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HEALTH EFFECTS of human spaceflight

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Health effects of human spaceflight

As sojourns in space grow longer, concerns about their effects on human health are increasing. The ISS serves as a flying laboratory where the responses of real people in a radiation-prone microgravity environment can be studied in real time. Observable changes, psychological as well as physical, are more prevalent and varied than scientists once believed, and some have come as a surprise to researchers.

by James W. Canan
Contributing writer

The international space station has emerged as the crucial testbed for human spaceflight to faraway places. Sending astronauts to Mars or anywhere else in deep space would be prohibitively risky, if not impossible, without the knowledge gained from ISS research on the physical and psychological effects of daunting, long-distance missions.

NASA's ISS-based human research program (HRP) is the only way for the agency to learn how astronauts react to weightlessness and isolation from Earth for months or years on end, how to counter the numerous ill effects of such unnatural conditions, and to determine whether crewed missions to Mars or other faraway places would be physically feasible. Given its problem-solving history, NASA most likely will be able to come up with countermeasures to negate or mitigate those effects, although nothing is certain.

The space station holds the key. "ISS research is providing incredibly critical data on human performance in the microgravity environment," declares William H. Gerstenmaier, associate administrator for NASA's Human Exploration and Operations Directorate. "We're finding that there are lots of things in the human body that react differently in microgravity. We've got to learn about all that now, so we don't go on a journey to Mars over a long period of time and discover that some things about our bodies don't work very well."

Diverse impacts

The effects of prolonged weightlessness and confinement are many and varied. NASA notes that space travel takes the human body—"a remarkably complex assembly of systems"—out of its natural habitat and puts it in "an unknown and sometimes harsh environment." The HRP is aimed at enabling astronauts to survive and fare well in that environment.

Major areas of research on spaceflight effects include bone density, muscle mass, cardiovascular and sensorimotor functions, immune systems, physical strength, vision, sleep deprivation, disorientation, and the effects of overexposure to radiation beyond Earth's atmosphere. The bodies of astronauts traveling long distances must be able to compensate for all such physiological and psychological effects. NASA is using data from this ISS research to devise compensatory countermeasures.

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Expedition 34 flight engineer Tom Marshburn exercises on a combined operational load bearing external resistance treadmill in the ISS Tranquility node.

Russian cosmonauts Anatoly Ivanishin (foreground) and Anton Shkaplerov participate in a crew health care system medical contingency drill in the Destiny laboratory. This drill gives crewmembers the opportunity to work as a team in resolving a simulated medical emergency onboard the station.

"You don't learn things about the human body in spaceflight without putting the human body in space," says John Charles, chief of the HRP's International Science Office. "Right now the international space station is the best and only way of keeping people in space for long periods of time."

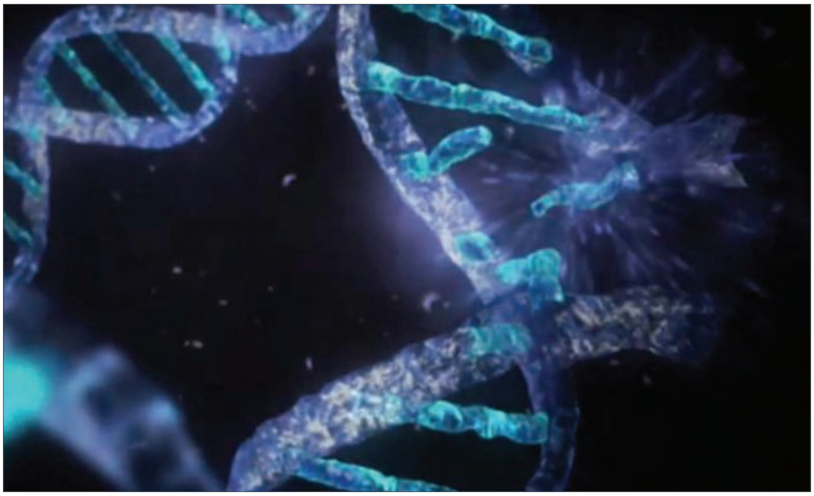
The ISS-based HRP should become even more meaningful in the near future. NASA and Roscosmos, the Russian space agency, will each send a crewmember—NASA astronaut Scott Kelly and Russian cosmonaut Mikhail Kornienko—on a year-long mission aboard the station in 2015. Throughout the station's 12 years in orbit, crewmembers typically have inhabited it for no longer than six months at a time.

The longer lasting ISS missions "will enhance our understanding of what really happens to astronauts in a confined and novel environment when they're far away from here and unable to interact for a long time with other people on the ground," Charles explains. The missions will give researchers a much better idea of when prolonged confinement, remoteness, and isolation from life on Earth become a psychological issue, and of how to deal with it.

