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Paper Session I-C - An Update on Zero Gravity effects on Human Space Flight and a Progress Report on Artificial Gravity Experiments

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AN UPDATE ON ZERO GRAVITY EFFECTS ON HUMAN SPACE FLIGHT AND A PROGRESS REPORT ON ARTIFICIAL GRAVITY EXPERIMENTS

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ABSTRACT

The future commercialization of space will require increased human presence. This is due to the risk and complexity associated with the manufacture, assembly, operation, maintenance and modification of facilities in space. This human element is a natural outgrowth from the discovery and exploration stages to the habitation phase of space. However, for mankind to be successful in this endeavor, we must build space vehicles and facilities that reflect our “natural” earth environment - when possible. One of those critical environmental factors is gravity and its associated role in the health, orientation and mobility of living organisms. International space flight experience over the past thirty-six years has provided volumes of medical research data on the near term and projected long range effects of micro-gravity on humans. Unfortunately, this analysis is widely scattered in government research libraries, databases and bookshelves around the earth in English, Russian, French, German, Italian and Spanish. Also, these reports are written in highly technical and statistical terms and as such, the results of years of analysis, millions of research dollars and difficult training remain hidden from the general public (who ultimately pay for our space efforts) and the beginning researcher. This paper reviews that research - as currently available from both the Russian and United States manned space programs. Specifically, this paper focuses on the zero-gravity effects on the physiological make-up of man. These effects play a key role in our ability to cope with the detailed and myriad tasks in space.

As an addendum, this paper reviews our present understanding of gravity, gravity waves and various nations’ efforts around the world to create artificial gravity on past, present and future space vehicles.
INTRODUCTION

Since April 12, 1961, when Yuri Gagarin (the first man and Russian) was placed in a low earth orbit from the launch site in Tyuratam, a parade of international astronauts and cosmonauts have logged hundreds of thousands of hours in earth and lunar orbits. Along with these human travelers, man has sent various other living organisms into that harsh void of space. Included in the list of space travelers are plants, bacteria, insects, eggs and small animals. All of these varied passengers have taught us many valuable lessons about man’s adaptability and resourcefulness. Of all the earth’s environmental elements of which man is accustomed (heat, air, water, food, motion and protection from the vacuum, extreme temperature changes and solar radiation in space) the understanding and control of gravity have, at least until now, eluded him. It is perhaps because of this lack of understanding and control that national space medical research teams have placed the majority of their funding and research. Zero-gravity is a prime design consideration (and cost factor) for space vehicles and facilities, and has provoked the most debate as to its significance for the long term presence of man in space. This paper was written with those concerns and the general public in mind. It is hoped that this summary paper will provoke a renewed interest and effort to uncover the fundamental properties of gravity and its control.

SUMMARY OF HUMAN MICRO-GRAVITY EXPOSURE

Let us first review the combined American and Russian manned space programs (since they are currently the only nations with an operational manned space launch capability). This will help us better understand and appreciate the opportunities that have been available to explore the effects zero-gravity on living organisms. This is summarized in Table 1 below. This data represents the available mission information through February 1, 1996. This summary does not include research from sub-orbital flights, simulated low gravity experiments on earth or lunar surfaces, the time from launch to achieve low earth orbit (approx. ten minutes) or the time from de-orbit burn to landing (approx. one hour). These later corrections were based on a typical United States Space Shuttle mission profile.

On previous flights (along with the Russians and Americans) the following nationalities were represented:

<table>
<thead>
<tr>
<th>Canada</th>
<th>France</th>
<th>Saudia Arabia</th>
<th>W. Germany</th>
</tr>
</thead>
<tbody>
<tr>
<td>ESA</td>
<td>Mexico</td>
<td>Italy</td>
<td>Japan</td>
</tr>
<tr>
<td>Czechoslovakia</td>
<td>Poland</td>
<td>E. Germany</td>
<td>Bulgaria</td>
</tr>
<tr>
<td>Hungary</td>
<td>Vietnam</td>
<td>Cuba</td>
<td>Mongolia</td>
</tr>
<tr>
<td>India</td>
<td>Syria</td>
<td>Afghanistan</td>
<td>UK</td>
</tr>
<tr>
<td>Austria</td>
<td>Romania</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

prior to 2/96
### TABLE 1.

