MOON GAIT:

FIRST PILOT EXPERIMENT RESULTS

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MOON GAIT

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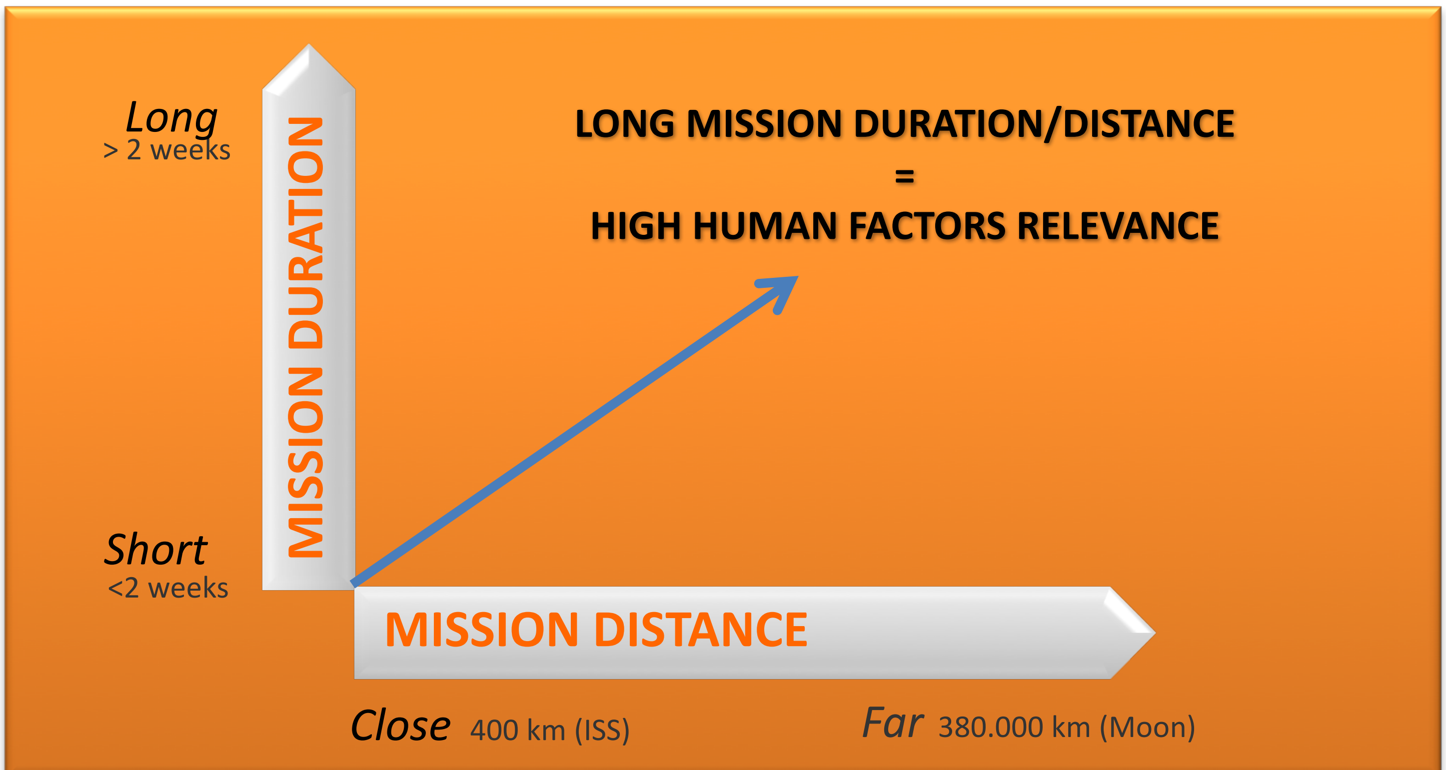
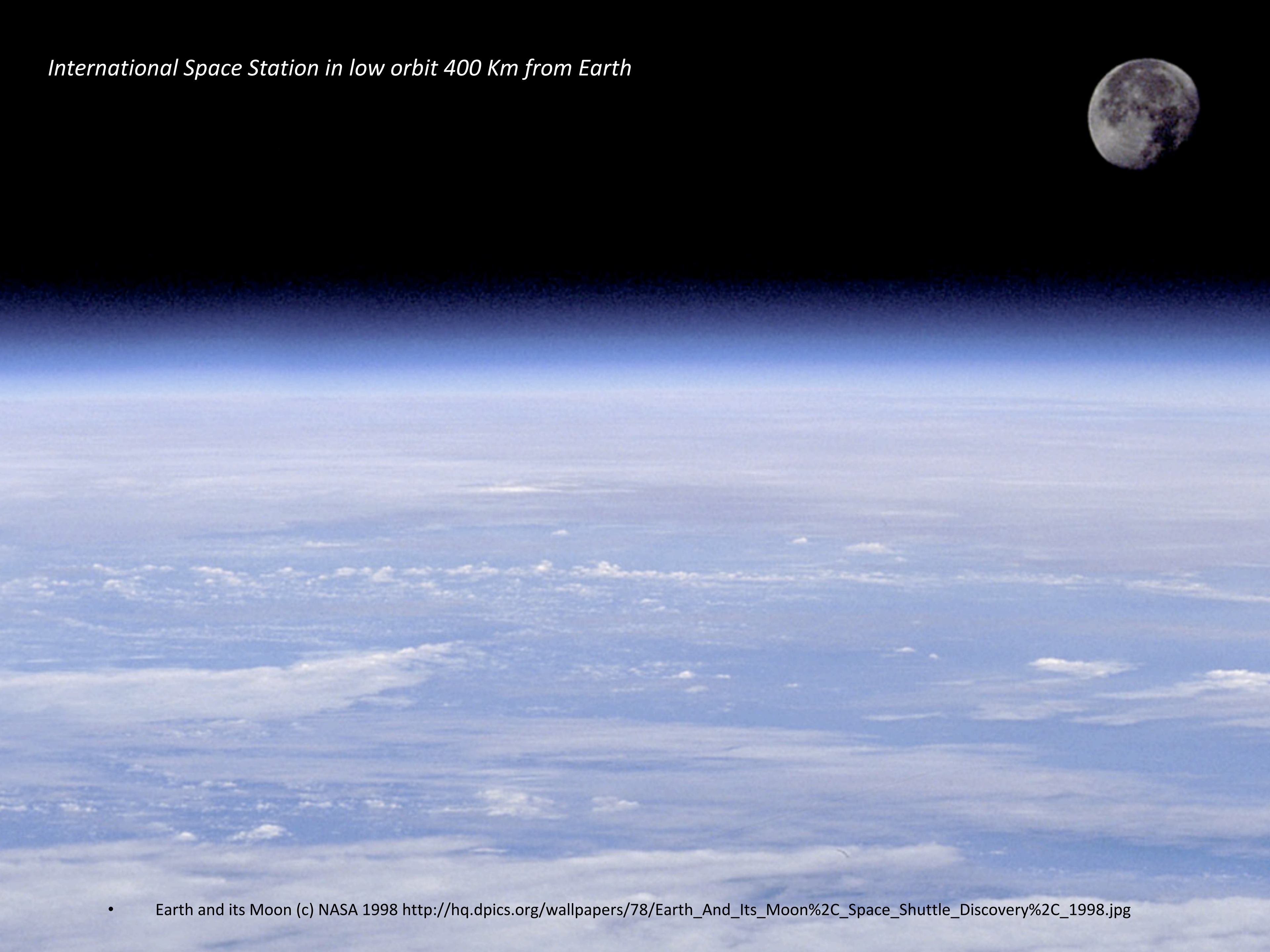
Human Factors = Usability = safety, performance, comfort

