From virtual reality to neutral buoyancy – methodologies for analyzing walking pattern on Moon & Mars.

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Abstract. In the past, anthropometrical data have been collected only on micro-gravity, or measured from Apollo mission images, leading to low accuracy of the data [1]. Starting with Virtual Reality – based experiments, this research provides an investigation into methodologies that focuses on the collection of basic anthropometrical and postural data needed to develop interfaces for the Moon and Mars gravity environments.

The learning objectives of this work are:

- Analysis of methodologies for studying human movement & posture in Moon-Mars gravity
- Development of new instruments of investigation and methodologies
- Support of user-centered design in Moon Mars habitat projects

Keywords: Human Factors · Human-systems Integration · Safety · Deambulation · Simulation · Virtual Simulation · Space Mission · Difference of gravity.

1 Introduction: Safety and simulation

This Space radiation, differences in gravity, rarified or very tenuous atmosphere, extreme temperatures and isolation characterize the Moon & Mars as extreme work environments. In those environments, the human biorhythm, its sensory perception, and its entire psycho-physiological system are severely challenged. This affects human subjects' perception, deambulation, motion, and general interaction with the environment. To create future Moon and Mars habitats based on "human-centered design", we will have to investigate all the factors that impact human interaction to try to increase the safety, productivity, and comfort of the astronauts. In this perspective, we are focusing on the investigation of anthropometrical data and interaction movements to address the walking patterns and the interactions of the astronauts inside and outside the habitat.

The walking pattern is a factor that is determined by all the human factors in relation to the system:

- Physiological factors (the configuration and the state of the body impact the walk, e.g., weight, muscular mass, stiffness of the legs, age, eyesight, perception of gravity and verticality…)
- Psychological factors (the personal approach and the psychological feeling impact the walk, e.g., being tired, afraid, happy, late, ..)
- Operational and technical factors (the task that we are approaching impacts the walk, e.g., carrying material, over short distances, over long distances, outside, inside, with extra vehicular suits, without EVA, …).
- Environmental factors (the environmental characteristics influence the walk, e.g., mechanical properties of the soil, partial gravity, temperature, light, bare visual surroundings with no reference, interior habitat crowdedness, gravity, radiation, …)
- Socio-cultural factors (your culture in relation to social aspects influence the walk, e.g., you are alone, in a group, on vacation, in a work context, with background music, …)

This means that in order to truly understand walking patterns, we should analyze them during the mission. However, considering that in order to conduct a Moon mission, we should have been collecting these data, we need to apply different solutions to get as close as possible to the real factors. Isolating a determining analysis factor could also help to achieve better results. For example, focusing the research on the interaction between walking and the effects of reduced gravity may help to understand a specific aspect, later this will then need to be validated in relation to the influence of all the other factors (psychological, operational, etc.). Gravity is indeed one of the most interesting aspect. Influence of gravity acceleration (g= 981cm/sec^2 on Earth, 162 on Moon surface), considering that the g coefficient acting on the *maculae* of *utriculus* and *sacculus* inner ear gravity and motion sensors [2] is an unavoidable element of their mathematical functions.

For example, research led by our work group [3] and using images and videos from NASA's Apollo missions [4] shows that when we walk on the Moon with one of the three modalities – modified walk, hop, side step [5] – the different walking patterns have an impact on the visual field. In particular, the head is more tilted downwards; as a consequence, our eyesight is lowered and we see a narrower visual field. This could, for example, reduce the perception of obstacles and decrease balance. In other words, while we walk, we cannot see so far, which makes it more difficult to avoid obstacles and increases the possibility of tripping up [3]. This research show for example the strong correlation between walking movement and eyesight.

2 Methodologies

There are different methodologies to simulate the Moon & Mars environment in order to analyze kinematic and anthropometrical data:

2.1 Real images and video.

Analysis of existing Apollo mission videos and images. Posture and movement are real and not reconstructed; we also have direct influence on all factors involved, such as terrain, bare visual field, psychological impact of being on the Moon far away from Earth; reduced weight, etc. The problem is that the angle of view is not optimal for the data analysis; also, we do not have any exact reference for the measurements. In the image, the research on the sight line using an image from the Apollo 14 mission is depicted [3].

