IAC-09.A1.2.3

THE LARGE RADIUS HUMAN CENTRIFUGE 'A HUMAN HYPERGRAVITY HABITAT, H^3

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Abstract

Over the last decades a significant body of knowledge has been gained on the adaptation of the human body going into near weightlessness conditions as well as for the re-adaptation to 1×g Earth conditions after an orbital space flight. Ground-based paradigms for microgravity simulation have been developed such as head down tilted bed rest or dry-immersion studies. In such systems adaptations of the human body to long term immobilization and increased upper-body fluid shifts bed have been studied.

But could we learn something on human body adaptations to altered gravity conditions using centrifuges? How does the body adapt to a long duration (days, weeks or longer) exposure to a hypergravity environment? And, once the body has fully adapted to a hypergravity environment, how does it re-adapt going from a hypergravity condition to a relatively hypo-gravity condition of 1×g, or even going from centrifuge / hypergravity environment into a bed-rest setting? Can such transitions learn us something about the gravity transitions as a crew will experience going to Moon or Mars. Is hypergravity therefore a good model to study the effect of re-entry in gravitational environments after long duration space flight?

We established a Topical Team sponsored by ESA ans supported by NASA and JAXA in which we address the issues as mentioned above. We like to address the questions for all organ systems known to change under altered gravity conditions. We will identify to which gravity levels the human body can be exposed to for longer periods of time and what protocols could be applied to address the questions at hand. We also need to identify if and how we could perform such long duration hypergravity and re-adaptation studies. Issues like ethics, safety and required technology are addressed.

The final outcome of the ESA Topical Team will be a clear answer about the feasibility of long duration hypergravity, and if and how hypergravity studies can provide useful knowledge to support future space flight on the one hand and the medical issues in *e.g.* the ageing population with its contemporary lifestyle on the other hand (osteoporosis, cardiovascular diseases, obesity).

Introduction

In the field of space flight research we want to make use of the unique microgravity environment, where the impact of gravity is compensated by the fact that systems are in free fall, to learn about the effects of weight on the physiology. When we consider physical parameters acting upon a system the factor weight is basically not any different from *e.g.* temperature or pressure, and in order to understand how the systems responds to environmental variables we need to modulate them. For many systems it is therefore as relevant to look at hypergravity (above Earth 1g) as well as hypogravity or even near weightlessness. Since mankind developed the capability to go into space, numerous space flight experiments, of some significant duration, have been performed, first on board the Soviet Salyut [1] and later on the American Skylab crews [2] in the early nineteen seventies. These cosmonauts / astronauts have been under near weightlessness conditions for several months and longer. Most hyper-g studies have been performed using relatively short-arm centrifuges and short exposure times. However, if one is interested in the long term effects of gravity on human physiology we need to expose humans to both hypo- and hyper-gravity conditions for periods of days, weeks or even months. In his flying career the Russian cosmonaut Sergei Krikalev has been exposed to hypo-gravity conditions on board orbital space stations for more than 800 days. However, there has never been a single person exposed to more than 1.0g for period of time coming near to this 800 days. The longest period to which humans have been exposed to hypergravity was for a few weeks during a study performed in Downey, (CA, USA) in the nineteen sixties. In this facility 3-4 subjects lived in a camper size and like system attached to a large arm centrifuge. No publicly accessible reports have been released from this study.

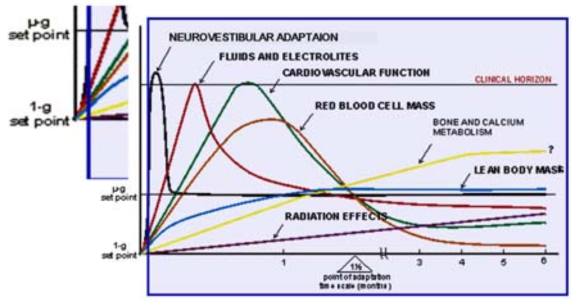

Figure 1: A schematic representation of the time course of the physiological adaptation and pathophysiologic responses to long duration (6 months) space flight as reported by Nicogossian [21]. The graph is based on actual flight data while our knowledge for human body adaptation to hypergravity is only a very narrow band in this graph (see also inset on the left had side). Picture adapted from [21]

The research emerging from the exposure of humans to long duration hypergravity would be completely new, providing basic knowledge and understanding on how the human physiology is regulated with respect to sustained increased weight. Recently NASA looked into the operation of a nearly 16 meter diameter human centrifuge for studies in the order of weeks [3]. In the past also studies in Japan have looked into large radii centrifuges (data not available).

