Earthlings: Humanity's Essential Relationship with Gravity

by

Iris Mónica Vargas

B.S. Physics
Universidad de Puerto Rico, Río Piedras, 2000

M.S. Physics
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Signature of Author.......... ....
Graduate Program in Science Writing
May 15, 2009

Certified by.. ....
Russ Rymer
Visiting Professor of Science Writing
Thesis Advisor

Accepted by........ ....
Thomas Levenson
Professor of Science Writing
Director, Graduate Program in Science Writing

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ABSTRACT

A realm of serious scientific questions about gravity's role in biology is being researched in labs around the world, from NASA's Dryden Research Laboratories in the Mohave Desert, to Japan's Radioisotope Center at the University of Tokyo. Space biology research, as the field is often called, involves subjects as seemingly disparate but intrinsically related as hermaphroditic snails, brine shrimp, space chickens developing normally and space frogs growing enormous heads. Not to mention astronauts re-learning to walk on depleted leg bones and individual human cells attempting division with damaged internal structures. The questions asked of all of the subjects overlap: What is the most fundamental level at which life perceives gravity? Which biological processes on Earth have evolved as a result of and depend upon the presence of gravity? What is the smallest organization of life at which the presence and direction of gravity can be detected? For the purpose of space exploration, we might have to take gravity with us wherever we go outside of Earth. Yet after 52 years of space flight, and 47 years of manned missions, we still don't know what the prescription for gravity would be. Will human beings ever be able to completely escape its pull? Or are we unavoidably Earthlings?

Thesis Advisor: Russ Rymer

Title: Visiting Professor of Science Writing

Acknowledgments

When I was an undergraduate student at the University of Puerto Rico, every Friday after school, I got into a public bus and rode to Viejo San Juan. Viejo San Juan must be one of the most beautiful cities in the world; it is colorful, and very vibrant. My Friday afternoon trip to the city always managed to bring magic to my world. On the bus ride to the city there would always be someone singing some *salsa vieja*, and not a day would go by without someone sitting beside me to confide in me their afflictions or to offer me their wisdom. Walking the streets of Viejo San Juan, I would observe everyone as they went about their everyday activities, talked to their loved ones, gossiped, and even flew kites. I felt like a "true writer," spying on everything around me, hoping to learn about life so I was later able to write about it. There was something about observing, about thinking myself a potential writer that imbued the world with magic. On those days, I thought my absolute love and adoration for writing was sufficient.

I miss those days, but something happened upon becoming a part of MIT's Science Writing Program.

MIT's Science Writing Program returned some of that magic –but in a more meaningful way. It was an intense year, I confess, filled on occasion with the stress of deadlines and the insistence of fears and insecurities. Nonetheless, from Shannon Larkin's beautiful smile and wonderful voice telling me that everything would be okay, to Robert Kanigel's inspiring questions and refreshing curiosity towards everything, Marcia Bartusiak's true passion for the science behind the writing, Thomas Levenson's expectations that we all work to be the best we can be, Phil Hilt's sharpness and professionalism, and all the support, encouragement, and kind words of my very talented classmates, I felt motivated to learn all I could, and to once again observe and enjoy everything around me as a person, and a potential writer. Two people, however, I feel especially thankful to, for particular reasons.

Russ Rymer and Alan Lightman both imbued my world with some kind of magic I didn't even know existed. Alan's incredible belief in me, his utterly kind words encouraging me to continue writing and to believe that my soul will come through in my writing if I continue putting my heart in what I do, and Russ' amazing gift for teaching and for showing me a craft with traditions, rituals, and passion like no other, offered me great inspiration.

I wish all graduate students to have a mentor like Don Russ (since I am Puertorriqueña, I confer him the title of Don instead of Sir). As my incredible mentor, Russ did something else too: He directed me patiently so I would realize by myself, and through his example, that love and magic aren't enough after all.

Like any relationship, it is persistent work and, at times, heartache, as well as a certain blind faith that repetition and confidence will always bring laughter, what will render my ties with the craft of writing stronger. It is continuous work and patience what will shape me into the writer I dream to become in whatever big or small way possible.

For all the above, and a thousand other lessons learned, I humbly say *thank you*.

This thesis is dedicated to my family: my brother Gabrieluis Vargas, my best friend Dr. Sandro Molina Cabrera, my nieces Krystal Soé and Alondra Rubí, my Abuelita Panchi, and my beautiful parents, Carmen Iris Medina and Luis Gabriel Vargas without whom I would not have had the opportunity to even dream about learning English as a second language. Thank you for being visionaries who believed that I had to continue watching Minny Mouse on the screen, even when I couldn't understand a word she was saying, because "one day you will understand." I will do everything in my power to give you back in love, care, and support all you've given me through the years.

This work is also dedicated to the most amazing, supportive, loving, funny, and beautiful partner that has ever existed on the surface of the Earth: Alexander Robert Green, my wonderful soul mate and partner of adventures. I adore you, I respect you, and I thank the Universe for allowing me the privilege of your company.

"Space is an unnatural environment and it takes an unnatural people to prosper there."

