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NEED FOR ARTIFICIAL GRAVITY ON A MANNED MARS MISSION ?

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ABSTRACT

Drawing upon the extensive Soviet and our own Skylab medical observations, the need for artificial gravity (g) on a manned Mars mission is discussed. Little hard data derived from well done experiments exist. This dearth of information is primarily due to two factors. We cannot collect tissues from astronauts for ethical or operational reasons. Second, there has not been opportunities to fly animals in space to systematically evaluate the extent of the problem, and to develop and then to prove the effectiveness of countermeasures. The Skylab and Space Station will provide the opportunity to study these questions and validate suggested solutions.

The need for some form of "artificial gravity" aboard a spacecraft may be necessary during Earth-Mars-Earth transit. The most conservative approach would be to artificially provide one g during a round trip to Mars. Economic and engineering prudence will demand a validation of the assertion one g need be provided. Fortunately, the need can be determined onboard the Space Station, given proper and early study of people and mammals. If those studies should prove the need for one g and the consequent extensive engineering measures, the determination of "how much" or "what kind" of accelerations would provide the necessary minima will also require rather extensive testing. By its very nature, this testing will require years to conduct. One important question that would then follow is if 0.17, 0.38, or near 1.0 g is sufficient? There are no data to guide us (although it is presumed continuous 1.0 g would be adequate).

Observation of people who have spent extended periods of time in free fall suggest at least two, and possibly three, reasons to suspect that some form of artificial gravity might be needed on very long duration missions; especially on missions requiring on-surface EVA. These observations are: (1) Rather extensive orthostatic hypotension following long exposure to free fall, in spite of considerable hours of exercise designed to counter this cardiovascular sequella; (2) There is consistent, measureable, and progressive skeletal and muscle atrophy of the anti-gravity bones and muscles of the body; and finally (3) there seems to be a continuous loss of calcium from the skeleton, and possibility, from other calcium deposits within the body.

On the Soviet four to seven month missions, Cosmonauts have needed considerable assistance to egress from their spacecraft. Their ability to do on-surface extensive EVA is not known, but is suspected to be minimal. Furthermore, their return to full pre-flight cardiovascular competence has reportedly taken weeks to months. This, even with special on-orbit exercises and devices designed to tax their hearts and their large muscle groups. In spite of various exercise regimes, there have been measurable muscle mass losses in both cosmonauts and astronauts. Skylab input/output studies actually measured a negative nitrogen balance (indicative of muscle loss), in spite of exercises designed to prevent such losses. It should be remembered that once muscle fibers are lost they are never replaced. The residual fibers, can through exercise, increase their bulk, and thereby their strength, but if too many fibers are lost that muscle's function can never be recovered.

Soviet and U.S. studies of rat muscle tissue suggest a rapid and massive change from "slow twitch" to "fast twitch" fibers in muscles that normally have both types of fibers. In the predominantly "slow twitch" or anti-gravity muscle groups, the changes are even more remarkable following only seven days of weightlessness. These morphological changes and other histochemical changes observed in the animal studies, and on relatively short duration missions, give physiologists considerable cause for concern for the integrity of muscles exposed to weightlessness for years. The longest a rat has flown in space is 21 days, so long term effects are not known in even this simple mammalian species. No direct data exist on the extent of comparable changes in humans. To make obtaining valid answers even more difficult, astronauts and cosmonauts rightfully resist muscle (or any tissue) biopsies.

It is not known if some partial g loading, or if aperiodic g loading, would prevent these "normal" adaptations to the microgravity environment. There may be exercise devices that could attenuate or prevent these changes. The Soviets have developed special flight garments designed to exercise the heart by putting the lower half of the cosmonaut's body at a negative pressure. This to expand the volume of the legs and lower abdomen into which the body fluids shift, causing the heart to work harder. They have required their cosmonauts to wear other devices designed to exercise the large anti-gravity muscles. This suit consisted of strong elastic bands attached in such a way as to force these various muscles to work against the elastic bands during flight. The Soviets have reported no systematic data on the effectiveness of these devices. It is known that some of the cosmonauts do not like wearing them. There may even be dietary means to help alleviate the muscle wastage seen on long duration missions....but again, no data exist.

It should be emphasized that the changes here described are considered to be the normal adaptations of the body to a new environment, weightlessness. These adaptations seem to be well suited to the micro-gravity environment and present complications only when the body is then placed into an environment requiring adaptation to increased g loadings, or when asked to "work" in physically demanding situations. Since Mars' gravity is approximately 0.40 that of Earth's, there would be significantly less stress placed upon the body than when returning to Earth. However, EVA and a desire to accomplish as much as possible while on the surface of Mars, will be physically demanding. The procedures to best assist astronauts to re-adapt to the rigors of 1.0 g here on Earth, after 2 or 3 years of weightlessness are but dimly understood.

From the physiological point of view there are, then, several necessary sensitivity analyses that should be undertaken to determine the relative importance of each element of a research program. For example, it is not known if the loss of calcium in weightlessness will stabilize at some acceptable high level...or, if some partial level of g is necessary to prevent excessive losses of this important mineral from the body. If any form of acceleration is found to be necessary, then a similar analysis must be done to determine the "best" means of providing it, e.g., if the habitat modules must be designed to rotate, the maximal acceptable angular velocity will need to be determined (relative to the radius of the habitat and the position of the body within it).

Similar analysis must be done to determine the priority of research programs in preventing skeletal muscle atrophy or cardiovascular deconditioning, and developing proper exercise physiology methods (germane to EVA on the surface, if such be the case), etc.

Clearly the Spacelab, followed by the Space Station, will provide the United States for the first time the means to objectively assess these problems (rather than via experts' opinions and pronouncements). Most importantly, these machines will provide the laboratories where the best answers to these vexing questions can be obtained. It must be kept in mind that these problems are complex in-and-of themselves. They are even more complex when the physiological requirements interact importantly with engineering design considerations. The opportunity to start the processes of identifying the solutions must be seized now, and the search for answers begun. Since the fundamental issues deal with long duration exposures to zero gravity and with biology, there is no way to "speed up" some of the experiments! For example, if there is a question of how long it takes the loss of calcium to reach some asymptotic level during weightlessness, (and we strongly suspect it's longer than 238 days based on Soviet experience) then it behooves us to start the experiments early. This is especially true if we then must devise and test inexpensive countermeasures rather than artificially providing one g. The time it will take to do these experiments is further compounded if one is either curious about or ethically compelled to understand how (or if) the bones re-adapt once the crew returns to a one g environment.

It is reasonably well understood that animal models will have to be used to conduct many of these experiments. At some point however, it will be programatically prudent, and possibly ethically acceptable to validate conclusions from the animal studies by experiments upon humans. These experiments would include biopsies from people exposed to weightlessness for long periods, biopsies from others who have been "protected" by proposed countermeasures, and then later more tissue biopsies after varying periods of recovery. The alternative is to either take the risk of using unproven techniques and countermeasures or to provide a suitable one g environment for most of the round trip voyage to Mars.