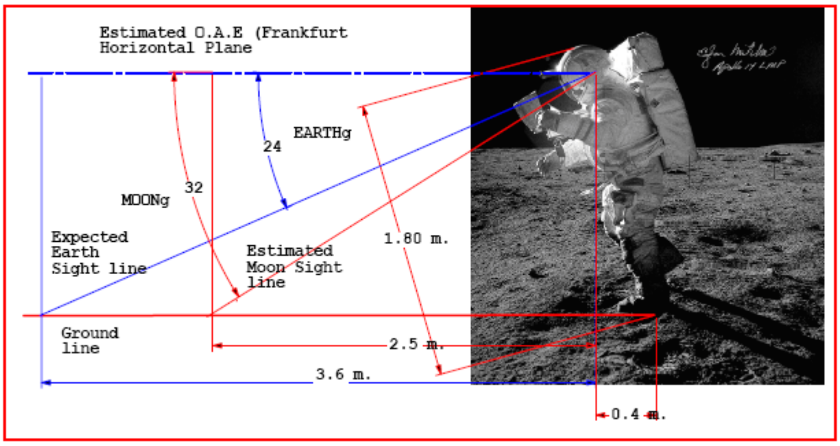

Fig. 1. Tentative interpretation of Moon walking posture and sight-line Image. Apollo 14, 1971 © NASA & M. Masali.

2.2 Virtual Reality with unloaded weight

The user interacts with the virtual Moon-Mars habitat and landscape, while the Moon gravity is simulated with the help of special cables that are balanced in proportion to the user's weight. Inside a 3D virtual environment, the user's movements are tracked and reproduced by an avatar. This solution is very effective in giving the user a visual perception of the surroundings. The image depicts an image by the Italian Mars Society of the V-ERAS system during a Mars mission simulation.

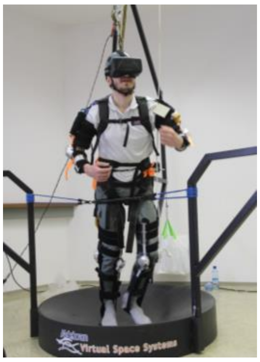

Fig. 2 V-ERAS system of the Italian Mars Society © Italian Mars Society [6]

2.3 Neutral Buoyancy (adapted for Moon / Mars gravity simulation)

The Neutral Buoyancy Facility is a swimming pool where a person's body is in buoyancy to simulate microgravity. By using a combination of distributed mechanical loads on different parts of his body (and, possibly, of floaters to optimize the application point of the resultant force) a realistic reduced gravity effect can also be achieved. Inside, the subject can interact with a Moon or Mars habitat or terrain created within the Neutral Buoyancy Facility. The picture shows 3 different neutral buoyancy facilities: the ALTEC Neutral Buoyancy Test Facility (NBTF) (5x9x4m) with windows, the Neutral Buoyancy Lab at NASA's Sonny Carter Training Facility, and the Neutral Buoyancy Facility at the Astronaut Training Center of the European Space Agency (ESA). Both are equipped with a control room, a crane to hoist and submerge equipment; the dimensions allow hoisting of a full size ISS mock-up. Combined use of neutral buoyancy and virtual reality could also be used to increase science results [7]. This kind of solution is very convenient to reduce the weight and control the movement, but needs to consider the viscosity of the water and the equipment or tubes for breathing under water.

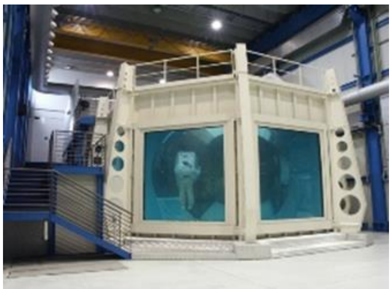

Fig. 3 Neutral Buoyancy Facility Altec ©Altec [8]

Fig. 4 Control Center, Neutral Buoyancy Facility at the European Astronaut Centre ©ESA–H. Rueb [9]

Fig. 5 Neutral Buoyancy Lab at NASA's Sonny Carter Training Facility © NASA [10]

2.4 Vertical treadmill (adapted as inclined treadmill)

The user is attached to strings distributed along his body and walks on a treadmill that is vertical if he is simulating exercise in microgravity. Currently the DLR is developing a treadmill that has an inclination that results in weight reduction corresponding to Moon or Mars gravity. As explained by the co-author Prof. Rittweger, the angle is calculated using the gravity level of the Moon (0.16g) and Mars (0.38g) and computing them with the arc sin (= asin) function. Thus, asin (0.16) = 9.207°, and asin (0.38) = 22.33°. The treadmill will then be inclined by 9° for simulating walks on the Moon and by 22° to simulate walks on Mars.

