A LARGE RADIUS HUMAN CENTRIFUGE: THE HUMAN HYPERGRAVITY HABITAT

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ABSTRACT

Life on Earth has developed at unit gravity, 9.81 m/s^2, but how would plants and animals have evolved on a larger planet, *i.e.* larger than Earth? We are able to address this question simply by studies using centrifuges. In the past decades numerous experiments have been performed on cells, plants and animals grown for longer durations, even multi generations, under hypergravity conditions. Based on these studies we have gained interesting insights in the physiological process of these systems when exposed to artificial gravity. Animals and plants adapt themselves to this new high-g environment. Information of adaptation to hyper-g in mammals is interesting, or maybe even proof vital, for future human space flight programs especially in light of long duration missions to Moon and Mars. We know from long duration animal studies that numerous physiological processes and structures like muscles, bones, neuro-vestibular, or the cardiovascular system are affected. However, humans have never been exposed to a hyper-g environment for long durations. Human studies are mostly in the order of hours at most. Current work on human centrifuges is all focused on short arm systems to apply artificial gravity in long duration space missions. In this paper we want to address the possible usefulness of a large radius human centrifuge on Earth, or even on Moon or Mars, for both basic research and possible applications. In such a centrifuge a group of humans may be exposed to hypergravity for, in principle, an unlimited period of time.

1. 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 weeks or 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 person exposed to more than 1.0g for such a period of time (Fig. 1). The longest period to which humans have been exposed to hypergravity was 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. 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).

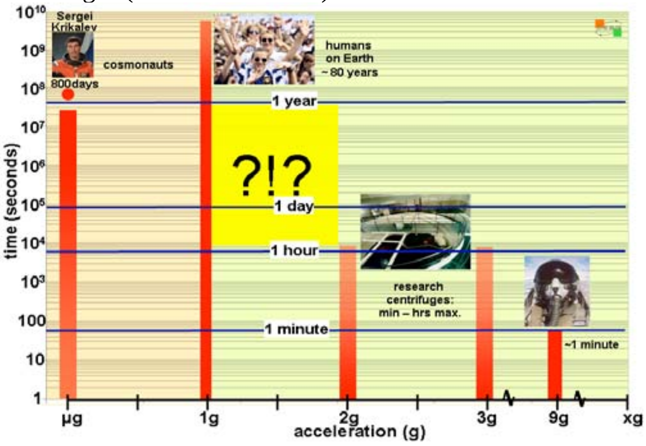

Fig. 1: Gravity over time spectrum in human research and application.

For 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 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

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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 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 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 (0.373×g) 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 travel time is 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 1.8×g. The limiting factor might be the body fluid balance (personal comment R. Burton). Bone and muscle systems are used to high loading although these peak loads are of short durations.

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 1.5×g 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.

2. REFERENCES

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