In preparation for long duration missions to Moon or Mars, there is a focus on short radius centrifuges [4-9]. The main rationale for these relatively small centrifuges is that they would be applied on board *e.g.* a Mars mission. This should be beneficial for the musculoskeletal and cardiovascular system while effects like Coriolis are still present. Di Prampero proposes a large drum where crew members generate their own g-force while riding a bicycle. [10]. However, if we elaborate a bit on the possible application of a large radius Earth based centrifuge in preparation of Moon / Mars missions, what could we use it for? If we consider the paradigm of a gravity continuum, *e.g.* that physiological processes scale with the magnitude of applied acceleration [11-12] one may learn about the long term adaptation of the body to different g-loads. How fast does the human body adapt to a hyper-g load, but also how fast does the body respond when returning to 1g after long duration centrifugation? We might even combine such hypergravity studies with bed rest experiments before or after hyper-g exposure. Such studies provide valuable insights in adaptive processes. On Earth we might be able to precondition a crew by hypergravity before their voyage to Moon or Mars. They can build up “reserves” in terms of *e.g.* muscle and bone to alleviate the subsequent hypo-gravity periods. It has been shown that humans can cope with microgravity for much longer than a year, as was shown in the flight by Valeriy Polyakov in 1994-1995 when he stayed on board the Mir station for 438 consecutive days. Based on this one might argue that we could go to Mars, a one way voyage of about 9-10 months without any novel countermeasure protocols. If the adaptive effects for *e.g.* muscle, bone or the cardiovascular system have a higher threshold level than Mars gravity (0.373g) one could even argue the application of a centrifuge on the Mars surface. This argument holds even more for Moon missions where the weight is reduced to less than 17% from that on Earth, although the expedition time is far less compared to a Mars mission. While on the planet the crew can be exposed to any suitable g-level, building up sufficient ‘reserves’ for their return trip to Earth. While Moon missions are regarded as stepping stones towards Mars we could generate Mars gravity on Moon in order to learn how the body adapts to Mars-g. On Earth, studies in a large centrifuge with multiple crew members could also be beneficial for psychological studies. In an on-ground centrifuge we have ample possibilities to make these investigations and, as such, a large centrifuge environment could be complementary to other space flight related analogues such as Antarctic station [13]. The aforementioned arguments are mostly concerning space flight related issues but a large ground based centrifuge might also be applied for more Earth-bound applications like diagnostics, treatment or rehabilitation of some diseases. One such disease is obesity. This contemporary phenomenon is one of the major threats for *e.g.* the cardiovascular, pulmonary and skeletal system and increases the prevalence of cancer [15,16]. The relationship between hypergravity and the decrease in body fat was first hypothesized E.C. Dodds in 1950 and later confirmed by many others [14,17]. Another area of application might be in athletic training.

Since no long durations hyper-g studies have ever been performed it is difficult to define the maximum g-level a human body can tolerate. We could, as a first approach, rely on extrapolating data from long duration animal studies or short duration human experiments. From a study by Wunder *et al*. [15] we could extrapolate a maximum value around 1.5 to 1.8xg. The limiting factor might be the body fluid balance (personal comment R. Burton). It is known for bone and muscle systems that they are used to high loading conditions although the most effective loads are peak loads : high magnitude but of short durations.

We also need to identify the technology required to accomplish such long duration hypergravity and re-adaptation studies. These could be systems on ground (levitating trains, conventional trains), systems on water (very fast boats) or flying systems.

But also issues like ethics, safety and required logistics should be addressed. As there is limited experience with exposure of human test subjects to prolonged periods of moderately increased g-forces, unexpected harm may occur. Therefore, the information, disclosure and informed consent procedures need special attention. Active or potential astronauts, military personnel and scientists as research subjects should be considered "vulnerable populations", because they are highly motivated and willing to submit to substantial risk. Therefore, possible exposure of research subjects to harm will be formally discussed in the protocol and as the knowledge base in this field grows, test subjects will be informed on regular occasions.

First outcome of Topical Team meeting

What should this Earth-based centrifuge look like? In a first approach we might think of a centrifuge with diameter of some 300 meter. [18] This needs to be some kind of either conventional or magnetic levitating train track with a series of cabins to occupy the test subjects, their living and working quarters (laboratories), support rooms for leisure, storage, waste, energy, communication, workshop etc. A gravity level of 1.5g resulting from rotation on a 942 meter track would result in a speed of 169 km/h with a rotation frequency of 3 rpm. This speed could be easily achieved by modern train systems but we need to maintain this speed for weeks or months without interruption

In a first evaluation as discussed with all Topical team members a diameter of 150 meter with a maximum design load of 2g seems the best option. The actual gravity loads used in long duration studies is likely to be less than the maximum design loads, might be exposure. In a first approach values of 1.4-1.5 should not be exceeded. This maximum exposure load should be built up in steps of 0.1g over hours or longer, for each step. For such a system, i.e. 150m diameter and running at 1.4g, the rotation rate 3.4 rpm and a speed of 97 km/hr.

The final outcome of the Topical Team will be a clear answer about the feasibility of the use of hypergravity as a tool and analogue for space research, and if and how hypergravity studies can provide useful knowledge to support future space flight on the one hand and current medical issues in the ageing population (osteoporosis, cardiovascular diseases, obesity) on the other hand.

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Acknowledgements

We like to acknowledge the support for the European Topical Team by an ESA TT Grant and for the Japanese and American members via a respectively, JAXA and NASA Grant, This work is support for van Loon through the NWO-ALW Grant MG-057 via the External Program Office of the Netherlands Institute for Space Research, SRON.