By Kim Tingley

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As an incubator of life, Earth has a lot going for it, something we often fail to appreciate fully from within its nurturing bounds. Merely sending probes and rovers to the moon and Mars won't do. For various reasons — adventure! apocalypse! commerce! — we insist upon taking our corporeal selves off-world too. Multiple private companies have announced plans to put hotels in space soon. NASA is aiming to 3-D-print lunar neighborhoods within a couple of decades. And while it will probably take longer than that to build and populate an outpost on Mars, preparations *are* being made: This summer, four NASA crew members began a 378-day stay in simulated Martian housing at the Johnson Space Center in Houston.

When you look at the renderings of these cozy dwellings, it's easy to lose sight of how hostile space is to Earthlings. As a reminder, consider what would happen if you found yourself in low Earth orbit or on Mars or the moon without a spacesuit on. You would pass out from a lack of oxygen within a matter of seconds, a condition known as hypoxia, and die soon thereafter. In the brief meantime, all the gases inside your body, including any air still in your lungs, would expand in the absence of external pressure. Depressurization would also cause your internal fluids to bubble. Not because they're heating up, but because they are transmogrifying into their gaseous state.

The temperature wouldn't be much of a problem, at least, even though thermometers in low Earth orbit produce readings from minus 85 degrees to 257 degrees Fahrenheit, depending on whether they are in shadow or in light. Space, as a near vacuum, has very little mass to conduct heat to or away from you, so you are not likely to feel instantly hot or cold.

While hypoxia is potentially a real threat should your space vessel or extraterrestrial habitat leak, it's a manageable one (assuming you haven't leaped naked out of your space capsule or off-world dwelling). But two other major challenges confront our fragile bodies when we leave our planet, neither of which has been entirely solved yet, even indoors: variable gravity and radiation.

Gravity is determined by the mass of objects and their distance from one another. Because Earth is so big, it is impossible, while on it, to escape its gravity for any serious length of time. As a result, we don't know very much about what our lives would be like without — or under some diminished influence of — this omnipresent attraction. On the moon and on Mars, which are smaller than our world, the gravitational tug will be much less: a sixth and a third, respectively, of what it is here.

Conversely, radiation exposure intensifies with elevation, because there's less atmosphere above you to block it. And you incur a much larger dose if you get beyond the protective bubble of Earth's ozone and magnetosphere, the magnetic field that stretches roughly 40,000 miles out at its most compressed point. The solar and galactic radiation that washes over Mars, which at its closest is 34 million miles away, will potentially be 700 times as great as what passes through our magnetic defenses. Space travelers beyond low Earth orbit will also be bombarded with high-energy atomic nuclei from exploding stars throughout the galaxy, which are normally deflected by the magnetosphere from reaching the surface of our planet; those particles are so heavy and moving so fast that they penetrate spaceships, spacesuits and skin, banging into other particles in their path and damaging any attendant cells in ways researchers are only beginning to understand.

So far, most of what we know about the effects on the human body of these threats comes from astronauts in low Earth orbit, and because safety is a paramount concern, we don’t send many of them up there, and we don’t let them stay for long when we do. Six months is the average length of a visit to the International Space Station, and fewer than 300 people have made the 250-mile voyage.

While that collective experience is enough to have taught us how the body responds when gravity’s pull is substantially reduced, the magnetosphere still shields the I.S.S., and only the 24 astronauts who flew in the Apollo program have gone beyond it. (The moon orbits an average of more than 238,000 miles away.) Though these two dozen astronauts spent little more than a week at a time without its protection, they have died of cardiovascular disease at a rate four to five times as high as that of their counterparts who stayed in low Earth orbit or never entered orbit at all, which suggests that exposure to cosmic radiation might have damaged their arteries, veins and capillaries.

We can't send people to Mars, or to live on the moon, until we can be reasonably confident that they'll survive getting and residing there. But the space-based medical science needed to make that possible has been hindered by small sample sizes that aren't representative of the general population. (All of the Apollo astronauts were white men born between 1928 and 1936.) Space tourism, though, promises to offer opportunities to study the effects of radiation and low gravity on a much broader demographic than "really well-selected superpeople," as Dorit Donoviel, the director of the Translational Research Institute for Space Health (TRISH) at the Baylor College of Medicine, describes those who have historically qualified to leave the planet. "Old, young, pre-existing health conditions — we are starting to gather a knowledge base that in the future will be essential even for NASA," Donoviel told me, "because we have to learn about the edge cases to really understand what is going on in our bodies to adapt to a hostile environment. You don't learn as much from people who are healthy. It's when people get sick that you understand how people get sick and how to prevent it."