Radiation and countermeasures

There is one outstanding and potentially insurmountable problem: the exposure of astronauts to radiation in space, beyond the natural protection of Earth's magnetic field and atmosphere. Spaceborne radiation derives from such sources as sunlight, the subatomic matter now known to be prevalent in space, and neutrinos. Radiation from solar storms is especially intense and potentially deadly, which is why predicting solar flares in advance of space missions is a high-priority requirement.

Human epidemiology studies of exposure to various doses of X-rays or gamma-rays provide strong evidence that cancer and degenerative diseases are to be expected from exposures to galactic cosmic rays or solar particle events.



Radiation destroys human cells by damaging their chromosomes. It is greater in LEO than on the ground because Earth's atmosphere no longer attenuates it, and it intensifies all the more beyond the protective reach of Earth's magnetic field. Research and understanding of radiation effects on astronauts are in early stages, but NASA knows enough to be cautionary and very concerned. Station astronauts have experienced the equivalent of eight chest X-rays per day, HRP researchers have found, and at some point, enough is enough.

"Right now, our limit for radiation exposure in flights is about nine months," Charles explains. "At that point, astronauts will have accumulated enough radiation to predispose them to an increased risk of cancer over their lifetimes beyond what we're willing to tolerate. It's not a purely biological limit; it's a policy limit decided upon by other [environmental and health-monitoring] agencies of government in conjunction with NASA. But it can be seen as a biological limit, because the basis of the policy is the biology."

A round-trip mission to Mars would take much longer than nine months. Russian and U.S. estimates of the elapsed time needed to reach the planet, do their jobs, and come home range from 16 months to 30 months respectively.

"In either case, there would be far too much radiation exposure," Charles declares. "We would have to speed up the trips or provide additional shielding to minimize the effects of the radiation, or provide metabolic or pharmacological countermeasures to offset the effects. That's an area of very active research within NASA and by all of our international partners involved in spaceflight."

Researchers aspire to countermeasures in the form of drugs that would prevent, greatly lessen, or undo radiation-induced damage to chromosomes. They also are exploring nutritional means of withstanding radiation, including food and drink—such as green vegetables and red wine—that are rich in antioxidants.

Nutrition concerns

Proper nutrition is a pervasive requirement for astronauts and a high-priority element in all aspects of HRP research. Learning how to preserve the food that keeps astronauts alive and healthy during and after long hauls in space is among the most important goals of space station research. The ISS accommodates research by the agency's Nutritional Biochemistry Laboratory on how spaceflight affects the nutrients in the foods stored onboard.

Scott M. Smith, the laboratory's lead scientist, has asserted, "If the radiation environment in space is causing the nutrients to break down in the foods before they're eaten, that could be catastrophic." All of the food that will be required during a Mars mission, he notes, will likely be transported to the red planet in advance of the astronauts' later arrival.

"If the crew gets there, and we find out all the vitamin C or all the folate or vitamin B12 has broken down, we've got a real problem," says Smith. Researchers learned a lot about nutrition issues on the Russian Mir space station in the 1990s and on Spacelab missions, he notes, "but there is still a lot to learn."

Senses and movement

The extended ISS missions scheduled for the near future should also provide much more data on sensorimotor system effects. NASA defines that system as a network including motor controls, parts of the nervous system, and the sensory organs—eyes, ears, and skin. It governs the body's ability to perceive and respond to the external environment, and to move about.

According to NASA, common sensorimotor issues the HRP has identified in spaceflight include diminished control of movement, changes in the ability to see and interpret information from the eyes, problems with spatial orientation, motion sickness, and difficulty walking. The longer the sojourn, the more intensely astronauts are likely to experience these symptoms.

"This pattern poses a significant challenge for future missions that will focus on long-term space exploration," a NASA paper says. It notes that methods of preventing and reducing sensorimotor problems include exercise regimes, along with self-assessment and self-adaptation measures now being devised by HRP researchers.

Psychological effects

As of now, researchers know more about the physical effects of living and working in protracted microgravity than they do about the psychological and behavioral effects, Charles notes. "We need to know: At what point does it become a psychological issue, and what have we done in the meantime to prepare astronauts against those psychological effects? So that's a big one," he says.

NASA has learned that sustained, seemingly endless spaceflight in the absence of change from night to day can be psychologically stressful, induce loss of sleep and anxiety, and affect the health, safety, and operational capability of crews. HRP studies are aimed at finding ways of keeping crewmembers motivated, cohesive, and productive while maintaining morale. HRP behavioral health researchers have developed environmental tools such as sleep-enhancing lights and monitoring devices that alert astronauts to the onset of abnormal behavior.

