Man's response to zero-g

Scientists now have a working hypothesis about the observed physiological effects of weightlessness. Better understanding will have to await next spring's Skylab mission.


NASA
Berry monitors astronauts' heart rates and O_2 use on moon.

by Everly Driscoll

Technologically, man is better prepared now to mount an international planetary expedition than he was 10 years ago to prepare for the moon. Political and economic considerations will probably continue to delay any such effort, but the other principal barrier is the inadequate knowledge of man's physiological and psychological responses to space.

Soviet research in space biology has had a high priority. U.S. biomedical investigations, in contrast, have been severely limited by the operational demands of lunar landings. (The guiding principle has been to get the men there and back safely.) Most of the biomedical instrumentation flown on Gemini and planned for Apollo had to be removed following the Apollo fire in 1967. Skylab, to be launched April 30 and May 1, 1973, will be the first intensive U.S. study of the body in space.

Currently NASA is conducting an experiment of paramount importance at its Manned Spacecraft Center in Houston. Called SMEAT (Skylab Medical Experiments Altitude Test), it is both an attempt to establish a medical baseline for Skylab, and a dry run of the medical instrumentation and equipment to be used. Three astronauts —Robert L. Crippen, William E. Thornton and Karol J. Bobko—entered an altitude chamber July 26 where they are scheduled to remain until Sept. 20. This simulates the longest planned Skylab mission of 56 days. All of the major biomedical aspects of Skylab are being duplicated except for weightlessness and the stress associated with space flight. Included are the same diets, atmosphere, rigorous work schedule, isolation, cabin temperature and cramped quarters.

Last week on their 35th day inside the chamber, the crew reported, almost in unison, that they all missed most their wives. Thornton, a physician, reported that he had observed few deviations from prechamber tests. Only one of the instruments, the metabolic analyzer, is believed not to be working according to specifications. "There have probably been slight changes related to keeping people closed in in a new environment," Thornton said. "There may be a barely detectable change in our cardiovascular conditions," he added, "and our limb sizes have decreased slightly." Both of these conditions were expected and are probably due to lack of the kind of movement and exercise that the crew gets on the outside. A nasal congestion one of the men had going into the test—"irritation due part and parcel to the Houston atmosphere"—had cleared up. The men were eager to continue the entire 56 days.

A total of 57 persons have spent 13,007 hours in the weightlessness of space. The longest flight was the ill-fated three-man Soyuz/Salyut mission in 1971, which lasted 24 days (SN: 8/12/72, p. 107). None of the drastic consequences predicted 10 years ago, such as hallucinations or euphoria, have occurred. "With few exceptions," says Charles A. Berry, director of life sciences at NASA headquarters, "adjustment to weightlessness has been virtually effortless."

But Berry adds that results indicate that man does pay a physiological price for adapting to zero gravity. (Relatively little research has been done on the psychological price.)

The price includes effects on the cardiovascular system, the bones and muscles, the body fluids, endocrine system and the nervous system:

- Cardiovascular deconditioning—a decrease in the ability of the heart and blood vessels to perform in normal earth gravity (1-g) after having adapted to weightlessness. Manifestations include increased pulse rate and decreased blood pressure when astronauts stand up in one-g after being in space.
- Loss of exercise capability—measured by amount of work done on a bicycle ergometer for a set heart rate and oxygen use.
- Lessened bone density and muscle tone—probably due to reduction of mechanical forces on weight. In spite of exercise, all crews, with the exception of Apollo 14, have appeared to lose bone density. (This depends on the technique used.) A breakdown of the muscle tissue shows up as increased nitrogen output over intake. There has been no indication of significant muscle atrophy in U.S. astronauts. After the 18-day Soyuz 9 flight, however, Soviet physicians noticed a deterioration in muscle tone and a diminished circumference of the lower extremities. M. A. Cherepakhin and V. I. Pervushin concluded that the longer the space flight, the more stressful adaptation to earth's gravity may be.
- Loss of body weight—probably a combined result of increased diuresis (in which body fluid is lost) and body-tissue loss. Only one astronaut, Alan B. Shepard, gained weight in space—one pound. Body-fluid loss occurs at the intracellular (inside the cell) level, as well as extracellular level.
- Plasma volume level loss—these losses have varied from zero up to 13 percent.
- Red blood cell mass loss—thought to be the result of the nearly 100 percent oxygen environment of some periods of Apollo flight, although this has not been verified as the sole cause. In the current SMEAT test, an atmosphere of 70 percent oxygen and 30 percent nitrogen is being used at pres-

sures one-third sea level—the same as on Skylab (SN: 7/8/72, p. 26).