Epidemiologists face the same predicament on Earth: Before they can figure out how to protect the population, they must wait for harm to come to enough people to expose the causes. As less-rigorous medical screening allows more tourists to reach space, the chances increase significantly that someone will get hurt or have a health emergency there. Aerospace medicine is one of three specialties certified by the American Board of Preventive Medicine, because surgeons for a given flight tend to be stuck on the ground; they have to optimize the health of their patients and ward off potential disasters *before* departure. The problem is, they can't know what those disasters will be until they occur. Which means that, as with every expedition into the unknown, at some point some intrepid or desperate souls are just going to have to blast off and see what happens.

Scientists once predicted that we couldn't live in the absence of Earth's gravity. Without this still-barely-understood force pulling us downward, how would we swallow? Wouldn't our tongues loll back into our throats? Wouldn't we choke on our own saliva? And if we survived those perils, wouldn't escalating pressure in our skulls kill us after a week or so? But when Yuri Gagarin returned from his single, 108-minute orbit around our world in 1961, humanity's first trip beyond the mesosphere, he proved that our internal musculature could maintain our vital functions in conditions of weightlessness. He ate and drank up there without difficulty. Technically, he hadn't escaped Earth's influence; to orbit is to free-fall toward the ground without ever hitting it, and he was in a condition known as microgravity. This felt, he reported, "like hanging horizontally on belts, as if in a suspended state," a circumstance passingly familiar to anyone who has been on a roller coaster or jumped off a diving board. Gagarin said he got used to it. "There were no bad sensations," he added.

Either Gagarin was fibbing, or he had a strong stomach. Initially, many space travelers puke, or at least feel motion-sick — space-adaptation syndrome, or S.A.S., is what such nausea, headache and vomiting are called outside our atmosphere. "It's the same as sitting in the back of the car in childhood, reading something with your head down," says Jan Stepanek, director of the aerospace-medicine program at the Mayo Clinic in Scottsdale, Ariz. "It's a mismatch of what the eyes are seeing and what the inner ear is telling you." Only in this case, that mismatched perception is a result of the organs and hairs of the vestibular system floating free without their usual gravitational signals. You acclimate eventually. In fact, researchers only learned about the prevalence of S.A.S. symptoms in the 1970s, when they heard Skylab astronauts talking about it with one another over a hot mic. Astronauts, it turns out, are not ideal subjects for medical study, because they are notoriously stoic and unforthcoming about any symptom that might ground them.

On Earth, your body maintains your blood pressure such that enough oxygen reaches your organs and waste is ferried away. One of the biggest oxygen users — your brain — is positioned above your heart for much of the time you are awake. But microgravity suddenly stops pulling blood downward into your legs, just as lying down or getting into a pool does, except more so. That lets blood collect in the upper body, triggering pressure sensors in your heart and the carotid vessels of your neck, which then send hormonal instructions to urinate more and decrease blood production. (This is why you often feel the need to pee shortly after climbing into bed or sinking into a body of water.) On our planet, that's usually enough to reduce your blood pressure and rebalance the system.

In microgravity, however, the blood volume above your neck will most likely still be too high, at least for a while. This can affect the eyes and optic nerves, sometimes causing permanent vision problems for astronauts who stay in space for months, a condition called spaceflight-associated neuro-ocular syndrome. It also causes fluid to accumulate in nearby tissues, giving you a puffy face and congested sinuses. As with a bad cold, the process inhibits nerve endings in the nasal passages, meaning you can't smell or taste very well. (The nose plays an important role in taste.) The I.S.S. galley is often stocked with wasabi and hot sauce.

These sensory deficits can be helpful in some respects, though, because the I.S.S. tends to smell like body odor or farts. You can't shower, and microgravity prevents digestive gases from rising out of the stew of other juices in your stomach and intestines, making it hard to belch without barfing. Because the gas must exit *somehow*, the frequency and volume (metric and decibel) of flatulence increases.