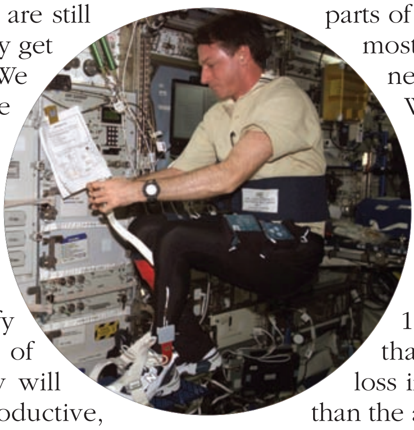
Astronauts often have a hard time sleeping and become overly excited. This brings on the 'hyperarousal syndrome,' a condition that is conducive to fatigue and loss of weight, concentration, coordination,

NASA astronaut Catherine (Cady) Coleman participates in the ambulatory monitoring part of the integrated cardiovascular assessment research experiment in the Kibo laboratory.

and cognitive function. Well managed workloads, adequate rest, ample leisure time, and regular radio contact with family and friends on Earth are among countervailing strategies prescribed by NASA.

Some experienced astronauts have contended that their earthbound controllers and communicators are a principal cause of their sleep deprivation, interrupting their slumber too often, changing their schedules on the fly, and otherwise disrupting their routines. As a result, they "are pretty confident that once spaceflight matures and we're not having so many alarms in the middle of the night, the problem will solve itself," Charles says.

It may come to pass that when astronauts are on their months-long journey to Mars, they will be out of touch with Earth much or even most of the time, and will settle into more regular sleep-and-work routines. "But what if they are still having problems when they get there?" Charles asks. "We want to make sure that the astronauts are well rested and well nourished and refreshed, because when they arrive, they will have to do very important work for a long period of time, working very hard to justify the monumental expense of sending them there. They will have to be extremely productive, otherwise the costs of their mission will be prohibitive, and people will say that sending them there was a bad idea."



Astronaut C. Michael Foale balances on the footplate of a special track attached to the Human Research Facility rack in the Destiny lab to perform foot/ground reaction forces during spaceflight/electromyography calibration operations. Foale is wearing the lower extremity monitoring suit, cycling tights outfitted with 20 sensors, which measures forces on joints and muscle activity.

Surprising visual effect

Visual impairment is one profound problem that comes as "a bit of a surprise" and is currently of prime interest to researchers, Charles observes. It seems to be caused by fluid shifting into the upper part of the body and causing intracranial pressure that distorts eyes and alters vision. This could prevent astronauts from reading checklists in the final phase of a long flight, with possibly disastrous results, and could make it impossible for them to perform their tasks once they land.

Astronaut Sunita Williams performs the health maintenance system PanOptic eye exam in the Harmony node. JAXA astronaut Aki Hoshide assists.

"It would have been shocking to have discovered the visual impairment effect enroute to Mars," Charles says. "The problem seems to become apparent three or four months into a mission on the space station—about the same length of time as when our astronauts are roughly halfway to Mars. And they would also have to worry about it getting progressively worse."

Loss of bone and muscle function

NASA researchers have found that certain parts of the human body respond almost immediately to weightlessness, other parts more slowly. While body fluids begin building up and sensorimotor systems start malfunctioning within hours or days of flight in microgravity, bones react sluggishly, losing density at the rate of only 1-2% a month. But even at that, the average rate of bone loss in microgravity is much faster than the average rate of 1-2% a year in elderly individuals on Earth, NASA says.

The Russian Mir space station reportedly has produced valuable data on bone loss, and the ISS is expected to provide even more. Scientists have not bothered measuring loss of bone density on ISS flights shorter than three or four months, because the loss is relatively minor. The longer ISS missions will allow for meaningful measurements.

Bones that support the body the most in gravity, notably the leg and hip bones, are those that lose density most quickly in microgravity. Prolonged spaceflight has been found to bring on other problems related to bone loss, such as increased risk of kidney stones, fractures, hip and spine issues, and impaired healing ability. NASA notes that HRP researchers are addressing such ill effects on several fronts, including the development and testing of pharmaceutical and nutritional countermeasures.

"Eating right and exercising hard in space help protect International Space Station astronauts' bones," a NASA paper says. It notes that exercising supports bone remodeling, a natural process in which normal, healthy bone constantly breaks down and renews itself.

Human research studies indicate that long-term missions in space, such as a flight to Mars, could reduce overall muscle function by nearly half, drastically raising the risk of injury and making crewmembers barely able to operate their spacecraft and perform other mission-related tasks.

