The role of G in space using a short-radius centrifuge has operation implications in preventing physiologic deconditioning from weightlessness. The relationship between periodic gravity exposures on simulated weightless effects, once determined systematically, will provide crucial information on the role of gravity as a regulator of physiologic functions.

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Several adaptates have been identified that help develop this adaptation. Anatomical and physiologic adaptates include: (a) muscles, (b) exercise capacity, (c) body mass, (d) nutritional requirements, (e) plasma volume, and (f) red blood cell mass (5, 8, 9, 10, 16, 17, 18, 19). These adaptates are identical to those that change with extended exposures to weightlessness in space. These similarities provide substantial evidence that the body responses to change in G or gravity are qualitatively identical (20, 21). The quantitative nature of these changes appropriately follows the physical forces involved; i.e., affected parameters change in concert with an increase or decrease in the G/g forces.

So be it that as these aquatic animals, genetically adapted to the weightlessness of the water environment, moved onto land, physiologic stress occurred and in response adaptates were developed. By nature, stress is uncomfortable, even painful, so that these animals would escape the stress by returning to the water. There can be little doubt that adaptation to gravity occurred with regular periodic exposures to its physical force (6, 11).

We may also assume that regular exposures occurred on a daily basis and at about the same time, when animals are most active, since biologic activity has a significant influence on the activities of all animals; it is likely that this gravity exposure occurred in the middle of the day during peak-activity periods. It is reasonable therefore to believe that circadian rhythms will play a role in the response of the body to periodic exposure to gravity or G. This relationship is important to consider if and when gravity is substituted periodically by G on a regular basis in space to prevent physiologic deconditioning.

As these aquatically adapted animals moved onto the land, all physiologic functions were affected similarly, but it was probably the bones and muscles that were most abused by gravity. Although functional in water, their role was changed directly from singularly one of motion to an additional role of support against gravity. For the first time, extensors had a primary role to perform on land besides loading the flexors in their motion role in water. The bone and muscle development within these specific groups of muscles must have been substantial, limiting their daily exposure duration to land living. It is for this reason that exercise in space is not completely effective in preventing a decline in its functional capability, specifically its major role in support of the body against gravity.

The cardiovascular system was also challenged in support of terrestrial living. Cardiovascular stimulation by gravity is provided by the intravascular hydrostatic pressure that develops immediately upon exposure to it. A sudden increase in hydrostatic pressure within the vascular system in response to land habitation (i.e., hydrostatic pressure is directly related to column height because of G or g) had profound effects on arterial and venous blood pressure, flow, and volume, perhaps even red blood cell mass. This effect too then limited exposure to moving on land as blood constituent fluids rapidly leaked extravascularly.

1G represents the inertial force that develops in response to acceleration. G has been shown to be physically identical to gravity by Einstein and Mach in their Theory of Equivalence (Smith 15).
As animals became larger, the role of gravity on intravascular hydrostatic pressure related blood pressure (particularly blood column height) became more important.

More recently over the last several thousand years, bipedal posture of the human has placed an additional burden on the cardiovascular system in support of orthostasis and now even more recently with the advent of rockets and airplanes, increased G tolerance. The baroceptors were recruited by the body to perform this task. These clever regulators were perfect for the job since they were already regulating blood pressure in the brain to prevent cerebral hypertension. Adaptation in support of orthostasis by these baroceptors was not necessary as evidenced by arterial blood pressure responses of quadrupeds to increased G (3). Lower body negative pressure (LBNP) used in space in support of the cardiovascular system does not directly affect the intravascular hydrostatic pressures. Its very slow, indirect effects are a poor substitute for the direct profound effects of gravity.

The role of gravity in the maintenance of other physiologic functions is less clear (perhaps less direct). But measurement in space suggests that others may indeed prevail: e.g., the immune system. Much greater questions arise. Can terrestrial adapted animals remain healthy in a weightlessness environment indefinitely without gravitational stimulation? Once adaptation to the space environment has been completed (perhaps after several years), can readaptation (back to) Earth’s gravity occur?

Until we know these answers, there is no substitute for gravity except, of course, the inertial forces of acceleration that is provided by centrifugation (1, 2, 4, 7, 13 14). The application of gravity or G in its regulatory role in physiology is not well understood. Increased G animal studies have been helpful in this regard (8). But limitations are evident in its application in the maintenance of physiologic function to reduced gravitational forces. Increased G studies have identified those physiologic functions at greatest risk in space. These studies have even identified successful processes of G application that are useful in stimulating its adaptation process; periodic daily exposures to increased G were effective in adapting animals to continuous exposure to increased G environments (11). Physiologic regulatory processes are stimulated by periodic exposures to increased G, probably recapitulating the same adaptive processes that occurred when animals moved onto the land. And as with frequent exposures to increased G, frequent exposures to gravity maintains that adaptation.