-Bruce Sterling "Swarm" (1982)

"Dim and wonderful is the vision I have conjured up in my mind of life spreading slowly from this little seed-bed of the solar system throughout the inanimate vastness of sidereal space."

-H.G. Wells "The War of the Worlds" (1898)

"I love to write, but it has never gotten any easier to do and you can't expect it to if you keep trying for something better than you can do."

-Ernest Hemingway to L.H. Brague, Jr. (1953)

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Remember that instant when, as you ran around the shadows of imaginary jungles in your backyard, falling once and tripping twice, your gaze was caught by a fragile silky web with a tiny spider in the middle? You were mesmerized by the steady weaving of its many limbs –it would not easily fall down- simply swaying to and swaying fro, laboriously spinning and laying the symmetry of its web in what seemed to you such a magical, private moment –as though you were observing an ancient secret.

I was a child fascinated with space. The untamed and unsophisticated backyard of our humble house in the rural Barrio Bajuras in Puerto Rico contained an entire universe within it. At night it was the most comfortable seat for watching the grand opera of the skies, imbued with the aroma and consistency of dewed soil. During the day, hiding among branches and leaves and passion fruit vines, the handy-work of a single spider on the termite-ridden poles on which our zinc roof rested would transfix me. The fabric of its creation, the geometry of its silky space, would make me ponder what it was like to be her, that tiny spider, to live in her world, do what she did, and see what she saw. Did she see me as distant as all the cosmic bodies I saw in the night-sky? Was I as mysterious, as unrelated to her everyday life as that sparkling vault was to me? How come she always knew exactly where to weave her next thread? How come her threads were always so perfect, so symmetrical? What was telling her to spin as she did? If she were somewhere else, some far away world, would she still go about her routine, weaving her space fabric like she always did? As a curious child, I wondered what it would be like for a spider to live up on the Moon, or on another planet, another galaxy even.

Within the warmth of my tropical island backyard, I thought the Universe was the extension of my barrio, one welcoming fabric, seamless in its extension. I wondered if other creatures existed, within the vastness of space, that were different from me. Could they jump higher than I could? Would they look different than the tadpoles around me? Sing brighter than my coquíes, my tiny Puerto Rican frogs? I daydreamed about how everything and everyone else around me would behave when surrounded by the darkness and the vastness of space. What would space feel like to me? Could it make me feel freer, and would my backyard spider still be able to weave her web? Would it adapt to its new backyard? When witnessing the perfection of that tiny spider's craft, I wondered if she would still know what to do when no longer an Earthling.

Anita and Arabella went to space in 1973. That was before I was even born. In her very own yard, 2,684 kilometers from my tropical Caribbean island, and thirteen years before I started daydreaming about it, a young girl by the name of Judy Miles had been wondering too, whether spiders could spin their silky webs in the near-weightlessness of space. Judy was a high school student from Lexington, Massachusetts who managed to send her query up to space where astronaut Owen Garriot released two female cross spiders (*Araneus diadematus*), the first world spidernauts, Anita and Arabella, into a box similar to a window frame, near which a camera would recorded their spider activities aboard Skylab.

On July 28, 1973, space met two shy creatures unwilling to exit their space capsule –a storage vial with a water-soaked sponge to maintain them hydrated. Their erratic 'swimming motions' as they finally emerged from their capsules into the experiment cages, conveyed a struggle to adapt to the strange new environment they had been brought into.

Arabella was the first to decide that life had to go on. On the day after her arrival in space, she weaved a rudimentary web in a corner of her box –the first web ever spun in space. The following day she completed her work. Arabella's ability to cope with her new surroundings impressed everyone. On August 13, wanting to see whether Arabella was capable of repeating her feat, astronauts removed half of her web. At first, she didn't seem to fancy entertaining anybody's whims. When Arabella finally set herself to the task, she consumed the remaining half of her web, and began moving in circular patterns. The resulting web was more symmetrical than the first.

Perhaps because of the stress of their new environment (spiders have been known to behave abnormally under stressful conditions) neither Arabella's nor Anita's silk was like that they had produced on Earth. Some parts of their webs were thinner than others. Even the angles of their radial threads were unlike those on Earth. Although Arabella and Anita were able to spin webs in microgravity, they never performed exactly as they had done before they went to space.

Judy Miles wasn't the last one to wonder about spiders in space. Similar experiments were performed on space shuttle Columbia in 2003, and in 2008, aboard the STS-126 shuttle mission to the International Space Station.

I became a physicist in 2004, and after two years exploring elliptical galaxies at the Harvard-Smithsonian Center for Astrophysics, I realized I was still caught in the spider's orb. The same questions still pursued me, and I decided it was time to pursue them by following the work of those scientists who study such questions. Physics had taught me about gravity as the omnipresent and ubiquitous central theme in the story of the Universe -reflected just as much in the moons of Jupiter as in tiny Arabella's struggle to weave her orb web. Among the four elemental forces known to humans, gravity is probably the most widely known, influencing the exuberance of the Universe –in quasars and pulsars, gamma-ray bursters and supernovae, sleepy black holes, molecular clouds, and the cosmic microwave background radiation (the ancient footprint of what was possibly the beginning of our Universe).