- Decrease in heart size—probably due to the fact that, as with other muscles, the heart has to work less in weightlessness.
- Increase in leukocytes (leukocytosis)—believed due to stress and tension.
- Elevated catecholamine levels (a nerve transmitter related to hormones) —also probably due to stress.
- Increased renin activity. Renin is a kidney enzyme that acts to produce angiotensin which in turn increases blood pressure and stimulates the adrenal gland to secrete aldosterone. The exact mechanism of the cause of this renin increase is not completely known. It does respond to circulation changes in the kidney, to decreases in the extracellular fluid volume and to decreases in sodium. All of these occur during the body's adaptation to weightlessness, and ground-based studies are attempting to discern the exact quantitative and sequential role of this mechanism in compensating for the effects of zero gravity on the body.

The problem is made even more complex by the fact that biological responses vary from person to person. Scientists often test hundreds of subjects even to establish trends. The 57 men and women who have flown in space have had varied responses, making it difficult to establish norms.

For example, some astronauts have had a high metabolic expenditure (use of more oxygen), elevated heart rate and body overheating during activity outside the spacecraft. A few have briefly experienced motion sickness, a feeling of fullness in the head, stomach "awareness" and dizziness when turning the head. The Soviet cosmonauts seem to have more vestibular-related problems than the U.S. crews. Most astronauts have had initial problems sleeping, although this may be due more to external conditions such as engine firings, than any inherent aspect of weightlessness. Various crews have seen light flashes, probably due to cosmic-ray particles hitting the retina (SN: 5/30/70, p. 523). And finally, two astronauts of Apollo 15 had marked, but benign cardiac arrhythmias (irregular heart beats) in space.

None of these responses have been deleterious; none have interfered with the ability of the crews to perform in space. With the exception of Apollo 15 and the Soyuz flight, all crews have returned to preflight test values after two or three days back in earth's gravity. The effects appear to be reversible.

Physiologists have established a working hypothesis to account for most of the observed effects. The adaptation begins when weightlessness causes a reduction in weight of the long columns of blood in the body. This reduces pooling of blood in the extremities and concentrates greater amounts in the chest regions. There is then a change in the ratio of blood to air in the lungs. Increased amounts of blood return to the right side of the heart. This increases the volume in the right atrium and initiates a reflex stimulus (the Henry-Gauer reflex) to the pituitary gland. This reflex causes a reduction in the secretion of antidiuretic hormone; more urine is excreted. As urine flow increases, the adrenal gland is stimulated to increase the level of aldosterone, another hormone, probably due to the renin-angiotensin mechanism. Aldosterone causes the kidneys to retain sodium. But there is no observed system that causes the kidneys to retain potassium. Thus potassium is lost. The body has now entered a phase of electrolyte fluid imbalance. It is seeking to establish a new blood volume level that the reflexes indicate it needs. In addition to potassium losses, the lack of gravity also causes decreases in calcium, magnesium, chloride, nitrogen and phosphorus in the bones and muscles.

The heart irregularities of the Apollo 15 crew and the unusually long 15-day period required for them to return to preflight measurements caused a flurry of medical activity after the flight. NASA asked the National Academy of Sciences' space medicine committee headed by Edward Kass to set up a panel of experts to analyze the causes and to help establish a preventive program for future flights.

Both American and Soviet crews have had arrythmias in space. But these irregular beats have never occurred more than once or twice. The Apollo 15 cardiac arrythmias occurred during the lunar surface activity and on the return trip to earth. James B. Irwin, the lunar module pilot, experienced the first arrythmias—premature ventricular contractions—about 177 hours into the mission. Later he had 12 paired beats (bigeminal rhythm), and then premature auricular contractions. David R. Scott, the commander, experienced four premature ventricular contractions during sleep coupled with an abnormally low heart beat rate of 28. This was followed by premature auricular and ventricular contractions.

Ironically, by most accounts, the Apollo 15 crew was in the best physical condition of any crew flown. So other factors have to be taken into account to explain their deviations from the norm.