The time requirements of daily exposure to increased G or gravity to maintain that adaptation is not known. Nor is the role of the intensity of this G stimulation on this adaptation process understood. Can these gravity based regulatory processes be stimulated more rapidly by G levels greater than 1g? Certainly this question is profound and intrinsic in understanding the bases of gravitation regulation of physiologic processes.

It is well known that the general nature of loss of physiologic regulation in weightlessness begins rapidly and continues unabated for an undetermined period of time. This loss of regulation can be interrupted with various stimulations (some better than others) and most effectively when regularly applied (Figure 1). Consistently, regulatory phenomena respond to the active process of a useful stimulation more rapidly than the passivity of its decay in the absence of that stimulation (Figure 2) (12).

![Figure 1: Theoretical response of physiologic function in a microgravity environment.](image1)

![Figure 2: Physiologic functions respond to active stimulation (a) more rapidly than the passive nature of the loss of function (c). Functional stimulation continues (b) even after the stimulant has been removed.](image2)
increased G exposures is useful and higher G levels are most beneficial. Relating those data of Shulzhenko and Vil-Viliams (14) to the (G x Time) concept identified in Figure 4, the daily exposure period of time required to prevent any loss of tolerance to 3G is 245 min of 1G, but only 82 min of 3G (Figure 5).

More recently, Vernikos and Ludwig (22) reported on a 4-day -6% head down bedrest with controls (no standing nor exercise exposure) and 4 groups of the same 9 males each with daily periodic 2 or 4 hr exposures to standing or walking at 1G. Periodic daily exposures to 1G were useful in preventing decreases in peak VO₂, plasma volume, and orthostatic tolerance and increases in urinary calcium. Interestingly and quite unexpectedly, longer 1G periodic exposure periods were not always most beneficial nor was the inclusion of exercise (Table 1).

Earlier research in our laboratory (7) clearly showed that a short-radius centrifuge of 5 ft (1.5 m) radius was easily tolerated by humans in a flexed-leg position up to 7G (76 rpm). Also that with the subject’s head only 26 in (66 cm) from the centrifuge center, beneficial cardiovascular effects of the increased intravascular hydrostatic pressures from the increased G were provided. Simply, this short-radius centrifuge produced G that would be effective in stimulating the cardiovascular system in space.

Recent Relevant Research Results:

Recent weightless simulation studies have supported this concept of periodic increased G exposures to prevent space deconditioning. Shulzhenko and Vil-Viliams (14) using 3-day dry immersion simulation of weightlessness measured human tolerance to 3G. Three days of immersion reduced 3G tolerance by 21%, but approximately 2 hrs of daily 1.2G, 1.6G or 1.9G with immersion showed less reductions in G tolerance of only 18%, 7% and 1% respectively. Their conclusion is irrefutable that increased G exposures is useful and higher G levels are most beneficial. Relating those data of Shulzhenko and Vil-Viliams (14) to the (G x Time) concept identified in Figure 4, the daily exposure period of time required to prevent any loss of tolerance to 3G is 245 min of 1G, but only 82 min of 3G (Figure 5).

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**Operational Concerns:**

Using regular daily exposures of increased G to prevent physiologic deconditioning during stays in microgravity will require considerable research to determine if the concept is useful and the optimum G exposure schedules. In addition, the role of biohymic interaction with gravity in physiologic regulation and the interaction of numerous other "treatments" with periodic G exposure to prevent physiologic deconditioning in microgravity will have to be determined (Figure 6).

**FIGURE 6:** The relationships of exercise, lower body negative pressure (LBNP), diet, drugs, and electrical stimulation with periodic G exposure to prevent microgravity physiological deconditioning is unknown.

**Conclusion:**

The role of G in space using a short-radius centrifuge has operation implications in preventing physiologic deconditioning from weightlessness. The relationship between periodic gravity exposures on simulated weightless effects, once determined systematically, will provide crucial information on the role of gravity as a regulator of physiologic functions.

**REFERENCES**


14. Shulzenko, E.B. and I.F. Vil-Viliams. Short body negative pressure (LBNP), diet, drugs, and electrical stimulation with periodic G exposure to prevent microgravity physiologic deconditioning is unknown.