Other metabolic processes are similarly disturbed. Urine adheres to the bladder wall rather than collecting at the base, where the growing pressure of liquid above the urethra usually alerts us when the organ is two-thirds full. "Thus, the bladder may reach maximum capacity before an urge is felt, at which point urination may happen suddenly and spontaneously," according to "A Review of Challenges & Opportunities: Variable and Partial Gravity for Human Habitats in L.E.O.," or low Earth orbit. This is a report that came out last year from the authors Ronke Olabisi, an associate professor of biomedical engineering at the University of California, Irvine, and Mae Jemison, a retired NASA astronaut. Sometimes the bladder fills but doesn't empty, and astronauts need to catheterize themselves.

The longer astronauts stay in microgravity, the more they change. Because they don't need to support any weight, bones and muscles begin to atrophy — much faster than they do in advanced age on Earth. Bone density in the hips and spine can decrease by 1 to 2 percent per month in space, compared with 0.5 to 1 percent per year in elderly Earthlings. The calcium that leaches from the bones is expelled in urine, increasing the risk of kidney stones. Muscle mass ebbs, too: Astronauts must exercise vigorously for more than two hours a day to keep in decent shape. (They also must constantly dab their skin with a towel while doing so, to prevent their sweat from beading and floating into colleagues or equipment.) The discs between their spinal vertebrae spread farther apart — astronauts grow taller, but their lower backs hurt. The body's sensors that on Earth raise our blood pressure when we stand up from lying down, so that we don't faint, grow lazy with disuse. This degeneration, along with reduced muscle mass, is why astronauts must be carried from their capsules when they return to terra firma after a long mission.

The body recalibrates to normal. But protracted stays in microgravity (the current record, 437 days, was set by the Russian astronaut Valeri Polyakov in 1995) make for painful recoveries. After 340 days in space, Scott Kelly, a NASA veteran of three previous shorter missions, described the period immediately following his return as "much, much worse" than those of earlier trips: "All of my joints and all of my muscles are protesting the crushing pressure of gravity," he wrote in his 2017 memoir, "Endurance." (Legend has it that Polyakov, for his part, strolled out of his capsule unfazed, bummed a cigarette from a friend and started smoking.) Of course, "recovery" in this case — in every case, so far — means reacclimating to Earth's pull. But what if you never come back and, instead, stay in orbit or on the moon or Mars for the rest of your life?

If you spin a bucket of water around your head fast enough, the water doesn't spill out. The same physics underpin most plans for creating what is colloquially referred to as artificial gravity. In those scenarios, the space travelers are the water. The tricky part is that the speed at which you spin them must be faster the closer they get to the axis. In other words, you can have either a gigantic spacecraft that rotates slowly or a small one that rotates rapidly. Engineering and transporting such an apparatus into low Earth orbit has so far not been a major priority for government agencies. It's much easier and cheaper to give astronauts tools to manage their weightlessness.

But just because NASA hasn't used spinning vessels to simulate gravity doesn't mean it's not possible, says Rhonda Stevenson, the chief executive of Above Space. Once it raises the necessary funding, her company plans to put a small luxury hotel into orbit within five years and have a larger facility operational within another 10 years. In renderings, these establishments look like giant gears with rooms in their cogs. "Folks don't realize where we are right now and how technologically advanced we are today," she told me.

Stevenson's priorities, like those of other space-tourism operators, are oriented toward fun and comfort, not forbearance and science. Astronauts never complain, but paying guests love an excuse to leave a one-star review. (Especially when they'll be shelling out millions for a weekend stay.) In other words, there must be amenities and flush toilets (a contraption whose evolution was also guided by gravity). “Nobody wants to go up there and be lonely and eat algae paste and crickets,” Stevenson says. “That just doesn’t sound like a good time.”

Image

Credit…Illustration by Max Guther

Eventually such wealthy vacationers will want somewhere to go — a space mall, a mini-golf course — and they’ll want cosmopolitan cuisine. Stevenson and others predict that commercial parks, factories and farms will all be built in space to meet their demands.