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



Schlacht PhD (2011) Space Habitability. TU Berlin; Kanas & Manzey (2008) Space Psychology and Psychiatry



- Earth and its Moon (c) NASA 1998 http://hq.dpics.org/wallpapers/78/Earth_And_Its_Moon%2C_Space_Shuttle_Discovery%2C_1998.jpg

- Earth rising above the lunar horizon (c) NASA 1968 http://www.britannica.com/bps/media-view/68867/1/0/0

Human Factors on Moon gravity

Human system interaction in Moon *g*

- has advantages:
  - Lifting
  - Jumping and Climbing
- has disavantages:
  - Pushing and Pulling
  - Torqing Down
- has a strong influence on system design:
  - Ceiling height, door dimensions
  - View angle & interface position
  - Gait pattern & interior interaction

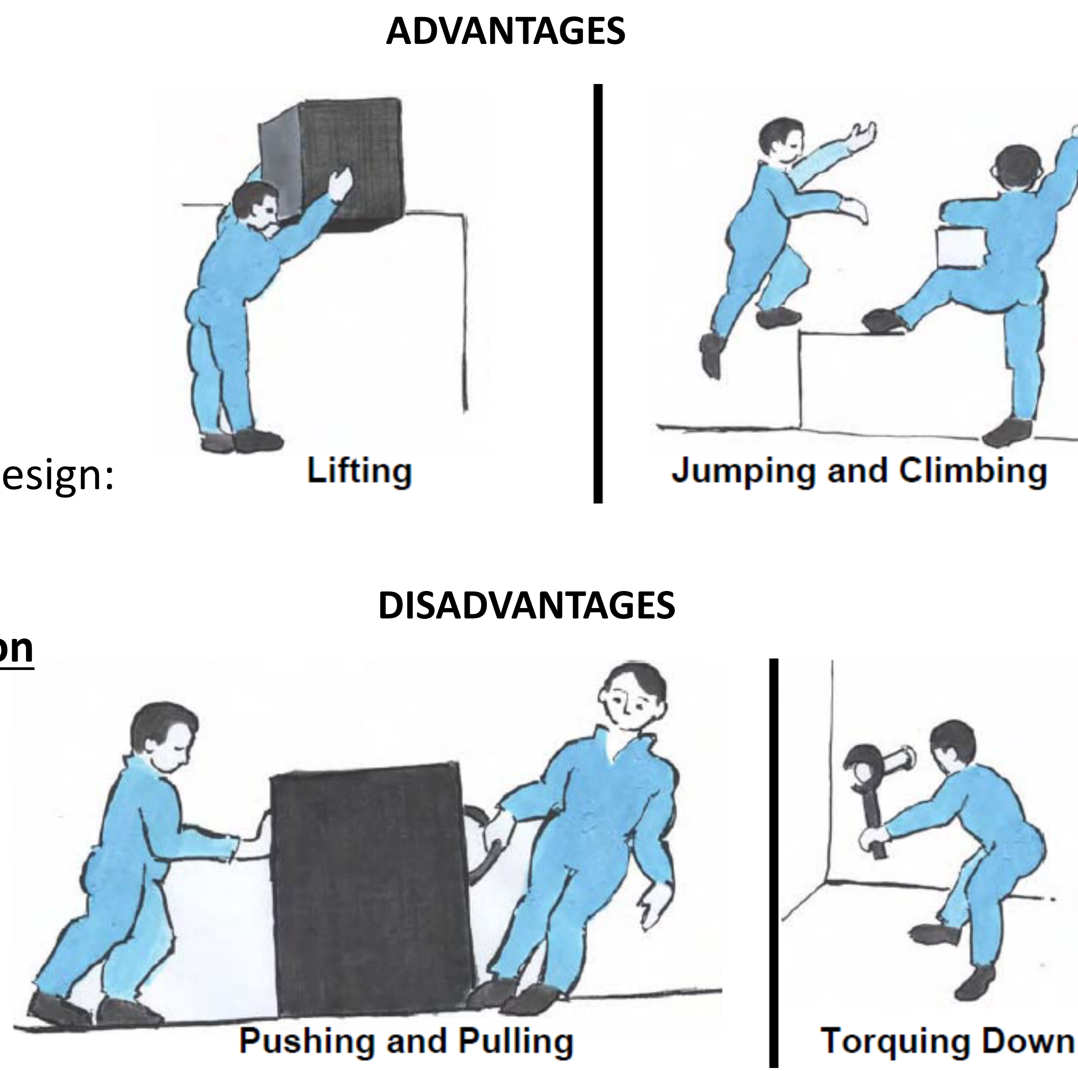


Image: Advantages and Disadvantages in Moon gravity (c) SICSA

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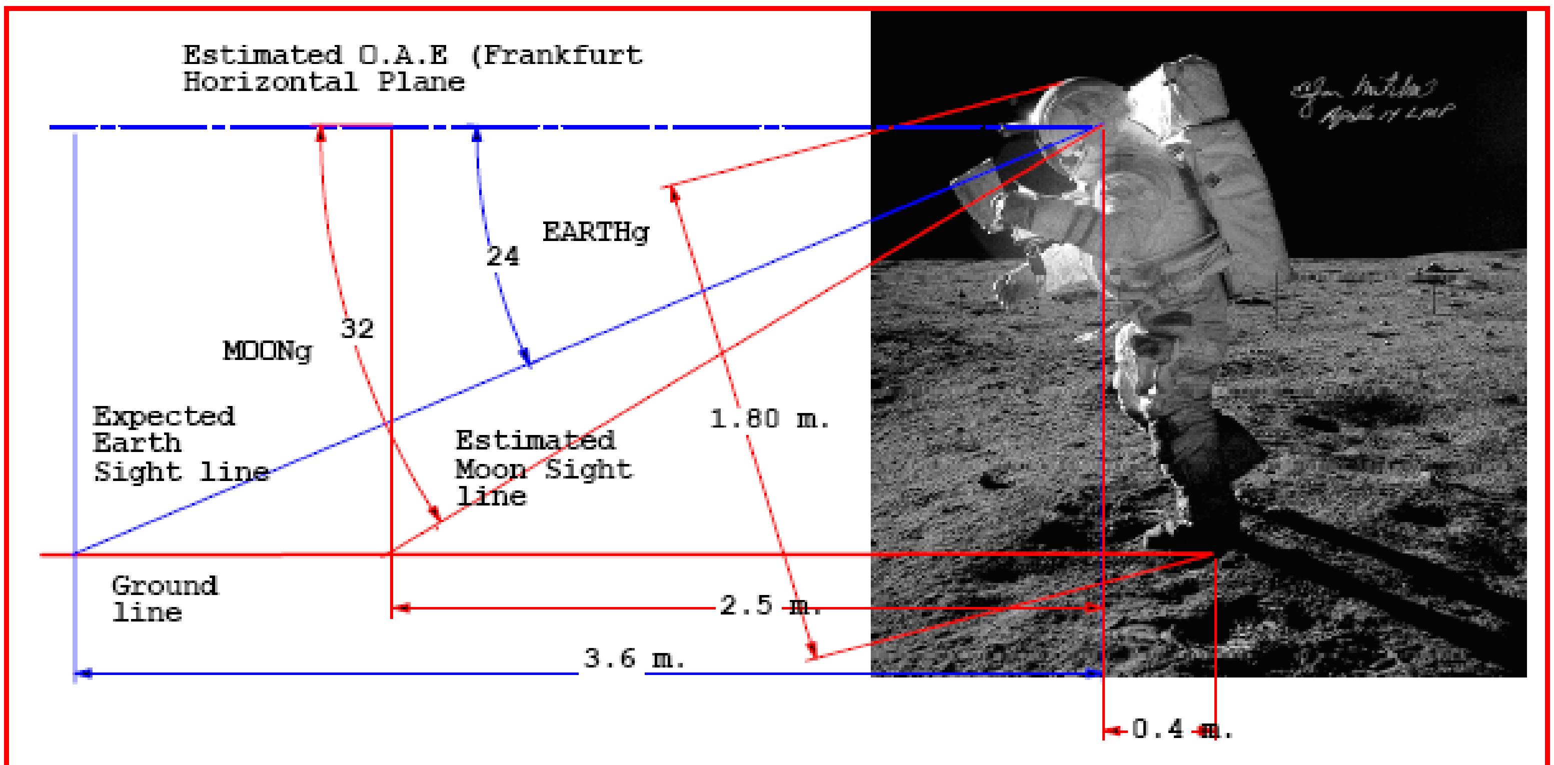
Moon Gait

