend</td>
<td>Mass</td>
</tr>
</tbody>
</table>

- Test chosen to be used: Kruskal Wallis H Test.
- Significance Level 5%
- Null Hypothesis Ho: There is no significant difference b/w group 0.3g & 1g at 4km/h.
- Alternative Hypothesis H1: There is a significant difference b/w group 0.3g & 1g at 4km/h.
### MOON GAIT results

#### Results of Kruskal-Wallis H Test for OAE Angle: No statistical significance

<table>
<thead>
<tr>
<th>No.</th>
<th>Test</th>
<th>Statistical Significant Difference</th>
<th>Kruskal-Wallis H Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test 1 on 4km/h</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in OAE angle of the participants <em>between</em> 0.3, 0.6g &amp; 1g weight load while he is running at the same speed of 4km/h.</td>
</tr>
<tr>
<td>2</td>
<td>Test 2 on 11.5km/h</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in OAE angle of the participants <em>between</em> 0.3, 0.6g &amp; 1g weight load while he is running at the same speed of 11.5km/h.</td>
</tr>
<tr>
<td>3</td>
<td>Test 3 on 0.3 weight load</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in OAE angle of the participants <em>between</em> 4km/h &amp; 11.5km/h at the same weight load of 0.3g.</td>
</tr>
<tr>
<td>4</td>
<td>Test 4 on 0.6 weight load</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in OAE angle of the participants <em>between</em> 4km/h &amp; 11.5km/h at the same weight load of 0.6g.</td>
</tr>
<tr>
<td>5</td>
<td>Test 5 on 1g weight load</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in OAE angle of the participants <em>between</em> 4km/h &amp; 11.5km/h at the same weight load of 1g.</td>
</tr>
<tr>
<td>6</td>
<td>Test 6 Connection Parameter Analysis</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in OAE angle of the participants <em>between</em> 1g vertical and horizontal treadmill at the same speed of 4km/h.</td>
</tr>
</tbody>
</table>

Results of Kruskal-Wallis H Test for OAE Angle: No statistical significance
## MOON GAIT results

### Results of Kruskal-Wallis H Test for Vertical Displacement: One statistical significance

<table>
<thead>
<tr>
<th>No.</th>
<th>Test</th>
<th>Statistical Significant Difference</th>
<th>Kruskal-Wallis H Test Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Test 1 on 4km/h</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in Vertical Displacement of the participants between 0.3, 0.6g &amp; 1g weight load while he is running at the same speed of 4km/h.</td>
</tr>
<tr>
<td>2</td>
<td>Test 2 on 11.5km/h</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in Vertical Displacement of the participants between 0.3, 0.6g &amp; 1g weight load while he is running at the same speed of 11.5km/h.</td>
</tr>
<tr>
<td>3</td>
<td>Test 3 on 0.3 weight load</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in Vertical Displacement of the participants between 4km/h &amp; 11.5km/h at the same weight load of 0.3g.</td>
</tr>
<tr>
<td>4</td>
<td>Test 4 on 0.6 weight load</td>
<td>No</td>
<td>Test showed that there was no statistically significant difference in Vertical Displacement of the participants between 4km/h &amp; 11.5km/h at the same weight load of 0.6g.</td>
</tr>
<tr>
<td>5</td>
<td>Test 5 on 1g weight load</td>
<td>Yes</td>
<td>Test showed that there was statistically significant difference in Vertical Displacement of the participants between 4km/h &amp; 11.5km/h at the same weight load of 1g.</td>
</tr>
</tbody>
</table>
MOON GAIT results

Kruskal-Wallis H Test showed that there was statistically significant difference in vertical oscillation running at 4km/h & 11.5km/h at the same weight load of 1g (simulated Earth gravity) on the vertical treadmill, while there was no statistical significant difference in vertical oscillation running at 4km/h and 11.5km/h at the same weight load of 0.6g and 0.3g (simulated hypogravity).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Chi-square</th>
<th>Asymp. Sig.</th>
<th>Statistical Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amplitude at Earth Gravity</td>
<td>9.255</td>
<td>5.677</td>
<td>7.410</td>
<td>.006</td>
<td>Yes</td>
</tr>
<tr>
<td>Amplitude at Martian Gravity</td>
<td>8.791</td>
<td>6.372</td>
<td>2.564</td>
<td>0.109</td>
<td>No</td>
</tr>
<tr>
<td>Amplitude at 0.6g Simulated Gravity</td>
<td>19.38</td>
<td>8.495</td>
<td>1.844</td>
<td>.175</td>
<td>No</td>
</tr>
</tbody>
</table>

This significant result of the Moon Gait pilot experiment brought about an enticing hypothesis.

- On Earth vertical oscillation variates relative to speed of running, as literature
- Hypothesis: on Mars or any other hypogravity region like the Moon this behavior is completely different, the vertical oscillation during the gait has no major change at both slow and fast speed.
- This hypothesis should be investigated with improved experiment setup.
MOON GAIT improvements

Three main improvements were found for the development of this project:

1. Increase number of participants to 30.
2. Analyse each step of the gait cycle.
3. Use a Linear Mixed Effects Model for statistical analysis.
4. Specific quality improvements
   (Camera setup consistent on camera focus and distance, Video 60fps, Marker contrasting color and position marker on shoe, Head support design, Bedrest)

![Graph showing OAE Angle (Degree) over Time (second) for different participants](ava36_4kmh_1g)

**Figure 17: Step-by-step Graph 2**

<table>
<thead>
<tr>
<th>Participant</th>
<th>0.3g</th>
<th>1g</th>
</tr>
</thead>
<tbody>
<tr>
<td>ava 15</td>
<td>28.66587</td>
<td>3.852435</td>
</tr>
<tr>
<td>ava 27</td>
<td>5.190405</td>
<td>0.841389</td>
</tr>
<tr>
<td>ava 33</td>
<td>6.113734</td>
<td>4.212464</td>
</tr>
<tr>
<td>ava 35</td>
<td>2.999423</td>
<td>4.110293</td>
</tr>
<tr>
<td>ava 36</td>
<td>4.413988</td>
<td>3.282267</td>
</tr>
</tbody>
</table>
Future application of this research are:

- Vertical displacement analysis.
- Determination of space suit gear loading.
- Gait rehabilitation in the medical field.
- Safety optimization in Space missions
- Study on effects on Vestibular Plane
- Study on and optimization of Motigravity tool.

Figure: Motigravity by Mars Planet
Past Literature and the Moon Gait experiment confirmed normally in Earth gravity vertical oscillation variates with respect to gait speed, however the experiment further showed no relevant change in vertical oscillation in hypogravity.

Further research can be done in validating this as hypothesis to:

- support the design development of a safe Moonbase
- gate data on countermeasures and causes on the loss of equilibrium during Moon mission
- obtain data applicable on gait rehabilitation related to bone, muscular diseases on Earth
- design softwares or physical simulations for the future.
Thanks

Thanks to all people involved and in particular for their suggestions and availability

- Hervé Stevenin (ESA-EAC)
- Mario Benassai (Atec)
- Raùl Feuillard (Karlsruhe Institute of Technology, Germany)
- Dr. Martin Daumer (The Human Motion Institute, Germany)
- Prof. Walter Kuehnegger (PROF MOON!, Germany)
Publication on Moon Gait experiment


Main Reference of Moon Gait

- Define the Variables. psu.edu. Retrieved January 05, 2017, from PennState Lehigh Valley website: http://www2.lv.psu.edu/jxm57/irp/var.htm)

On line:

... more reference on Schlacht I. L. 68th IAC publication and Mukadam M. M. Bachelorarbeit
Questions?