Scott and Irwin worked for 18 and a half hours on the lunar surface, twice as long as the Apollo 14 crew. They had difficulties with the surface drill that required a lot of energy. They did not get sufficient rest. Their work load was heavier in space than had been planned because of some operational difficulties. But these conditions in themselves would not have been enough to cause what was seen (although frequently arrythmias occur in students cramming for exams).

Berry thinks that the potassium deficiency may have been the triggering element, added to fatigue and stress. Low potassium levels are frequently seen in heart patients. Previous Apollo crews have lost two to three percent of their body potassium as a result of weightlessness. Studies using potassium 42 isotopes were conducted on the Apollo 15 crew. The results showed that Scott and Irwin lost 15 percent of their total body potassium; Alfred M. Worden, the command module pilot, lost 10 percent (he had no significant in-flight problems).

The body does not store potassium. Potassium has to be resupplied daily by intake of food and liquid. A normal diet varies from 70 to 150 milliequivalents (the value for a certain amount of potassium ions per given quantity of food or fluid) a day. An examination of the Apollo 15 diet revealed that crew's intake had been closer to 70 than 150 milliequivalents daily.

The body loses potassium through the Henry-Gauer reflex. But it can lose potassium by other mechanisms as well. Theoretically, if a person breathes 100 percent oxygen for a long time, he can get respiratory acidosis, in which the body retains carbon dioxide. The result is loss of electrolytes such as potassium. Biologists believe an intracellular exchange of potassium for hydrogen ions occurs when the body potassium level is lowered. Increased epinephrine (adrenalin) causes irritability to cells, as does potassium loss. When this cell irritability occurs in the heart, it can cause an electrical impulse that triggers a heart beat. Normally this impulse comes from the pacemaker (the sinoatrial node). If the electrical impulse comes from the auricle, for example, the beat is called a premature auricular contraction.

Working with the theory that a combination of factors including potassium loss caused the Apollo 15 anamolies, NASA set up a rigorous prevention program for the Apollo 16 crew. And it appears to have worked. The crew received potassium-enriched food and liquid in flight (105 to 135 milliequivalents a day), including the now famous orange drinks. Urine and fecal samples were collected in space and returned to earth. The 24-hour urines from flight showed significantly greater losses of potassium in the astronaut than similar collections on the ground.

Although these results tend to point toward loss of potassium as the cause of the arrythmias, scientists are hesitant to make this conclusion. "Other factors such as slow resting heart rates, fatigue, excitement, dehydration and individual variations very likely contributed," says Sherman P. Vinograd, director of biomedical research at NASA. "The extent to which each factor was causative cannot be discerned at this time."

In an attempt to simulate the space conditions that may have caused the problems, space biomedics conducted ground-based studies. These consisted of bed rest to simulate weightlessness, heavy work loads and a minimum of potassium intake. Although the potassium intake was severely restricted, the loss of exchangeable potassium similar to Apollo 15 was not reproduced. "We saw only a very few premature contractions and none of experimental significance over the control periods," says Vinograd.

The potassium-related problem is only one of many unanswered questions about space biology. The unknowns are endless. Only one astronaut, Frank Borman, for example, has worn an electroencephalograph in space to determine the depth of sleep and thus evaluate the effects of space on the nervous system.

Space medics do not fully understand the stomach "awareness" some astronauts experience. In most cases, the symptoms disappear after a few hours or days in space. But with Irwin a curious pattern developed. He had the condition until he reached the one-sixth gravity of the lunar surface. When he returned to weightlessness for the trip to earth, the condition did not return. But once he got back to one-g of earth, the symptoms reoccurred. "This is very difficult to explain," says Berry.

While scientists have meticulously analyzed these effects, they still do not understand their etiology—the mechanisms of the body that trigger these responses. Nor do they know at what point in time the effects would level off during space flight. Do the decreases continue? Do the bone and muscle deteriorations continue? The greatest unknown variable in all of this continues to be the influence of increasing flight durations on man's physiology.

These questions will be answered, in part, from Skylab. The SMEAT results should allow separation of other effects from those of weightlessness.

So far, space biology has resulted in a multiude of unpublicized spin-offs such as bio-instrumentation and miniaturization now in use in hospitals and research laboratories across the nation. Basic studies of the biological mechanisms, however, when they involve invasion of the body with sensors, are best done on animals. Thus while much ground-based space research on both man and animals continues, future study must eventually involve the observation of research animals in space by trained biologists.

Skylab should answer how and when this will be possible. □