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How the Human Body is Affected by Exposure to Microgravity During a Long-Term Space Mission

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Appendix E - UNIVERSITY HONORS PROGRAM
SENIOR PROJECT - APPROVAL

Name: Spencer E. Godwin


Faculty Mentor: Dr. J. Evans Lyne

PROJECT TITLE: How the Human Body Is Affected by Exposure to Microgravity During a Long-Term Space Mission

I have reviewed this completed senior honors thesis with this student and certify that it is a project commensurate with honors level undergraduate research in this field.

Signed: Dr. J. Evans Lyne, Faculty Mentor

Date: 5/8/01

General Assessment - please provide a short paragraph that highlights the most significant features of the project.

Comments (Optional):
How the Human Body Is Affected by Exposure to Microgravity During a Long-Term Space Mission

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Abstract

Even as we enter the 21st century, there is much to be learned about space travel. A manned mission to Mars is becoming increasingly feasible, but little is understood about how a human will react to a 2½-year mission outside the Earth's gravitational field. Research was conducted to primarily provide a concise and comprehensible account of what is currently known about long-term effects in microgravity on the human body. Many studies have been done in the area of simulated microgravity because real conditions are limited to much shorter periods of time. There is a great deal of knowledge about what to expect from prolonged exposure to microgravity. However, how and why the body acts in such manners, for the most part, remains to be seen. It is very plausible that scientists know enough about the body's behavior to deem long-term missions safe, and the more intriguing variable is the astronauts' psychological, mental, and emotional well being.

Introduction

Since the beginning of time, man has looked to the stars, searching for such things as other life forms to the origin of our own planet. Over the past 40 years, human beings have progressed from landing on the moon to inhabiting space stations in orbit around the Earth. Technology has evolved to the point where our next logical step is to journey to the Red Planet. A mission to Mars would almost guarantee that the current space endurance record would, at the very least, be doubled. The engineering required to design such complicated vehicles and systems aren't even quite fully developed. Nevertheless, more is known about how to design such components than is understood about how a human will react to a 2½-year mission outside the Earth's gravitational field. This report is an attempt to provide a comprehensive, yet concise, account of information known to date about long-term exposure to microgravity. Simultaneously, an additional goal is not to limit this document to only those individuals with a medical or technical background, but to become a source of information easily understood by most professionals.

The musculoskeletal system has evolved on Earth according to the Earth's physical features (water, land, air) and its gravitational field. These factors determine the physical demands which are imposed on all living animals. The construction rules of developmental mechanics have evolved over hundreds of millions of years to produce organisms which are designed specifically for this planet. The advent of space travel and the possibility of transporting animals to planets with different gravitational fields, present interesting questions in terms of immediate biological effects, the development of offspring, and the future evolution of species.

– Dennis Carter
The previous quote (v. 24, Journal of Biomechanics) expresses a simple basic fact: human beings (and all life on Earth for that matter) were not made to function in outer space. As manned space missions have the likelihood of becoming longer and longer, the human body will begin to far exceed current space endurance records. To date, the longest continual number of days in space by a human is 438, by Russian cosmonaut Valery Polyakov. The American endurance record is only 188 days (held by Shannon Lucid), not even half that of the Russian record. By comparison, current missions to Mars suggest one-way travel time of 4-6 months, with a surface stay of 500 days. This corresponds to a total mission of approximately 860 days...almost double the current record and 4½ times the longest American spaceflight. Thus, it would be highly beneficial to be able predict or simulate the effects on the body before such a long-term mission ever takes place.