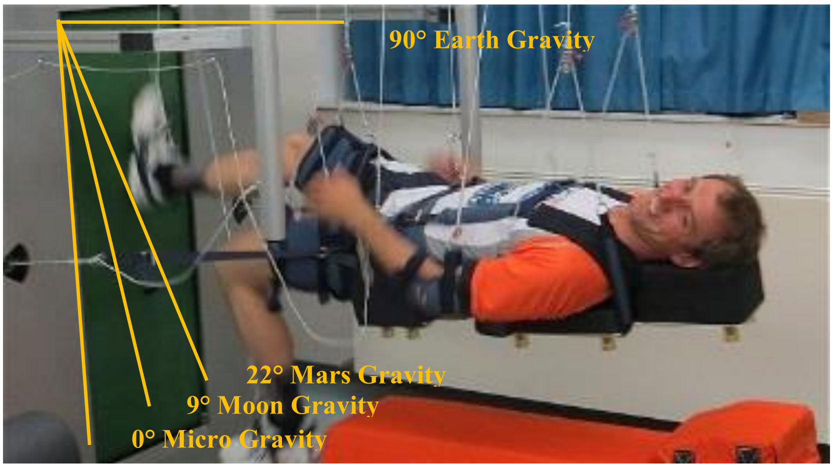

Fig. 6 Vertical Treadmill of DLR © DLR edited by Schlacht & Rittweger [11]

2.5 Tradmill with reduction of weight.

As reported by Kram et al. [12] p. 823: "This device applied a nearly constant upward force to the subject's center of mass. The harness consisted of a bicycle saddle attached to a U-shaped section of polyvinyl chloride pipe (total mass 1.74 kg). A wide padded belt held the subject at a comfortable location on the saddle. Upward forces applied to the subject were measured using a force transducer. Two spring elements were arranged in series, connected by cables and separated by a pulley. To increase the amount of tension, additional rubber springs were added in parallel. Additional springs were only added when the force of the original springs became inadequate, in order to maximize spring length and keep the force fluctuations as small as possible. A hand winch reeled in a cable connected to the springs, allowing us to control the length of the springs".

2.6 Unloaded deambulation on Moon or Mars terrain

The user is followed on his path on Moon or Mars terrain by suited suspension cable systems that decrease the user's weight to reproduce Moon or Mars gravity. This system is easily applicable for simulation of extra vehicular activity, while it is a bit more complex to build for simulation inside a Moon-Mars habitat analogue. The problem is that being connected to cables restricts the freedom of movement, reducing the possibility of spontaneous movement. On the other hand, this system is very good for testing the interaction with the environment, which is not possible, for example, inside the treadmill. Moreover, the system could also be used in mission simulations where other human factors that influence the walk are also considered and supported (e.g., isolation, terrain, bare visual surroundings, …)

Fig. 7 ALTEC Moon-Mars Terrain for IVA test© LUNA consortium, visualization: Space Applications Services, 2015 [13]

Fig. 8 ESOL European Simulation and Operations Laboratory © LUNA consortium, visualization: LIQUIFER Systems Group, 2015

2.7 Parabolic flight

The user experiences the interaction in a different type of gravity for 20 seconds in a parabolic flight maneuver that recreates Moon or Mars gravity. Parabolic flight is the only way to test the effect on the vestibular system. However, the problem is that there is only a very limited amount of time and limited space (the airplane's interior) available (e.g. Noverspace flight [14]). To face the second problem, one solution that has been applied before is to have a treadmill on the flight.

2.8 Combination

The methodologies presented here can be combined into new methodologies. For example, research has been done on the analysis of walking by simulating different types of gravity with: treadmill in parabolic flight, treadmill in a neutral buoyancy facility, and virtual reality in a neutral buoyancy facility [15,16].

Fig. 9 Parabolic flight with Moon gravity and treadmill © NASA [17]

3 Conclusion

In summary, during the Apollo missions more than 50 years ago, no anthropometrical studies were carried out as far as we know. The necessity to collect data is very consistent with state-of-the-art research. We still have little knowledge of how people will interact with the Moon environment. Specifically, it is not known which posture, which kind of walking and running motions they will use both inside and outside a Moon station. Considering recent plans for Moon and Mars missions where humans will spend extensive time in reduced gravity conditions, the need for field data is a priority in order to be able to design the right architecture, infrastructure, and interfaces.

This research is aimed at reconsidering the methodologies from the viewpoint of anthropometry and human system interaction in different types of gravity and carrying out new investigations that may help to prepare for the next Moon mission, but which can also be used for advanced applications on Earth. The various experimental setups and methodologies described here are also extremely promising in terms of basic research aimed at better understanding human physiological mechanisms ruling equilibrium, deambulation, and related topics. Nevertheless we must take in account that out of the case of Moon-Mars gravitation simulation in parabolic flight (or centrifuge for Jupiter) any Earth surface experiment would be unavoidably biased by the terrestrial value of *g* on the vestibular system.

Thanks

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