There is also something in us that feels gravity nearer, knows it much more intimately. We are in a sensual tango with gravity, a dance in which it leads, and we heed its whims. Even as we protest its rule with a spider's ingenuity—with columns and beams, arches and domes to prevent the roof from crashing down—we rely on it to maintain our protective atmosphere, to propel our planet in its reliable orbit. We are dance partners, and we are masons, as well. We want to understand how gravity erects the invisible boundaries around us. Our ultimate freedom depends on outwitting it.

The journey to know the truth about gravity's effects on biological systems, like the spider, like ourselves, its continuum of influence at the smallest scales –the way an adult body understands and responds to it, the way an embryo is sculpted by its instructions, as well as the manner in which a single cell 'feels' its strength- will most likely see us emerge one day – humans, rats, and fish alike - as slightly altered species. We will be altered not only as a consequence to likely changes that will occur in our physiology (and eventually in our morphology) resulting from an environment lacking or in excess of gravity, but also because the freedom we will acquire by escaping our planet's boundaries, will unavoidably transform us beyond the Earthlings we always have believed we are.

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During the first weeks of November, 1994, meteorologists at the National Weather Service noted disturbances in the weather around the Caribbean Sea. Two tropical waves were developing over the region, inducing the formation of cyclonic air currents to the north of Panama. The resulting hurricane, named Gordon, embarked on an erratic path over the western Caribbean Sea–where its torrential rains and devastating winds would cause thousands of deaths on the island of Haiti–and the southwest Atlantic and Florida.

As Gordon turned east-northeastward and headed for Jamaica, NASA officials prepared for the inevitable: canceling the scheduled landing of a space shuttle at the Kennedy Space Center in Florida. Atlantis Space Transportation System (STS)-66 became the fourth space shuttle flight of the year diverted to Edward's Air Force base in California. When it got there, April Ronca would be waiting.

April Ronca is a developmental biologist in Obstetrics & Gynecology at Wake Forest University School of Medicine, where she researches subjects ranging from the importance of labor for newborns to problems experienced by babies following birth complications. In 1994, she was working for Indiana University, and was an NIH-funded investigator in an experiment on board STS-66. The experiment entailed sending ten pregnant lab rats into space to probe the effects of microgravity on the development of the pups growing inside their wombs.

That experiment was an early part of a larger effort that is accelerating today –to understand the role of gravity in biology, especially the biology of Homo sapiens, a species that seems on the verge of expanding its habitat into the gravity-deprived (by Earthly standards) realms of space.

Before Ronca could get her rodent subjects home to quiz them about the effects of space gravity, she would have to contend with some of gravity's earthbound tricks. If planet Earth exerted a little more gravity than its unvarying 1-G, Hurricane Gordon would have grown bigger but moved slower. A little less gravity and a smaller-diameter storm would have traveled faster.

Either way, the hurricane might have missed Cape Kennedy. Ronca had been at Kennedy for the shuttle's liftoff, watching from the VIP section, where investigators (and celebrities) get to stand. “It was very exciting,” she said. “My dad, my sister and my niece were there. My father went up and shook hands with Jacques Cousteau. I took a bunch of pictures.” To no effect: her film got stuck in her camera. “So I just have my memories,” Ronca said.

Along with the NASA brass, Ronca expected the shuttle to land just where it had departed. Nevertheless, soon after the liftoff she returned to California, to NASA’s Dryden Flight Research Center at Edwards Air Force Base, where a mirror image-laboratory had been set up just in case of a west coast landing. Duty required Ronca to be on hand. “I was in the half of the team that wasn’t supposed to be getting the rats,” she said.

A year earlier, after Ronca and her co-lead investigator, Jeffrey Alberts, also a developmental biologist, at Indiana University, secured funding for their experiment, their team had begun a series of pilot studies, “practicing anything and everything that needed to be practiced.” At NASA Ames Research Center, home of NASA’s Life Sciences Division, they set up their equipment and performed alternate ‘runs’. They met for intense ‘debriefings’ where they discussed the results, determined what had gone wrong, and decided how to improve the next time around.

“It was like we had a pre-dress rehearsal at Ames,” Ronca said. Because the flight was so expensive, “we didn’t want to take the chance of an animal not having fertilized eggs, or embryos, or not having sufficient numbers of them.” Their chore was also complicated by the sheer number of competing science teams from different institutions and countries, studying different things in the same ten pregnant rats, involved in the shuttle flight. “There was a lot to coordinate,” Ronca said.

Eventually the whole show advanced to Kennedy Space Center in Florida, where NASA allocated extra animal test subjects to use in repeated dry runs, and pushed the scientists to further perfect their processes so they could operate efficiently under pressure. “At the time we thought it was ridiculous,” Ronca said. “But now I can see the wisdom in it, because by the time we got to the flight we were a flawless team.” One of the contingencies was to split up the team between Kennedy and Edwards Air Force Base. “We never practiced at Edwards. We just set up at Edwards. We spent a whole year doing that.”