The hospitality industry is not the only one with space aspirations. Chemistry and drug discovery might thrive there: Crystals, like those used in pharmaceuticals, grow bigger and more symmetrically in microgravity. There are ambitions to mine the moon for rare metals. Solar-energy production could flourish in the absence of weather. And astrobotany, which will be needed to supply space settlements with fresh food, could eventually grow crops and send them back to Earth. In one experiment, wheat plants grew 10 percent taller in microgravity.

When that day comes, whether you're in space working or vacationing, tuning your gravity could become part of your 9-to-5, like adjusting your thermostat. You might spend your workday in microgravity. Then you might go for a jog or just rest in 1 g. Maybe as you age and your joints start aching, you move to rooms in 0.75 g, where gravity is tempered just enough to put the spring back in your step. Senior living — in space!

Even if gravity doesn't prove quite so easy to supply as envisioned, weightlessness would mostly be just an inconvenience for the few hours it takes to get into low Earth orbit or the few days' flight to the moon. But getting to Mars or back again will, at least at first, most likely require living in microgravity for more than a year. This raises physical concerns: Will those astronauts be able to stand up when they arrive? If they can stand, will they pass out? If they pass out, will they break a bone? And if they break a bone, will it heal as it would on Earth?

Researchers understand even less about astronauts' neurological states and whether cognition is affected by the pressure that fluids shifting headward put on the brain. "Few of the NASA astronauts want to volunteer to stick a needle in their brain or eye to measure pressure while in space," Donoviel says. "It's a risk. And they are afraid we might find something that might prevent them for medical reasons from being able to fly. We've had this experiment on the books for years."

Researchers are hoping that commercial-spaceflight passengers will be more amenable to volunteering for experiments, like having a new kind of pressure transducer surgically implanted inside their skull in the months before takeoff. If the device works as expected, it will answer longstanding questions about the impacts of microgravity inside the cranium. And it might also lead to insights that could help parents and doctors treat babies with hydrocephalus, a neurological disorder caused by a buildup of cerebrospinal fluid in ventricles deep within the brain.

Scott Kelly's mission on the I.S.S., nearly a year long, was designed to learn what might happen to astronauts during a flight to Mars. It took advantage of a unique scientific opportunity: Kelly has an identical twin brother, Mark Kelly, a retired astronaut and now a senator from Arizona. While Scott Kelly went to space, a genetic replica of him (or close to it) stayed behind; when he returned, researchers compared the two men at a molecular level to see what had changed in Scott but not in Mark. Soon we might be able to do this kind of experiment by using stem cells from an astronaut's blood to grow mini-organs that can be exposed to high levels of radiation or microgravity in space, which should show how the astronaut's actual organs would react to off-world living. "Our thinking was, in the future, each astronaut could give us a few milliliters of blood, and we could make a platform for each individual," Gordana Vunjak-Novakovic, a professor of biomedical engineering and medical sciences at Columbia University, told me.

Space appeared to remodel Scott Kelly in subtle but perhaps significant ways. He incurred a small amount of DNA damage, believed to be caused by radiation exposure. (Astronauts' radiation doses are tracked over their lifetime; if these become too high, they can no longer go to space.) He also experienced epigenetic changes, modifications in how genes are expressed that can be heritable, a feature that helps humans and other creatures preserve useful adaptations without waiting for evolution to do its brutal work. Those alterations, which reverted nearly to their baseline state after Kelly's return, gave scientists a sense of what genes might be most impacted by lengthier stays in space.

One of the most puzzling changes researchers observed was in his gut microbiome, as the community of bacteria, fungi and viruses that live in the digestive tract is known. The species of bacteria were the same, but their proportions in relation to one another had shifted considerably, probably in part because the food Kelly ate was quite different. Such rearrangements among the micro-organisms could be a cause for concern, because they are involved in digestion, metabolism and immunity, and changes to their composition have been associated with neurological and physiological conditions. Reduced immunity could be especially dangerous in space, where microgravity also appears to cause bacterial cell membranes to thicken and make bacteria more resistant to antibiotics and more likely to cause severe disease.