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?

Al Reinert (1989). For All Mankind http://www.imdb.com/title/tt0097372/

An analysis of mobility showed that the crewmenber 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/).

EXTREME-DESIGN

SAFETY: Causes for loss of balance

Cardiovascular System changes
(Fluid shifts ⬆)

Sensorimotor System changes
(mechanical and proprioceptive)

Bones and Muscles
(loss 20% per week)

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

Vestibular System
(Changed otolith signals of movement)

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

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)

***1,2**: Prof. Jörn Rittweger courtesy communication,* Workshop EAC 15.2.2016. ***Image reference**: Clément (2005) Effects of Microgravity on the Human Organism; From Manzey (2009). Seminar Raumfahrtpsychologies. Microgravitation 3; TU-Berlin.*

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 methabolism 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

https://humanresearchwiki.jsc.nasa.gov/index.php?title=Risk_of_an_Incompatible_Vehicle/Habitat_Design

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 **<u>in "Moon condition"</u>**.

http://moon.ouhsc.edu/dthompso/gait/knmatics/gait.htm More reference on final slide

EXTREME-DESIGN ILEWG

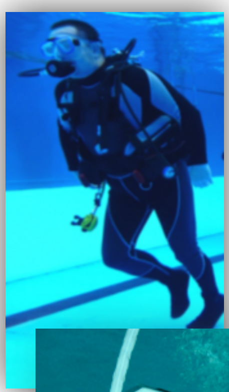
MOON GAIT possible experiments set up

<u>To simulate the "Moon condition "</u>we need to achieve the same physical state:

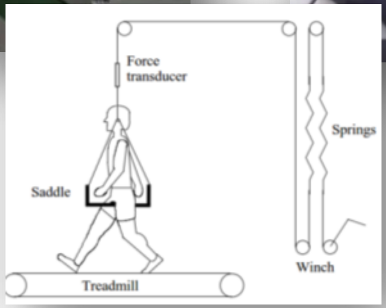
FIRST -> neuromuscular de-conditioning with Bedrest

SECOND -> Gait analysis in simulated hypogravity

IVA



EVA



buoyancy   balanced cable   Treadmill   Parabolic flight

ESA Bedrest http://sen.com/news/pillownauts-are-halfway-through-bedrest-study
http://moon.ouhsc.edu/dthompso/gait/knmatics/gait.htm More reference on final slide