The runway at Edwards Air Force Base is the longest in the United States. Approaching it that

November down highway 58, Ronca could see, under a cloud-specked sky, a covey of small, metal rectangles painted olive green, yellow, blue and white: the trailers she would call home and laboratory during the coming days. Outside the lab trailers was dust and heat—inside was a perfectly controlled environment, stocked with equipment from calibrated pipettes to computers, and bustling with researchers in lab smocks.

Very early on November 14, Ronca received a phone call. "It was NASA. They had decided not to wait and do another pass by Kennedy." The orbiter was headed their way. The warning didn't allow the team much time. "We went, 'oh my god!', and ran to the lab to make sure everything was in place." Then they stepped out of the trailer to wait, for what seemed like forever. "Of this I do have pictures," Ronca said. "All of us were standing outside the metal portables that were the labs… just standing out there and looking out on the desert."

At 4:33 AM Pacific Standard Time, exactly one day after it was scheduled to land in Florida, Atlantis touched down. "We actually saw the shuttle come in almost in front of us, and then all the personnel units rush out to process the payloads," Ronca said. "It was really amazing." Ronca's team headed back inside to await their payload: navy blue metallic boxes, each containing a series of smaller boxes which the researchers lined up on an array of tables. Wearing sterile coats and surgical masks, they unscrewed the bolts securing the boxes, then lifted off the lids. April reached in a gloved hand and brought out a little white-furred, red-eyed, nervously sniffing, rat.

Like the rats in the other boxes, this one was pregnant. As the space shuttle had circled the Earth, their embryo pups had existed in an almost perfect state of free-fall, experiencing one ten-thousandth to one millionth the normal strength of Earth gravity. How would that affect them? Would they look different? Would their behavior or development distinguish them from their earthbound counterparts? Would they hear, see, or feel differently? And what would such differences reveal, if anything, about the possibility of a space-faring *human* baby? Within two days, the rats that had just returned from orbit would give birth to litters of pups (one with the help of cesarean section) and Ronca would have some answers to her questions.

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A realm of serious scientific questions about gravity's role in biology is being researched in labs around the world, from NASA's Dryden Research Laboratories in the Mohave Desert, to Japan's Radioisotope Center at the University of Tokyo. Space biology research, as the field is often called, involves subjects as seemingly disparate but intrinsically related as hermaphroditic snails, brine shrimp, space chickens developing normally and space frogs growing enormous heads. Not to mention astronauts re-learning to walk on depleted leg bones and individual human cells attempting division with damaged internal structures.

The questions asked of all of the subjects overlap: What is the most fundamental level at which life perceives gravity? Which biological processes on Earth have evolved as a result of and depend upon the presence of gravity? Which processes are not dependent or sensitive to gravity's presence or absence? Is there a threshold level of gravity at which sensory mechanisms respond to gravity? Perhaps there is a special window during which the gravitational vector of the Earth exerts its influence over a developing organism, be it a chick or a human baby. What is the smallest organization of life at which the presence and direction of gravity can be detected? In organisms raised in the absence of gravity, would gravity-sensing mechanisms develop? Could we re-adapt to the Earth's gravitational field and its idiosyncrasies once we manage to be born in space's microgravity environment, or will a baby born in space land on Earth only to discover that its skeleton cannot support the weight of its body? In other words, what is required for life to survive, adapt and evolve in the environment of space?

Gravity plays a more relevant role in the everyday life phenomena of our bodies and those of other species than we would ever intuit as we go about our routines. That role has become the focus of increased concern as the United States and other countries contemplate longer manned space missions and even colonization of other planets and the Moon.

In the 1970s, when the hatch of the tiny and confining capsule opened after a 'prolonged' eighteen-day mission, the weakened cosmonauts would exit with great difficulty. Many factors contributed to their debilitated condition, but the most likely cause was muscle atrophy. Now, when the claustrophobic capsules have been replaced by capacious (relatively) space shuttles and space stations, and space missions can last more than three hundred days, the effects of microgravity continue to be experienced.

Many things happen to astronauts in space. Their faces flush, becomes thicker, and breasts go up no longer pulled down by the full earthly force of gravity. Their bodies float in a neutral posture. The knees and hips are bent; the spine is slightly rounded. No longer is movement controlled by the lower extremities–under microgravity, these can only serve to provide stability. The upper extremities, the hands and the fingers, do the job now. There are no more powerful muscle contractions like the ones that take place when standing up from a sitting position on Earth: they aren't needed.

"Your body doesn't particularly feel tired because you're not using it like you use it on Earth," says former astronaut Jeffrey Hoffman, a professor at the Massachusetts Institute of Technology. "Some people like to exercise a lot in space to keep their body well, but in my case, on shuttle flights which didn't last that long, I didn't do much exercise because I was just enjoying being there."

"I remember on my first flight I was so excited to be in space I didn't want to sleep. They would schedule us to go rest for eight hours every night but I would stay up late and just look out the window and watch the earth go by," he recounts of his astronaut days.