There will, of course, be surprises out there, some of them sure to be quite unpleasant. Jan Stepanek at the Mayo Clinic points out that scientists once thought blood clots were very unlikely to occur in the absence of Earth's gravity. But then one appeared. In fact, in a 2019 study, an international group of researchers reported that the blood flow in the jugular veins of six of 11 I.S.S. crew membersthey monitored had, by around Day 50 in space, either stagnated or reversed direction — and one of the six had a potentially fatal thrombosis with no symptoms. Luckily, physicians had already stocked the I.S.S. with a 40-day emergency supply of anticoagulants, among other medications, just in case.

Space-medicine experts are adept at imagining dire scenarios. "What if somebody develops appendicitis?" says Natacha Chough, an emergency medical physician and professor of aerospace medicine at the University of Texas Medical Branch. "If we go to Mars, you can't pull a U-turn. Do you send a surgeon? What if *they* are the one who gets appendicitis?" She and other flight surgeons are mindful of the case of a 27-year-old Soviet doctor, Leonid Rogozov, who in 1961 had to give himself an appendectomy at a base that he and a team of 11 others built in Antarctica. He did it by feel, after finding the inverted images in a mirror disorienting. Within two hours, he had removed the infected organ and sutured himself up (a helpful colleague snapped photographs for posterity).

U.T.M.B. often sends trainees in aerospace medicine to practice at a research station in Antarctica — an environment in which doctors may be called upon to perform medical procedures they haven't performed in many years, with limited supplies. Ronak Shah, director of aerospace medicine at U.T.M.B., puts the quandary this way: "Do you have the tools and support staff to complete those procedures?" Then, referring to the doctor on the original "Star Trek," he adds, "People often envision that surgical suite that Dr. McCoy had." In reality, it could cost $10,000 or more per pound to put a payload into orbit, and anything that goes on the spacecraft must earn its place at the expense of something else. There's a defibrillator and a portable ultrasound on the I.S.S., but no CT scanner or M.R.I. machine.

Major surgery could result in the patient's insides floating out. Even giving injections in space requires comprehensive planning. Rogozov could at least give himself Novocain. Chough was the flight surgeon for NASA astronauts on the I.S.S. when the coronavirus vaccine became available, and she had to decide whether to send it up on a routine resupply flight. The decision involved weighing the protection of the astronauts when they landed on Earth, conceivably with compromised immunity, versus considerations about how to get liquid into a syringe, how any side effects could make astronauts incapable of performing their duties, how to keep the vaccine cold enough and how to dose it without wasting any — an ethical conundrum in the days when there was not enough to go around on Earth. Ultimately, Chough decided they would have to wait until their return.

Credit…Illustrations by Max Guther

It's a truism of our species that the moment we encounter a new and challenging environment — a mountaintop, say, or an airplane bathroom — we feel compelled to find out what will happen if we engage in coitus there. Naturally, then, as soon as the first billionaires check into the first space hotels, they will be thinking about becoming the inaugural members of the 250-Mile-High Club. This raises the issue: There really aren't rules for medical experimentation in space that cover tourists' behavior. "If someone wants to have sex in space or have a baby in space, there's no framework to provide guidelines," Dorit Donoviel says. "We need to make sure commercial spaceflight provides opportunity for good science. The last thing we want to do is have it turn into the Wild West and do stupid things that could get people hurt or create bad press and turn people against space travel. That damages the whole industry."

So should space travelers choose abstinence until a formal entity declares space sex safe? Is it possible that this threshold has already been breached? Fewer than 700 people have flown to space so far, and it is often easy to identify who they are in research publications, which can make them reticent about details that might satisfy behaviorists. In short, says Simon Dubé, a postdoctoral research fellow at the Kinsey Institute at Indiana University, "we know very little about the intimacy and sexuality of astronauts."

But we do know some basics. "There are good indications that erection and lubrication are not inhibited in space," Dubé says. And it appears that microgravity doesn't subject contraceptives to additional side effects.

'If we take Earth with us, are we going to stall evolution?'

There are concerns about reproduction, however, that will have to be addressed if our species is ever to take up permanent residence somewhere else besides Earth. For the most part, scientists have studied aspects of procreation in space only in animals, including fruit flies, frogs, newts, geckos, aquatic crustaceans, quails, rats, mice and, intriguingly, rams. While producing and developing healthy embryos in space can be done, it clearly comes with considerable risks. Radiation exposure damages DNA and can cause infertility and sterility in adults, for example. Exposed embryos and fetuses appear more likely to have growth and cognitive delays, birth defects and higher rates of newborn mortality.