Hypotheses

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

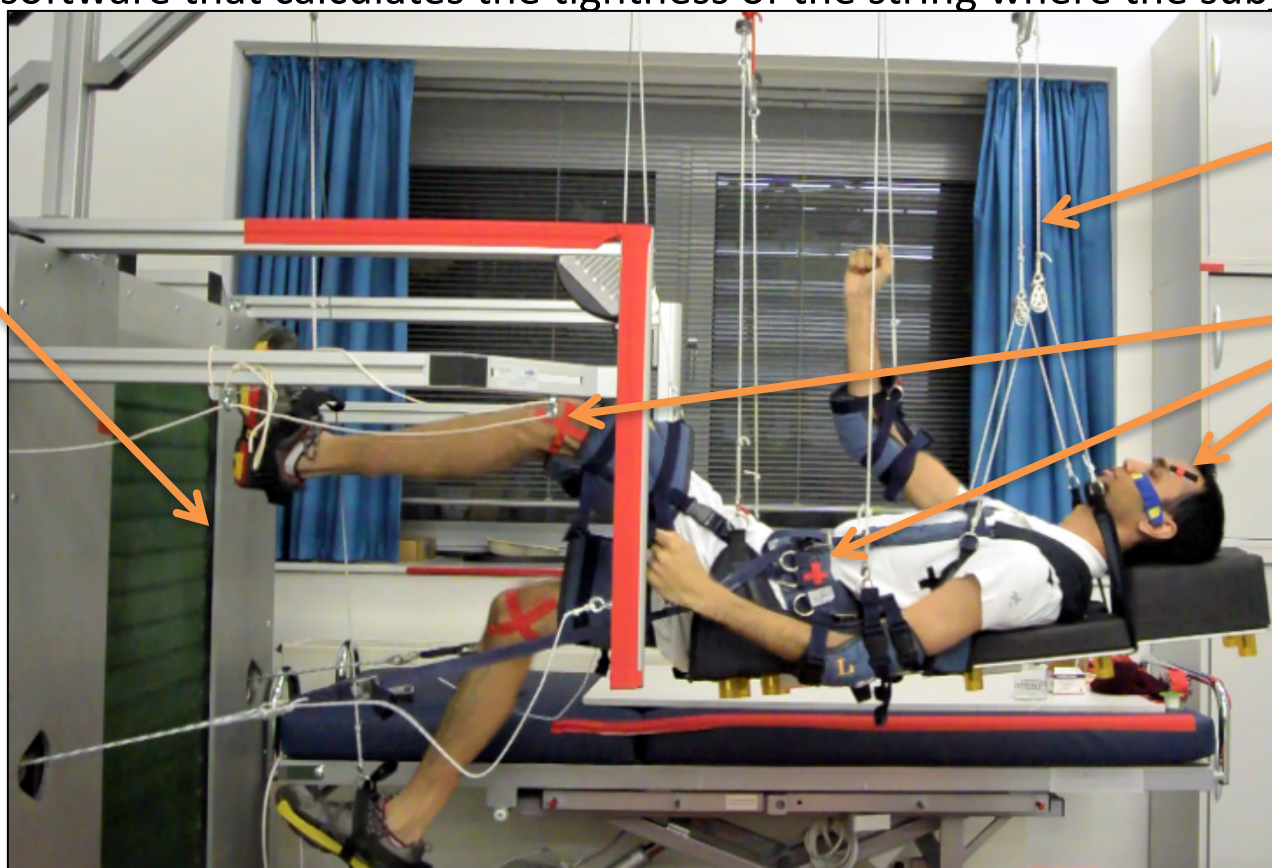
Variables

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.