This is another big reason why sustained exercise is considered imperative in the weightlessness of space. NASA has long observed that adherence to special exercise regimes before, during, and after spaceflight is necessary to maintain muscle mass by replacing the load that gravity normally imposes on the musculoskeletal system. Current HRP research is geared to improving and refining the exercises and equipment, including treadmills and mechanical restraints such as neck braces, that will enable astronauts to stay physically fit.

One idea that has been around for a while is to rotate a spacecraft continuously in flight to create artificial internal gravity. However, it might require engineering and technical advances too complex and costly to implement, by some accounts.

Cardiovascular and immune systems

Weightlessness threatens the cardiovascular system as well. "Even brief periods of exposure to reduced gravity environments can result in cardiovascular changes such as fluid shifts, changes in total blood volume, heartbeat and heart rhythm irregularities, and diminished aerobic capacity," states a NASA paper. It notes that such effects may linger when astronauts return to gravity, causing low blood pressure, fainting, and difficulty standing upright, a potentially big problem during and after landings.

"Heart muscle responds to the load being put on it, and when the load lightens, the muscle economizes because it no longer has to support a thick-walled heart, and there's a reduction of heart volume," Charles explains. "In general, the human body tries to economize its metabolism. If the body doesn't see a need to be expending metabolic energy on sustaining certain portions of itself, it expends the energy on other portions, or just produces metabolically useful energy in general."

To counter cardiovascular deterioration, the program has devised a protocol that combines physical exercise, balanced nutrition, and medication. Researchers are developing additional remedial and in-flight diagnostic measures as well, NASA says.

Cosmonaut Oleg V. Kotov collects medical data for the cognitive cardiovascular experiment in the Zvezda service module. Cardio-cog-2 will determine the impact of weightlessness on the cardiovascular and respiratory systems and the cognitive reactions of crews. The results of this study will be used to develop additional countermeasures to keep crewmembers healthy during long-duration space exploration.

Weightlessness tends to degrade the human immune system, defined by NASA as the complex network of organs, vessels, and highly specialized cells that protects the body from infection. A NASA paper explains that "immune system suppression seems to be a common problem in spaceflight, and because some bacteria and other microorganisms can be more dangerous in the space environment than on Earth, crew members may be at greater risk for contracting illnesses and diseases."

Space sickness

In the early stages living in near-zero gravity, the human vestibular system goes awry, causing astronauts to feel just plain bad and dysfunctional. When the vestibular system malfunctions, astronauts lose their sense of balance and spatial orientation, become disoriented, and can find it difficult even to locate their arms and legs. That system consists mainly of sophisticated sensors inside the inner ear, pressure receptors in the skin, muscles, and joints, and the senses of sight and hearing, all of which indicate motion and direction to the brain.

CSA commander Chris Hadfield uses the Human Research Facility pulmonary function system and the physiology module cardiolab leg/arm cuff system to conduct the first-ever session of this experiment. The test will help identify astronauts who could benefit from countermeasures before returning to Earth. This method has great potential for monitoring the health of the astronaut during future long-term spaceflights.

NASA astronaut Dan Burbank uses Neurospat hardware to perform a science session with ESA's PASSAGES experiment in the Columbus laboratory.

"This disorientation is the main cause of the so-called space adaptive syndrome, which one astronaut wryly described as 'a fancy term for throwing up,'" observes an ESA document. The malady, also called space sickness, includes headaches and poor concentration.

* * *

In the end, the many and diverse health effects of missions to distant planets or asteroids may prove altogether too difficult and too costly to counter, forcing decision makers to rely solely on robots for space exploration. Robots have done good work on Mars, for example, but many in the space community contend that humans could do it more quickly and efficiently. For those who must choose between people and machines for future space missions, the HRP program may well make all the difference.

One thing is certain: The international space station has become the sine qua non of preparations for human spaceflight far beyond Earth. "We won't be prepared to do Mars missions without the space station," Charles asserts. "Let's keep using it to prepare astronauts to go to Mars, or to decide if we can accommodate people" for such distant journeys.

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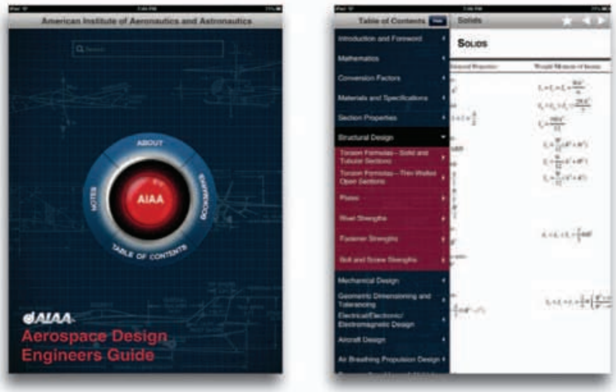

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