**Discussion**

Since the beginnings of its space program, the United States has focused primarily on short-term missions. The first major goal was to send a man to the moon; none of these missions lasted longer than 13 days. The duration of the longest Skylab mission was 84 days and currently the maximum time for a shuttle mission is around 16 days. Conversely, "In the late 1960s, when it became clear the Soviet Union had lost the race to the moon, Soviet policy makers chose long duration spaceflight as their as their main focus with the ultimate goal of sending humans to Mars." With NASA becoming increasingly focused on a manned mission to Mars, more attention is being given to long-term exposure to microgravity. To date, most American research has been conducted under simulated microgravity conditions at the NASA Ames Human Research Facility in California. Currently, the most common form of simulating microgravity is in bedrest or head down tilt (HDT) studies. In these studies, subjects are literally confined to a bed for long periods of time in a position where their head is below the center portion of the body. The lack of movement combined with the different orientation of gravity, leads to a method proven to be very effective in simulating microgravity. The Russians, on the other hand, have more real (as opposed to simulated) microgravity data because they engage in significantly longer-duration missions. The bulk of the Russian research associated with long-term exposure to microgravity comes from the Institute for Biomedical Problems (IBMP) in Moscow. The following subsections present relevant physiological and psychological information known to date about a long duration space mission and its subsequent impact on a human being.

**Space Motion Sickness**

Probably the least dangerous of all microgravity related symptoms, space motion sickness (SMS) affects more than 50% of all shuttle crewmembers. Though numerous studies have been conducted, there is still no conclusive evidence correlating a certain race, gender, fitness level, etc. to the likelihood of developing SMS. The cause of SMS is generally agreed to come from the same thing that causes motion sickness here on Earth. The body has three primary means of
determining its orientation: the nervous system (one can feel the direction in which gravity acts), the eyes, and the vestibular system (the inner ear). In a microgravity environment, these three signals are in disagreement and the result, similar to Earth based motion sickness, includes nausea, vomiting, loss of appetite, and fatigue. While these combined effects can have detrimental to the performance of the crew members, the body adjusts to the new environment at the latest within a matter of days. Thus, in any long-term mission, the concerns associated with SMS would be minimal.

**Bone Loss**

When the human body, and animals for that matter, are no longer exposed to a gravitational field, there is a serious change associated with the skeletal system. Bones tend to grow more slowly due to a significant loss of calcium, bone marrow, and other essential minerals needed for proper growth.4 “The loss of bony mass, which can reach 5 percent per month in certain weight bearing bones, would increase the risk of fractures.” Russian cosmonauts have demonstrated a loss of 19% of their bone mineral density in less than 5 months.5 The effects of bone loss and its impact on future long-term missions are still being heavily debated within the scientific community.

Michael Holick, of the Boston University School of Medicine, argues that women, who have a lower bone mass to begin with will be susceptible to osteoporosis even quicker than their male counterparts. Furthermore, he adds that a return to the Earth’s gravitational field would not guarantee a full recovery for a long-term mission.6 Balanced diets that are rich in calcium do not appear to hinder the loss.

Despite the fact that bone loss is an obvious problem, which must be addressed, there are several countermeasures currently being tested and used to combat it. The most common countermeasure, also used to battle muscle atrophy, is a rigorous exercise program. The stresses imposed on the bones as a result of exercise seem to be very effective in at least diminishing bone-loss. Cosmonaut Polyakov, upon returning from his 438 day mission, showed incredibly almost no bone loss at all. It was well known that he was an extremely fit individual who constantly engaged in vigorous exercise. Still, he is considered an exception to the rule as there are many accounts of HDT studies in which fit individuals exhibit greater bone-loss than their non-fit counterparts. Thus, it seems that while the loss of bone mass could be a serious potential hazard in long duration space flight, current missions have become increasingly successful in counteracting this problem.

**Muscle Atrophy**

Similar to bone loss, when a person is removed from the forces of gravity, their muscles begin to deteriorate. The explanation is fairly obvious in that there are many muscles are just not used in a microgravity environment. The legs and back no longer have to support the weight of the body and lifting objects become much more easy since everything is essentially weightless. Additionally, long-term space missions typically confine humans to a small
space and, thus, ordinary movement is vastly restricted.

There have been successful results obtained from using countermeasures, just as in bone loss. The Russians are sold on using intensive treadmill/resistance training to keep muscles from atrophying. According to the IBMP, “Measurements show that even in the first seven days of space flight, muscle loses about 40 percent of its strength, but it can regain its original strength after the first month using effective countermeasures.” The amount of muscle loss seems to be correlated to the type and extent of the countermeasure rather than on the duration of the mission. The use of lower body negative pressure (LBNP) to counteract both muscle and bone loss has been extensively tested in both the U.S. and Russia with encouraging results.