"I didn't feel physically tired, so the first few nights I got four hours of sleep each night. And on the third or fourth day, I was doing something… when suddenly I had a crew member shaking me saying 'wake up!'. I was floating and just closed my eyes and fell asleep. I was exhausted, but I didn't realize I was because I wasn't physically tired–my brain was," he says. "You do need sleep and… if you're gonna be up for six months at a time, you better exercise pretty heavily too or you'll be a mess when you come home." That is because in space, as on Earth, unused muscles lose their mass and strength.

Surprisingly, aerobic exercise isn't the best solution to the problem. What would be needed on Earth to improve fitness in untrained individuals would not be enough for astronauts. Compounding the problem is the fact that more exercise, while worthwhile, would be wasteful of resources in a long-duration (1 to 2 years) space flight. The availability of water, oxygen, and food is critical for survival during prolonged missions. But if each astronaut consumed approximately 3,100 kcal and 2.2 liters of fluid per day, the requirements for a 2-yr flight would be 2,263,000 kcal and 1,606 liters per astronaut. That's about 1,688 Whopper sandwiches a year!

Astronauts, then, must resort to an exhausting assortment of movements–dead lifts, bent over rows, squats, shoulder press, rear raises, tricep kickbacks–to keep the muscles involved in extending the ankles, knees, and back (the ones requiring the most work to keep in shape) as well conditioned as possible.

Cosmonauts in the Russian space program turn to 'The Penguin Suit'–a snug-fitting, long sleeved jumpsuit that maintains the muscles as stretched as possible–to help preserve muscle mass. The elastic inserts placed along the vertical sides of the suit as well as in the collar, waist, wrists, and ankles varies the fit and tension of the suit loading the body along the long axis by applying forces between 15 and 40 kilograms that adjust the position of the limbs.

Muscle de-conditioning and atrophy aren't the only difficulties space-explorers deal with both in orbit and upon their return home. "After standing on the deck for approximately 1 minute, the [astronaut] began to look pale and, although his face was already wet, new beads of perspiration appeared on his forehead. He swayed lightly and reported symptoms of impending loss of consciousness including lightheadedness, dimming of vision, and tingling of his feet and legs," read a post-flight report from a 1963 Mercury mission.

The astronaut described in the report was suffering from orthostatic intolerance–the development of symptoms during upright standing likely due to the change in blood flow and blood pressure regulation caused by his return to the gravity on Earth.

When astronauts go into the microgravity environment of space, they suffer from the redistribution of fluid in their bodies. Blood rushes from their feet to their head. Normally pooled in the lower body, it is displaced into the upper body. Skin unnaturally changes color and temperature, fluid accumulates in soft tissues and membranes, and the astronaut experiences visual disturbances. The cardiovascular system responds to the threat by changing the pulse rate, blood pressure, and the amount of blood pumped by the heart. Respiration, too, is affected.

"And you tend to lose your sense of smell too, a little bit, when you're up there because of the fluid shift into your head," says Hoffman, "which is probably a good thing since we don't take showers up in space. You sort of wash yourself with a wash cloth."

When an astronaut returns home, regardless of age, his or her body seems to have a lot in common to that of an elderly person. In the January 2009 edition of the online research journal Bone, researchers report on the first study conducted to evaluate bone strength in astronauts who had spent four to six months at the International Space Station. The sixteen astronauts showed an average of fourteen percent decrease in hipbone strength, a worse decline than had ever been observed. Three women astronauts in particular caught the researchers' attention: they showed a loss between 20 and 30 percent. By themselves these ciphers don't say much, but in the context of osteoporosis the observation is disturbing: the rates are comparable to those seen in older women who suffer from the condition.

The greatest rate of bone loss in space occurs in the hips. This isn't a trivial loss. It can lead to fractures which can lead to hospitalization, surgery, disability walking, and even death. Astronauts who have already experienced a significant loss in bone density and strength while in space have a greater chance of developing age-related fractures even decades after their service has ended.

Although he feels he didn't experience the full force of these changes, Hoffman can attest to them. "People adapt to space at different rates and they adapt to coming home at different rates, too," he says. "I was always in pretty good shape. I would test myself right when we would get on the ground, standing up and walking up and down the stairs in the shuttle just to see if I could do it in case we had to do an emergency evacuation. I always felt pretty good. But I've seen other crew members who couldn't get out of their seats. They felt so heavy. They were exhausted. Sometimes people got vertigo just from getting back into gravity."

Motion sickness (nausea, vomiting, drowsiness, cold sweat) isn't a chronic problem for astronauts outside of the first few days of a space mission and the first few days after landing, peak periods for this condition. "Your internal sense of balance is what gets affected the most, you know… to be able to sort of walk straight and go around the corner without looking like you're drunk, but after a shuttle flight of one or two weeks, usually by the second day, you can walk a straight line and you feel pretty much normal again," explains Hoffman.

However, as he puts it, "People coming back from six months in space will tell you different. For someone who's been up for six months it can take up to a month before all of their reflexes are a hundred percent back to normal," he says.