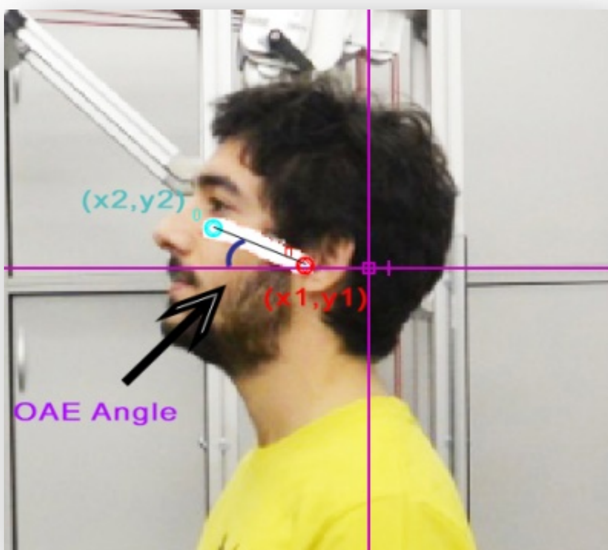


Vertical Treadmill
DLR Cologne

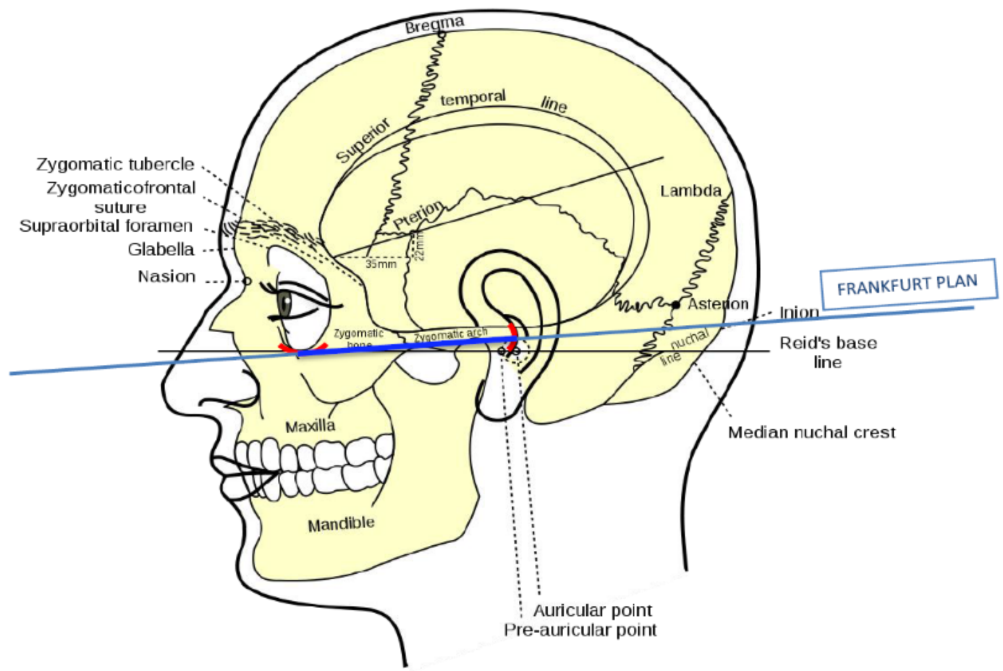
MOON GAIT aim

Expriment 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).



OAE angle



Frankfurt Plane (Image Gray 1918, edited by Schlacht 2016)

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

MOON GAIT methodology

1. Record participants video with defined markers on the vertical treadmill
   - 50-60 older
   - 20-30 younger
   - different gender, mass, age

Anthropometric Data

Participant n°	Gender	Age in years	Height in cm	Wight in kg
ava15	f	**54**	169	60
ava27	m	**55**	182	75
ava33	f	**28**	160	57
ava35	f	**23**	164	60
ava36	f	**20**	168	51

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 (0.3*g*, 0.6*g* & 1*g*)
- Time length 10 seconds.

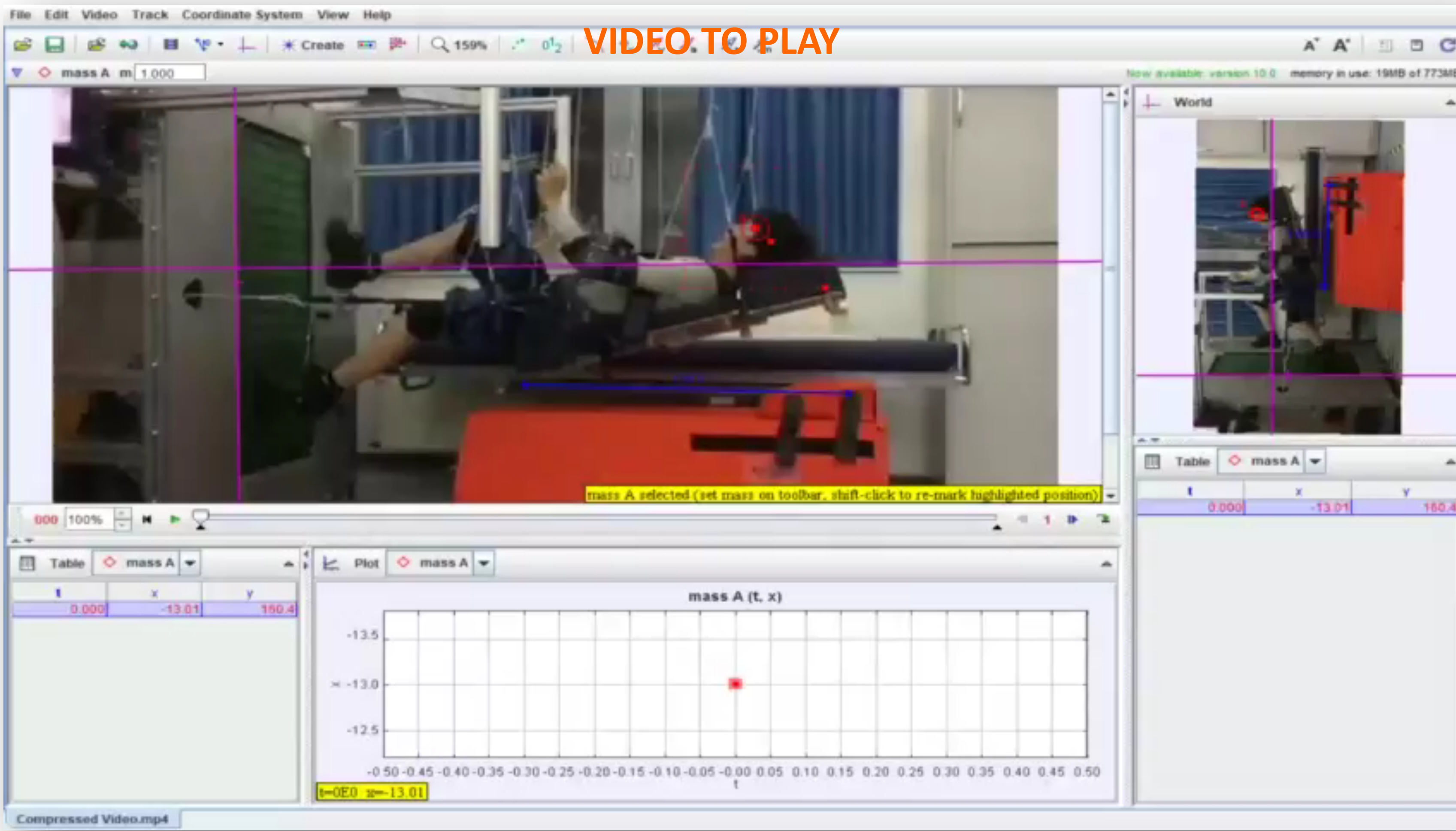
Participants have been running for 60 minutes at different speeds, including the maximum subjective speed, only the most relevant and shared ones between all the participants have been analyzed for comparison.