**Summary of Human Micro-Gravity Exposure Opportunities From April, 1961 to February, 1996**

<table>
<thead>
<tr>
<th>Years</th>
<th>American Launches</th>
<th>Russian Launches</th>
<th>Grand Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Launches</td>
<td>No. of Astronauts Launched</td>
<td>Total Days of Micro-Gravity Exposure</td>
</tr>
<tr>
<td>1961-1965</td>
<td>11</td>
<td>18</td>
<td>56</td>
</tr>
<tr>
<td>1966-1970</td>
<td>12</td>
<td>31</td>
<td>186</td>
</tr>
<tr>
<td>1971-1975</td>
<td>8</td>
<td>24</td>
<td>676</td>
</tr>
<tr>
<td>1976-1980</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>1981-1985</td>
<td>23</td>
<td>118</td>
<td>791</td>
</tr>
<tr>
<td>1986-1990</td>
<td>14</td>
<td>74</td>
<td>412</td>
</tr>
<tr>
<td>Present</td>
<td>1</td>
<td>6</td>
<td>(60)est.</td>
</tr>
<tr>
<td>Sub Total</td>
<td>105</td>
<td>489</td>
<td>4,552est.</td>
</tr>
</tbody>
</table>

Grand Total No. of Launches = (184)est.
Grand Total No. of Crew Members = (671)est.
Grand Total No. of Days Exposure = (17,566 days or 48 years)est.
PREDICTED WEIGHTLESSNESS EFFECTS

In 1958, before any manned launches took place, the National Research Council Committee on Bioastronautics met and identified various potential problems for future astronauts. Those concerns were later expanded to the list in Table 2 below. These concerns were largely based on past military and test flight experiences (including the X-15 test flights - some of which reached “space” altitude above 62 miles (FAI definition)).

Table 2.

Medical Concerns for Astronauts
(pre-manned space programs)

<table>
<thead>
<tr>
<th>Concern</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anorexia</td>
<td>Deminerlization of bones</td>
</tr>
<tr>
<td>Nausea</td>
<td>Renal calculi</td>
</tr>
<tr>
<td>Disorientation</td>
<td>Motion sickness</td>
</tr>
<tr>
<td>Sleepiness</td>
<td>Pulmonary atelectasis</td>
</tr>
<tr>
<td>Sleeplessness</td>
<td>Tachycardia</td>
</tr>
<tr>
<td>Fatigue</td>
<td>Hypertension</td>
</tr>
<tr>
<td>Restlessness</td>
<td>Hypotension</td>
</tr>
<tr>
<td>Euphoria</td>
<td>Cardiac arrhythmias</td>
</tr>
<tr>
<td>Hallucinations</td>
<td>Postflight syncope</td>
</tr>
<tr>
<td>Decreased G tolerance</td>
<td>Decreased exercise tolerance</td>
</tr>
<tr>
<td>Decreased exercise capacity</td>
<td>Gastrointestinal disturbance</td>
</tr>
<tr>
<td>Reduced blood volume</td>
<td>Urinary retention</td>
</tr>
<tr>
<td>Reduced plasma volume</td>
<td>Diuresis</td>
</tr>
<tr>
<td>Dehydration</td>
<td>Muscular incoordination</td>
</tr>
<tr>
<td>Weight loss</td>
<td>Muscle atrophy</td>
</tr>
<tr>
<td></td>
<td>Infectious illness</td>
</tr>
</tbody>
</table>

Dietlein, 1977

ACTUAL PROJECT FINDINGS

NOTE:

The formal reports from space research (at least from the American programs) generally take several years to compile, verify and publish. For example, the Skylab program ended in 1973 with the Skylab 4 mission, however, the medical report (NASA SP-377) was not released until 1977. The delay could be even longer if a translation is required. Also, space research generally is not found in popular publications. They are usually found in NASA libraries under a SP (special publication) number- but not always will it be “SP” - it could also have some other prefix. A NASA database search first needs to be
done by subject title - like “micro-gravity” to get a listing of the prefixes and numbers. As an example, in the NASA KSC library there were (as of February, 1996) 6,618 “hits” in their research database on the word “micro-gravity” and over 540 hits on the word “artificial gravity”. The following is a snapshot of the major American space programs and their medical findings. See the reference section at the end of this paper for additional sources.

**Mercury**

The major medical findings were “.. initial weight loss due to dehydration and some impairment of cardiovascular function. Also, the final and longest Mercury flight had shown some orthostatic intolerance and dizziness on standing as well as hemoconcentration.” (NASA SP-4003).