"And that's one of the problems for going to Mars," asserts Hoffman. "When you get to Mars, after six or eight months in space, there will be nobody to take care of you. Here, when you land after six months in the space station, there is somebody to lift you up out of your capsule, and put you in a couch where you can lie down and they take you off to the crew medical facility. But there isn't anybody on Mars to welcome you like that."

Studying the physiology of gravity effects, not only in humans, but in other organisms, is teaching us how to minimize these effects and is providing researchers with clues about concepts as mysterious as the way we actually *sense* gravity. Knowing what we all do with that information could one day help us reach Mars. Researchers are trying to understand just how deep go the effects of gravity, and how pernicious is its influence. Returning astronauts wobble because they are reorienting themselves to gravity they'd grown up in. But what would be the effects on a creature who has known nothing else?

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April Ronca would see, first hand, some of these effects. The main question she addressed to her rats involved the sense of balance and orientation. In the weightless environment of space, her pregnant rats had floated, bumping into all of the surfaces of their cages, rotating their bodies with a frequency and with a diversity of orientations uncommon among their earth-bound counterparts. How would these dramatically changed conditions be sensed by the gestating fetuses?

From the moment they are born, normal rat pups placed belly up over a solid surface begin moving like clumsy corkscrews, straightening themselves until they get their legs back under them. Their response relies on balance organs in the ear (elements of the vestibular system), and also on a combination of tactile and proprioceptive (the sense of where the various parts of the body are located in relation to each other) cues along their backs. Ronca wanted to strip away the tactile clues and isolate the balance organs. Does gravity affect the way these organs develop and work? To find out, she immersed her newborn rats, so recently returned from outer space, into another foreign environment: water.

"It was a very simple, quick test," Ronca explains. "We put the pups upside down in a warm water bath. Just for ten seconds. And they right themselves. And we pull them out. Immersion takes away the proprioceptive and the tactile cues on the back, so that it becomes just a vestibular test."

A normal, earthbound, two-day-old rat, when placed in the water belly up and released, will immediately try to right itself through a series of corkscrew movements. It pivots until it is belly down, then swims for the surface. Its body has direction. Its instinct knows up from down. But when Ronca released her space-gestated pups into a tank of water, they floundered.

Ronca's experiment is an indication that the effects of gravity run deeper in the biological grain than we might have suspected. The question is crucial to the space colonization issue.

Perhaps gravity's effects are merely behavioral, of a sort that we can compensate for –or structural on a macro enough level that we can cure them with therapies. But maybe, instead, they are ingrained on a more microscopic level that would mean our systems are inherently earthly systems, unsuited to other gravities. The answer holds clues for some of the mysteries that have beset spaceflight through decades. Are we forever tethered to Earth?

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For years, space physiologists have studied these effects on what James Logan calls 'long duration fliers' –astronauts participating in protracted missions to space. As time and science advances, these researchers have witnessed their more optimistic ideas being replaced by grimmer ones. "Back in the day, a technique we used to measure bone density, for example, was something called bone densitometry," says Logan, a former astronaut physician, and currently manager of Medical Informatics and Health Care Systems at NASA. "This gave us the idea that you lose about 1 percent of your skeletal calcium per month while in space. But when we started using a later technique, spiral CT, to look at various bone compartment–the cortical and the tribecator bones–we found that the actual loss rate is twice what we thought."

It isn't that space physiologists like Logan didn't try to find countermeasures for these effects. "But when we look back at our collective experience, it doesn't look like our countermeasures work at all." Does that mean that countermeasures won't work on anyone? The question gives the riddle of gravity's effect on biological systems an interesting twist.

Researchers like Logan have identified three groups of astronauts: the ones who don't lose a lot of bone during space flights, and therefore, post flight have not much bone mass to gain back; the ones who lose quite a bit of bone mass and will replenish some of it after return to Earth; and the ones who lose up to twenty-two percent of their bone mass. "We cannot predict which astronauts will belong to which group, but the ones who lose 22% of bone mass in a six months mission… those don't get it back at all."

Not only does gravity –the lack or the excess of it- act within specific time windows during the developmental stages of certain organisms, but it seems that there is also an issue of susceptibility regarding its influence on different species -including humans. It is as if, for the 'problem' of gravity's effect on organisms, the concept of a simple approximation, or generalization, does not quite apply. There's no easy solution, says Logan, "I am amazed at how many people think that at NASA we have a special room we can go into and just flick a switch on the wall and immediately turn off gravity."

For the purpose of space exploration, that might mean we would have to take gravity with us wherever we go outside of Earth. "No engineer would argue that you shouldn't take food or water, because that's essential for life," Logan says. "Gravity may be in the same category. So we would have to create it: pseudo-gravity", which poses a problem by itself because we don't know the prescription. "After 52 years of space flight, and 47 years of manned missions, we still don't know what that would be."

Think of gravity as a drug, says Logan. "We can't tell you the dose, we can't tell you the frequency, and we can't tell you all the side effects. All we know is that one gravity, twenty-four hours a day, seven days a week, works," he says, "and we also know that six months without it doesn't."