	1*g*	1*g*	0,6*g*	0,3*g*
	Horizontal Treadmill	Vertical Treadmill		
25% VO2 Max	1			4
50% VO2 Max				
4km/h				
6,5km/h				
9km/h				
11,5km/h	6			48
14km/h				
16,5km/h				
19km/h				

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.

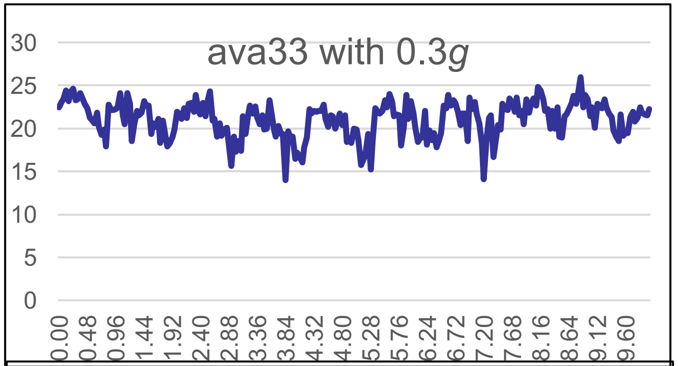


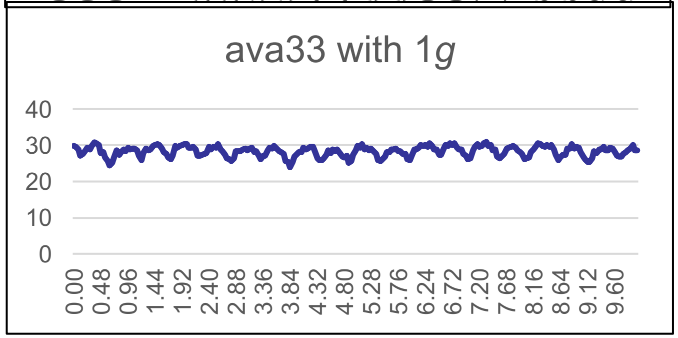
Formula used was: $arctan[(y1{-}y2)\,/\,(x1{-}x2)]$; Calibration is done identically in all the videos.

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

SUBJECT	0.3*g*	1*g*
ava15	45.768	8.8688
ava27	7.814	2.581
ava33	11.975	7.007
ava35	4.997	9.173
ava36	8.69	9.879

Mean

SUBJECT	0.3*g*	1*g*
ava15	2.7	6.95
ava27	6.16	-1.63
ava33	21.03	28.3
ava35	23.78	14.53
ava36	17.56	17.3

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.

MOON GAIT methodology

Independent variable	Dependent variable	Control variable
Speed	OAE angle	Age
Weight Load	Vertical Displacement	Height
	Posture	Gender
	Step Extend	Mass

5. Statistical test of the hypothesis

2 Groups = A & B consisting of same people.

Weight Load	0.3*g*	1*g*
4km/h	Group A	Group B
11km/h	Group A	Group B

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

MOON GAIT results

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

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

EXTREME-DESIGN

MOON GAIT results

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

No.	Test	Statistical Signicant Difference	Kruskal-Wallis H Test Result
1	Test 1 on 4km/h	No	Test showed that there was no statistically significant difference in Vertical Displacement of the participants between 0.3, 0.6*g* & 1*g* weight load while he is running at the same speed of 4km/h.
2	Test 2 on 11.5km/h	No	Test showed that there was no statistically significant difference in Vertical Displacement of the participants between 0.3, 0.6*g* & 1*g* weight load while he is running at the same speed of 11.5km/h.
3	Test 3 on 0.3 weight load	No	Test showed that there was no statistically significant difference in Vertical Displacement of the participants between 4km/h & 11.5km/h at the same weight load of 0.3*g*.
4	Test 4 on 0.6 weight load	No	Test showed that there was no statistically significant difference in Vertical Displacement of the participants between 4km/h & 11.5km/h at the same weight load of 0.6*g*.
5	Test 5 on 1g weight load	Yes	Test showed that there was statistically significant difference in Vertical Displacement of the participants between 4km/h & 11.5km/h at the same weight load of 1*g*.