Dubé is worried most of all about the psychological effects of intercourse (or a lack thereof) in space. “What I want to draw people’s attention to is that we are going to try to enact sexuality in all its complexity in a very small, remote, isolated, very small space, with limited partners who are people you work with and depend on.” Historically, in analogous situations, like military basic training, this has proved disastrous, mostly for women. “I’m much more worried about the next morning, after people have sex, how it’s going to affect the crew dynamic,” Dubé told me, “rather than, Are people going to be able to have sex or masturbate in the space station?”

The potential adverse health effects of loneliness and isolation in space have also been under-studied but will most likely become more significant the longer a mission lasts. Being in space is like the pandemic lockdowns many people experienced in 2020, except you can’t open a window or take a walk outdoors. And the farther you get from Earth, the more lag time there is between when you send a message and when your loved one back home receives it. (On Mars, the wait might be 20 minutes.)

In 2014, NASA issued a report, “Examining Psychosocial Well-Being and Performance in Isolated, Confined and Extreme Environments,” that considered data from submarines, underground bunkers and polar expeditions. It also detailed how career competition and differences in personality, values, culture and language derailed a 105-day I.S.S. simulation in 1999, in which a crew occupied connected hyperbaric chambers: “A physical fight broke out among two of the crew members, a sexual-harassment incident was reported and one protesting crew member withdrew from the study,” the report’s authors wrote. “In the context of spaceflight, where individual escape or mission termination is rarely an option,” they predicted, “events such as this will certainly place individual psychosocial health and performance, as well as mission success, in extreme jeopardy.”

Fortunately, the polar teams seemed to have fared somewhat better, with Antarctic groups that spent the winter there enjoying many aspects of their removal from society, including “excitement over experiencing the unknown; free time to self-improve, exercise and think; and the opportunity to remove oneself from daily hassles and negative aspects of life on Earth.”

Will we miss Earth, those of us who leave it? If we yearn to come back home, can we? It seems miraculous that, over billions of years, our planetary circumstances enabled protozoa to evolve into people. But really, we are just "a series of elegant sensors," Jennifer Fogarty, the chief scientific officer at Baylor's space-health institute, told me. Our bodies, obsessed with hoarding the energy we require to stay alive, ruthlessly divest themselves of any features and capacities that are going unused without, so to speak, a backward glance.

"If we do think all the way out to colonization," Fogarty wonders, "would those people who had a sustained presence there, would their body operate differently and be less compatible with Earth?" That wouldn't necessarily be bad; it would mean those people were better suited to the moon or Mars. But adaptation is a zero-sum game. "The concern would be if some of those capabilities are lost over generations," she went on. "Do we bring Earth with us? Create artificial gravity? If we take Earth with us, are we going to stall evolution? Or do we let people start with an adaptive response, and maybe it's hard for people multiple generations later to come back?"

In other words, are we, in some essential sense, Earthlings, incapable of fully casting off the biology our home planet designed for us? Or are we — could we become — the extraterrestrials we've so long fantasized about? It seems that, one way or another, we're committed to finding out.

Kim Tingley is a contributing writer for the magazine. She last wrote about the dangers of PFAS chemicals.

https://www.nytimes.com/2023/11/12/magazine/space-living.html

We are being horn-swaggled by people who seem the brainiac best of us touting the wonders and necessity of going to the moon and Mars. I have always loved *Star Trek: The Next Generation*, dangling participle or not, but one has only to stop and think to realized how preposterous—impossible—it all is. To begin with, no "universal translator" can suddenly make English the language of the universe letting Picard proclaim the prime directive to creatures in every corner of any star system who should appreciate it. Now the likes of Musk, Bezos, and Branson, along with all "the little people" convinced they have "The Right Stuff" to parlay into a trip to space, would have us buy into their grandiosity. Kim Tingley presents all the problems faced as questions yet to be answered by all these brainiacs—whose main "talent" typically has been the narcissistic charisma and ruthlessness, sociopathic as necessary, to exploit consumer propensities and make themselves billionaires. These are the people to whom we should trust our species, the human experience? Truly, we need to grow, evolve and develop, but not in these ways by these means. TJB