For the past three or four years, Logan has been asking every life-science researcher he comes across the following question: Based on what they know about zero gravity, do they think that an environment with one sixth the gravity of Earth (like that of the Moon) would have similar effects on life to those caused by zero g? "Every one of these scientists, every single one of them, has said that they don't expect it to be any different than zero g," Logan says. "Now, that raises an interesting strategic consideration when you talk about the humanization of space." If one sixth of gravity isn't enough, then the Moon will probably never be a civilization destination, Logan argues.

"And if one sixth of gravity isn't enough, it makes sense to ask if one third of gravity is, because that's the gravity of Mars. A lot of people, and I'm one of them, think a third won't be enough either," he says. As he sees it, for the moment, at least, we would have to say good bye to Mars as well.

For Logan, we are still far from achieving anything remotely close to our childhood fantasies about space, all that we saw in movies, and what we read in science fiction books. In his 1951 novel "Between Planets" Robert A. Heinlein wrote: "He knew now where he belonged – in space, where he was born. Any planet was merely a hotel to him; space was his home." Making space our home is more difficult than our imagination expected. Reality, it seems, is proving to be a bit more challenging.

"Here is what should have been done earlier in the space program that wasn't: If I had been running the space program in the early 70's right after Skylab, when we first got a handle on some of these long duration changes, I would have designed a space station that rotates at a lower orbit around the Earth," Logan offers, "...even if it consisted of two modules connected by a tether. I would have rotated the modules so they generated the amount of gravity on the Moon or that of Mars. Then I would have flown my 90 day, 180 or 380 days mission, and looked at what that did." The idea, according to Logan, is that corroborating the effects of Mars' gravity first would have saved us a lot of work.

"That means that if you have to create your own gravity, which would have to be above that of Mars', you know you're not going to be on the surface of a planet," he argues. As he envisions it, if we want a civilization destination, a settlement, that is, woman, men, children, and multiple generations in the planet of our choice, "we'll have to build our space habitats in space; huge platforms that rotate".

"Now, in a hundred years we might develop a magic pill, we might be able to completely manipulate the human genome. In fact, we might even figure out a way to create gravity by just going to the wall and flipping on a switch." For the moment, though, those are all possibilities that Logan doesn't expect to see in his lifetime.

Pseudo-gravity or artificial gravity, however, has its own set of problems –there will be side effects to centripetal acceleration. "We now that. But we are just not sure what the magnitude will be for those side effects, or what percentage of the population will be susceptible to them," he asserts.

Space biologists and physiologists alike are focusing instead on the side effects they have noticed on different organisms when in a microgravity environment. Besides bone loss, muscle atrophy, the shifting of blood inside the body, and motion sickness, there is a side effect that has captured their attention: the influence of gravity, or lack thereof, on the immunological system of an astronaut. Previous studies have long suggested that spaceflight blunts the immune system in both humans and animals. Oddly, it may simultaneously strengthen viruses. Naturally, the increased risk of infectious disease events during long-duration missions is of concern. But just how big a culprit is microgravity?

It isn't an intellectual somersault to suspect that mixing a more viral organism with a less effective immune system spells a bad combination. Understanding, however, the association between both elements and microgravity has required careful thought and experiment. In 2000, a team of researchers from Tulane University School of Medicine in New Orleans, Louisiana, Life Sciences Informatics, the Monsanto Company, and NASA, reported on the first study that provided evidence of microgravity's influence on the virulence of microbes.

For years, Salmonella enteric serovar Typhimurium, one of the serotypes of Salmonella, has been one of the leading causes of human diseases according to the National Center for Infectious Diseases. In humans it results in gastroenteritis, and in mice it has been shown to cause a lethal systemic infection similar to the human typhoid fever. The Tulane researchers decided to infect mice orally with the strain of Salmonella serovar Typhimurium. They artificially created conditions of microgravity with a bioreactor machine. The viral particles subjected to microgravity displayed increased virulence.

In space, Salmonella becomes more dangerous than on Earth –a big deal considering the potential interaction between the crew members of a long-duration flight, like one to Mars, and virulent bacteria floating around the self-contained environment of the spaceship. The consideration is especially important in individuals whose immunological systems' responses have weakened.

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Sitting among clocks marking the time at various places around the world, and pictures of sea lions and flamingoes –"why doesn't anyone have flamingoes at their office?"– microbiologist Randall J. Cohrs watches the planes take off and land at Denver International Airport from his office window at the new campus of the University of Colorado. On an early February afternoon this year, he recounted the story about his presentation at the International Herpes Virus Workshop back in the year 2000. "Every year scientists from around the world who work with herpes virus get together for about a week to exchange data in a pretty formal forum," Cohrs said.

As a basic science researcher at a clinical neurology department, Cohrs constantly gets samples from all over the world to analyze for the presence of the Varicella Zoster Virus, or VZV, as it commonly referred to. "We study the molecular biology and the clinical attributes of this virus, and its basic genetics," he said. He also has a very sensitive method for detecting VZV in autopsy samples; this is probably what caught the attention of NASA.