Fluid Reduction

On Earth, the body is accustomed to having gravity force fluid downward. When this force is removed, fluids begin to pool in the upper part of the body and diminish in the lower portion. This leads to puffy heads, swollen facial features, and reduction in leg mass. In itself, this is not of significant concern, because after only a few days, the body readapts to the new environment. Unfortunately, as a result of this fluid shift, there is an overall fluid loss is observed. U.S. astronauts have been reported to lose from 10 to 23 percent, while the total fluid volume of Russian cosmonauts has decreased from 10 to 20 percent. The major concern associated with such a loss of fluid is upon reentry, when extreme G-loading is prevalent. The fear of a possible stroke or hemorrhage exists, due to the adaptation of the body to the microgravity environment. Currently, it is common for both astronauts and cosmonauts to load up with fluids prior to re-entry in order to reduce the risks associated with fluid loss.

There have also been several bed-rest/HDT studies done which support the notion of overall plasma and blood reduction in the body. In one such study, there was observed a 16% reduction in the plasma volume after only 16 days of HDT. The subjects then performed a simple exercise with their lower legs (basically with the leg fixed, they had to rhythmically press down with the front of the foot on a pedal) until they could not continue. Interestingly, within 24 hrs, the plasma volume returned to levels before subjects were placed in HDT. Again, these effects have the potential to be dangerous, but it seems that countermeasures are currently sufficient.

Psychological Effects

Probably the most interesting of all symptoms are the psychological effects associated with long-term space travel. Scientists are slowly discovering that many of the changes associated with space flight may be less related to microgravity and more to the mental well-being of the astronauts. For example, it has been well documented that astronauts and cosmonauts have a reduced number of white blood cells upon post-flight analysis. Initially, and to some extent still today, it is believed to be a natural reaction to microgravity; similar to a reduction in red blood cells, bone mass, etc. However, there have
been several studies on Earth demonstrating a direct correlation between stress and white blood cell reduction. The high demands associated with space travel could easily induce enough stress to eliminate the conjecture that microgravity has anything to do with this.7

Though much is understood or at least predictable about the physical responses to microgravity, there is not nearly the focus on psychological research. With longer missions becoming more and more prevalent, it is an area which must be addressed. Looking at previous space missions, one can easily see why such studies are justified.

In 1976, two Russian cosmonauts set to break the endurance record, then at 63 days, but had the mission had to be ended early because the cosmonauts couldn’t get along. At this point, the IBMP realized this was an area of concern and began to study “behavioral and psychological reactions of small groups of people in confinement in different situations.” They have conducted compatibility studies between men and women. Even recently though, on 31 Dec 99, while undergoing isolation training two Russian cosmonauts broke into a fistfight and later one upset a female Canadian crewmember to the point where the hatches between the Russian and international crew’s living quarters were sealed.9

In a mission to Mars, the crew will have to undergo confined space with the same people, homesickness, and a more than 8 minute delay with Earth communications. A significant portion of each day will be spent performing very mundane tasks. The thrill of journeying to another planet will almost certainly wear off rather quickly. Their will be no familiar moon or even the Earth to look at once on Mars, and the landscape is void and plain. But unlike any space mission in the past, the crew will be unable to come back to Earth within a matter of hours or days. The May 2001 edition of Discover magazine even speaks of new technology being developed that would allow computers to monitor the mental health of the crew. All in all, the psychological effects involved in a long-term space mission is something that must, and increasingly is, be addressed.

**Conclusion**

The risks associated with prolonged radiation exposure, changes in the respiratory system, and several other issues were not even addressed in this report, simply because it is generally agreed that their effects are of minimal concern. In conclusion, the director of the Institute of Biomedical Problems in Moscow, Dr. Anatoly Grigoriev, puts it best in stating, “actually we don’t have [medical] restrictions on the duration of spaceflight.” On the contrary, there are definitely psychological concerns that must be addressed. Initially, this report was not intended to even touch on this aspect of a long-term space mission. However, it seems that for such applications, there is far less known about the emotional and mental health of humans than there is physiological well-being. As we continue to strive for successful journeys farther into space, there is much to be learned about our behavior here on Earth.
References