**Gemini**

- Loss of red cell mass (ranging from 5 to 20% from baseline)
- Postflight orthostatic intolerance in 100% of crew
- Loss of exercise capacity compared with preflight baseline
- Loss of os calcis bone density (7% from baseline)
- Sustained loss of bone calcium and muscle nitrogen
- Higher than predicted metabolic cost of extravehicular activity
  
  (NASA SP-121)

**Apollo**

- Vastibular disturbances
- Less than optimal food consumption (1260 to 2903 kcal/day)
- Postflight dehydration and weight loss (recovery within one week)
- Decreased postflight orthostatic tolerance (tilt/LBNP tests)
- Reduced postflight exercise tolerance (first three days)
- Apollo 15 cardiac arrhythmias (frequent bigemini)
- Decreased red cell mass (2 to 10%)
  
  (NASA SP-368)

**Skylab**

- Significant increase in the excretion of urinary calcium for full duration of flight
- Bone mineral loss on lower extremities (comparable to bedrest studies)
- Cardiovascular reconditioning for first four to six weeks
- Severe motion sickness on second flight
  
  (NASA-377)

What is interesting is that even though the Russian medical tests were designed under a different agenda and using different equipment and methodologies, their findings have generally agreed with American results. From both programs, the principal thrust of today’s biomedical research in space is focused around these four areas:
**CURRENT COUNTERMEASURES AND THEIR EFFECTIVENESS**

To combat the physiological effects of weightlessness, the American and Russian space programs have followed similar overall medical strategies:

1. A complete medical screening process in selecting candidates
   - This currently includes: medical history, physical exam, cardiopulmonary eval., musculoskeletal eval., radiographic eval., lab exams, otorhinolaryngologic (ENT) exams, ophthalmologic eval., dental exam, neuralgic eval., psychiatric and psychologic evals., and others
2. A strong biomedical training program
   - This includes classroom instruction, computed assisted training, simulator and mockup training, clinical settings and simulated-microgravity training
3. On-orbit exercises - geared to the individual’s needs
   - This includes treadmill, cycle-ergometer trainer, minigym, spring set, the “penguin” suit, LBNP devices, anti-gravity suits, seatless rowing device, electrostimulation
4. Use of medications (especially for motion sickness)
   - This includes injectable drugs, oral drugs and topical medications
5. Special diets
   - This area is still being explored. Various types of food have been tried and ideas are being explored all the time.
6. Constant biomedical monitoring of the crew

These measures have reduced the impact of some micro-gravity effects on the crews, but they have not eliminated all their concerns. One of the greatest concerns is loss of calcium in lower extremities (the weight bearing bones). More studies are needed in this area. There seems to be a leveling off point after an extended period of exposure. However, is the loss irreversible? This is one of the hot areas of debate today.

**Artificial Gravity**

Another approach that has had little attention and funding is the use of artificial gravity to reduce or eliminate the above medical issues. The technology is currently not available. However, if more focus could be put on this unchartered area, then perhaps a major breakthrough could be made. Little data is available on on-orbit attempts at generating artificial gravity. One such attempt occurred during the Gemini 11 flight in 1966 when a 100 ft. tether was used create a “dumbbell” effect between the Gemini and Agena crafts. For nearly 2 and 1/2 orbits a small (1/100th G) force was registered. Little more than the knowledge that gravity is an attractive force acting between two bodies is known about gravity. This is a rich area for exploration. It may be found that gravity is part of the electromagnetic spectrum, just as light, heat, x-rays, radio waves, etc. Other attempts to generate gravity in space include the use of devices that can create positive G forces, such as rotating chairs and railsleds. Of course the design of a rotating space station (like a wheel with spokes and a hub) is an old idea from the Von Braun era. An
idea that still needs to be evaluated. More research is also needed in the fundamental properties of gravity. Albert Einstein attempted to formulate a unifying theory between gravity, magnetism and electricity. He never finished that task. Maybe someone else will take up that challenge and create a breakthrough. One has to weigh the cost/benefits of creating gravity against the cost/benefits of working with a micro-gravity environment. Cost, weight, development time, space requirements and side effects; all have to be factored into the evaluation equation before a prudent decision can be made as to which approach is best. Currently, designing for a micro-gravity environment consumes more than half the development cost of a space vehicle.

CONCLUSIONS AND RECOMMENDATIONS

The American and Russian manned space programs have provided a rich medical database on which a clearer picture of the interplay between a micro-gravity environment and man can be drawn. Not all the answers are available. Not all the right questions have yet been asked. It seems clear, at least at this early stage of our understanding, that there are still certain physiological effects (such as loss of weight bearing bone mass, loss of red cell mass and space motion sickness) that need special research attention. Also, more effort needs to be made to answer the question whether it makes sense (or cents) to develop (artificial) gravity as an alternative approach to combating the physiological effects of micro-gravity during extended manned space flights.

NOTES AND REFERENCES

The following individuals have provided immeasurable service and critical information, for which the author is quite thankful: Dr. Effenauhauser, Dr. Jake Garland, Bill Muncey & Donna (NASA document research at KSC).