EXTREME-DESIGN

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 1*g* (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 0.6*g* and 0.3*g* (simulated hypogravity).

Variable	Mean	Std. Deviation	Chi-square	Asymp. Sig.	Statistical Sig.
Amplitude at Earth Gravity	9.255	5.677	7.410	.006	Yes
Amplitude at Martian Gravity	8.791	6.372	2.564	0.109	No
Amplitude at 0.6g Simulated Gravity	19.38	8.495	1.844	.175	No

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)

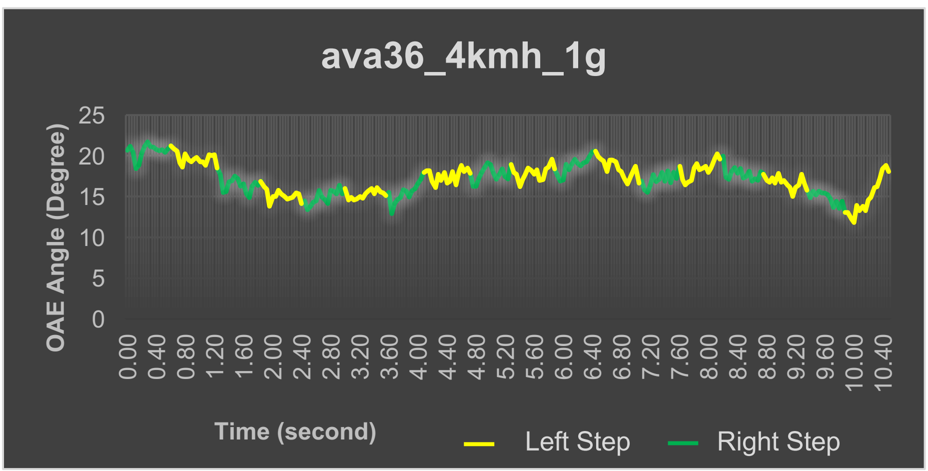


Figure 17: Step-by-step Graph 2

Participant	0.3*g*	1*g*
ava 15	28.66587	3.852435
ava 27	5.190405	0.841389
ava 33	6.113734	4.212464
ava 35	2.999423	4.110293
ava 36	4.413988	3.282267

MOON GAIT application

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.

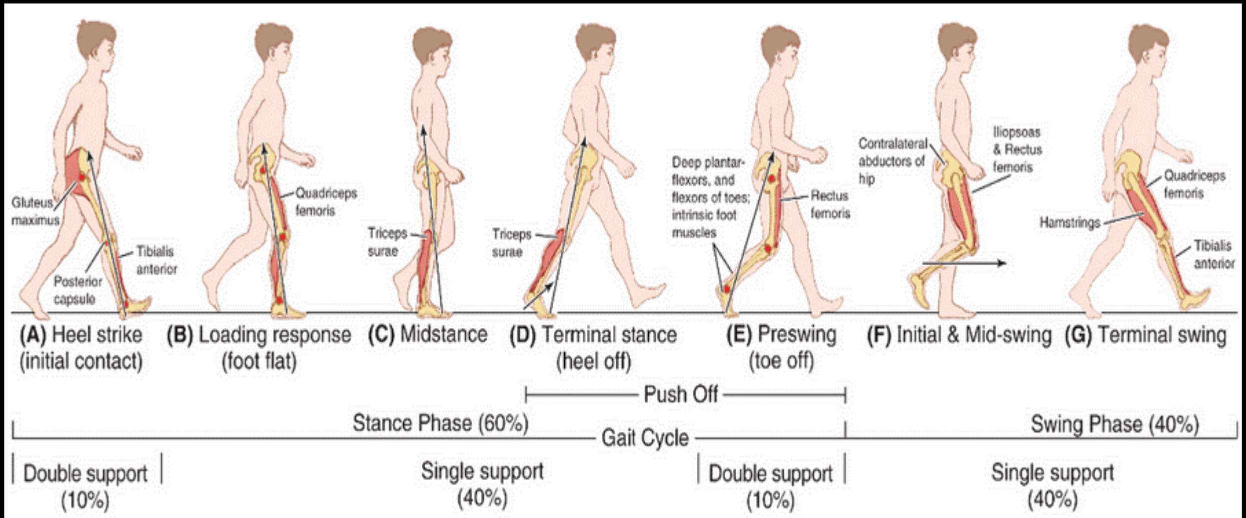
Figure :
Motigravity by Mars Planet

Conclusion:

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

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- Dr. Martin Daumer (The Human Motion Institute, Germany)
- Prof. Walter Kuehnegger (PROF MOON!, Germany)

Publication on Moon Gait experiment

Mukadam, M. M.: Moon Gait: Investigating a methodology for analysis of hypogravity gait posture for architecture design in space. Bachelorarbeit, KIT, 2017. Supervisors: Prof. B. Deml and I. L. Schlacht. Karlsruhe Institute of Technology, Karlsruhe.

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

Questions?