WHICH HYPERGRAVITY LEVEL FOR A LONG-RADIUS HUMAN CENTRIFUGE?

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ABSTRACT

This paper presents some scientific rationale for ground-based studies on humans in rotating environments, such as short- and long-radius centrifuges, and slow rotating rooms. The author also describes several approaches for determining the hypergravity level for a long-radius centrifuge with a tilted habitat so that the resultant gravitoinertial force is perpendicular to the habitat's floor. These approaches aim at supporting anticipated exploration-class missions and provide a platform for studying physiological responses in a continuum of gravity levels.

1. RECOMMENDATIONS

The ESA Topical Team on Artificial Gravity has provided recommendations for the short- and long-term research efforts required to understand the fundamentals and validate operational aspects of using artificial gravity as an effective countermeasure for long-duration space travel [1]. These recommendations included the need for a program of ground-based and in-flight research using both short- and long-radius centrifuge and slow rotating rooms for studying the effects of accelerations smaller and greater than 1 g (Figure 1). In addition to their operational relevance for developing an artificial gravity countermeasure to the detrimental effects of weightlessness during long-duration space mission [2], the results of these studies might prove to be of great interest in fundamental and medical research.

The potential use of a short-radius (< 2 m) centrifuge for intermittent artificial gravity exposure of astronauts is currently being validated in numerous ground-based studies as an effective way to overcome the deconditioning effects of bed rest [3]. Ground-based studies in a slow rotating room help determine the adaptability of human performance and cognition during exposure to rotating environments [4]. Particularly relevant are studies on locomotion and movement control, control of Coriolis forces and the ability to maintain simultaneous adaptation to rotating and non-rotating environments and to move between them without severe performance disruption [5]. Long-radius human centrifuges are generally used to study or adapt the tolerance to acceleration for various directions and amplitudes of the gravity vector. The addition of a habitat on a long-radius centrifuge, where crews could freely move about while living and working for extended periods of time (days to weeks), would present the opportunity to study the effects of higher gravity exposure for longer duration with limited gravity gradient across the body.

- **Short-radius centrifuge**
  - Artificial gravity prescription to counteract the physiological effects of bed rest
  - Effects of gravity gradient
- **Long-radius centrifuge**
  - Tolerance to acceleration
  - Direction of gravity vector
  - Adaptation to hypergravity
- **Slow rotation room**
  - Adaptation to rotation rate
  - Human factors constraints

Figure 1. Rationale for studies on short- and long-radius centrifuges and slow rotation room recommended by the ESA Topical Team on Artificial Gravity.

2. CENTRIFUGE LIVE-ABOARD STUDIES

Studies of the sensory-motor and human factors effects of extended exposure to hypergravity will determine how freely moving humans adapt to and perform in rotating artificial gravity environments. Neuro-vestibular hypergravity studies should focus on adaptation and transient changes in performance, as well as long-term changes in locomotion, material handling, gross and fine motor control, postural balance, and work-rest cycles [6]. Live-aboard studies of the cardiovascular, musculoskeletal, circadian and immune systems, for which interactions with the neurovestibular system have been demonstrated [7], should be part of these investigations. Studies of re-adaptation of these various functions to the normal gravity environment after centrifugation stops should also be designed to supplement the live-aboard studies.

Unlike the slow rotating room, which stays in the horizontal position during rotation, the habitat in the large-radius human centrifuge should be tilted so that the resultant of the gravitoinertial force is aligned with the subject's body vertical. This design will also allow for the hypergravity level to be fairly constant in all the locations of the habitat.

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3. HYPERGRAVITY LEVEL

The level of hypergravity to be generated in such a tilted habitat is a key requirement, because it is a function of the radius and/or rate of rotation, and therefore it will drive the dimensions the entire apparatus. For determining this hypergravity level, several approaches are possible. One is to extrapolate from existing gravity conditions, as shown in Figure 2. The relationship between gravity levels on the Moon, Mars and Earth is not linear, but it can be converted to a linear form by a simple logarithmic transformation. Extending the logarithmic fit to the hypergravity domain points to a value of 2.3 g. It is important to note that the physiological responses for each gravity level might (and probably will) not follow such a logarithmic relationship. However, with the stimulus conditions following a linear curve fit, simpler models can be used for representing empirical data.

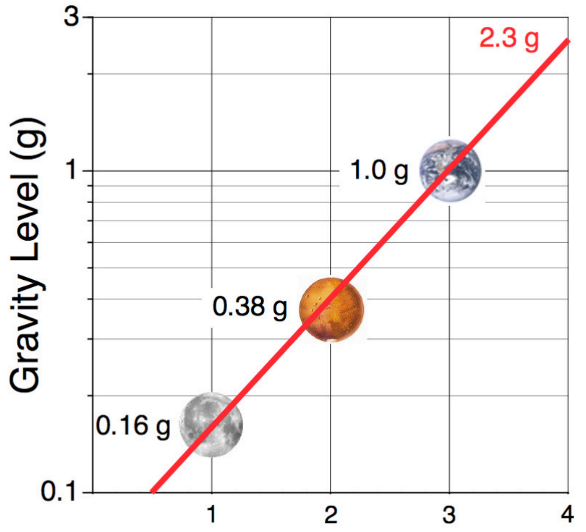

Figure 2. A linear relationship between the gravity levels on the Moon, Mars and Earth can be obtained by taking their logarithmic values. Extending this logarithmic fit to the hypergravity domain points to a value of 2.3 g.

Another approach is to focus on the adaptation/re-adaptation effects induced by transitions between gravity levels. This is particularly relevant to exploration-class missions since these missions will include four events with gravity transitions (1 g to 0 g; 0 g to 0.16 g or 0.38 g; 0.16 g or 0.38 g to 0 g; 0 g to 1 g) [8]. These transition periods have a major impact on the vestibular system. Vestibular-induced response dysfunctions, such as postural and gait instability, visual performance changes, manual control disruptions, spatial disorientation, and motion sickness, have been documented during and after gravity level-transitions [8]. The regulation of respiratory and cardiovascular systems, circadian regulation, food intake, and even bone mineralization are also affected, partly due to their interactions with the neurovestibular system [7].

After long stays on the Moon and Mars, astronauts will first go from 0.16 g and 0.38 g to 0 g. By centrifuging subjects at 1.16 g or 1.38 g for extended periods of time and studying their re-adaptation to 1 g after rotation stops, lessons can be learned about the effects of transitioning between gravity levels of 0.16 g or 0.38 g, and 0 g. Alternatively, going from 1 g to 0.16 g or 0.38 g can be viewed as a gravity step decrease of 0.84 g or 0.62 g, respectively. It might therefore be also interesting to study the re-adaptation effects following transitions from 1.84 g or 1.62 g to 1 g.

Hypergravity levels ranging from 1.16 to 2.3 g along the subject's vertical will require tilting the entire habitat by approximately 30 to 64 degrees relative to the horizontal, respectively. The rotation rate will depend on the affordable radius for the centrifuge design (e.g., about 9.3-17.5 rpm for a 6-m radius). The longer the radius, the lower the rotation rate and the lesser the interactions with Coriolis forces during subject's motion on the centrifuge [9].

4. REFERENCES

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5. ACKNOWLEDGEMENTS

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