Sitting in the audience at the conference back in 2000 was Duane L. Pierson, a NASA researcher whose job is to assess and identify possible risks to the astronauts or to the vehicles during long-duration missions. When Cohrs had concluded his presentation, Pierson approached him. "He comes to me and he says, 'We are interested in knowing what we have to be concerned about to maintain the health of the astronauts on long term space missions so they can mitigate infectious diseases, besides avoiding people with coughs before launch.' Then he asks, 'During long term missions, is there something like a latent virus that we would have to worry about reactivating?' "

"Humans carry a lot of microorganisms, obviously," asserted Pierson. "But if you're going to study astronauts, you need to study something relevant. Astronauts are a very healthy group; they are exquisitely conditioned to go up for this job. And so you don't want to be studying something like hepatitis virus or TB, because they're not going to have those."

Periodically, NASA would put together a 'blue-ribbon' panel of experts to determine what risks to look for when considering long duration missions, and they had recommended checking for the reactivation of latent viruses in the body. "We were analyzing herpes viruses such as EBV and CMV long before I had met Randy," says Pierson. He and his colleagues were wondering if the reactivation they had seen with other herpes viruses, such as EBV and CMV (member of the herpes-virus family) was found in other herpes. "So we decided to look at VZV."

In fact, of all the latent viruses that are capable of reactivating inside a person, "herpes virus is probably the one that comes to mind first."

There are eight human herpes viruses. "Most people up and down the street already have been exposed and have antibodies to varicella zoster virus," says Pierson. "And no matter what country you're from, developed or underdeveloped, by the time you're 25 years old, statistics show 95% of the world's adult population has the virus. Virtually everyone's carrying one kind of herpes at least. And most of us are carrying several different types."

As Pierson tells it, the difference between herpes virus and something like influenza is that while influenza makes a person feel bad for five to six days, the person recovers. The virus leaves the body. "Latent viruses like herpes are different. In these cases the immune system does begin to get the upper hand, but the virus doesn't go away and out of body. It sort of hibernates inside nerve tissue where it becomes latent. It adopts a quiescent state and stays like that for decades, maybe even for life, with no consequences."

"So I said, 'let's start looking at a group of astronauts to see if they are reactivating the virus in space.' Duane [Pierson] invited me to NASA and we talked about the plans and how we would go about doing this," Cohrs said.

They decided to take samples of astronauts' saliva before and after lift-off. "Duane and his colleagues would extract DNA from the saliva samples, divide the sample in two, and send one up to me to analyze," Cohrs said.

Cohrs had asked other people at the International Herpes Virus Workshop at that time if they wanted to be part of the project. "A lot of them said, 'you go ahead and do it'...they didn't think we would be able to detect it. Why would you detect VZV in the saliva when there is not clinical disease going on?"

But Cohrs did detect VZV in the saliva samples. "Lo and behold, all samples we worked with were positive for VZV," Cohrs said. Moreover, both laboratories, Cohrs' and Pierson's independently produced the same results. They had found the infectious viral particles in the saliva of astronauts immediately upon returning to Earth.

Pierson and Cohrs think this could be an indication that the virus reactivates in periods of stress, in healthy individuals (because the astronauts are healthy and they remain healthy) who don't experience the clinical symptoms of the disease. "We were all surprised," says Pierson, "Including the people who work with VZV on a regular basis."

The finding has important implications for everyday life and people other than astronauts. If the stress of space weakens the immunological system, causing latent viruses to reactivate, the same phenomena could be seen on people due to age or stressful conditions on Earth. "Anything that reduces immunity, allows virus reactivation," Pierson says. Because stressed, or old, but otherwise healthy people could be shedding a reactivated virus asymptomatically, says Pierson, it is possible that grandpa's kiss can give eight-year old Johnny the chicken pox without knowing it.

"It's an unusual finding," Corhs explained, "because although our samples have been very small so far, we don't see this on normal healthy people that are just walking around on the street." Cohrs and colleagues have looked at people over 60, non astronauts who don't have shingles, to see if they, too, are reactivating the virus. "Of the small number of people we looked at, none had the virus' DNA in their saliva. It seems like something that is unique to space, but how much can it be attributed to microgravity directly, we cannot say."

James Logan, NASA's astronaut physician, would probably refer to it as a synergistic effect, where the effect of two systems acting at the same, in this case the weakening of the immunological system due to stressful conditions, and the condition of microgravity, is much greater than the effect of two systems individually. The discovery certainly opens up a new field of clinical study on Earth, but it also fuels the concern about human beings interacting under microgravity.

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In 1901, George Griffith, a science fiction writer then considered the rival of H.G. Wells, published a novel chronicling a pair of star-crossed star-travelers, one Earl of Redgrave and his American wife, on their nuptial journey through the galaxy. "Honeymoon in Space" was a high-altitude heavy breather whose scenes might have played significantly different if Griffith had emphasized in his novelistic description the most novel aspect of space travel: weightlessness. Though had he done so, he might not have offered the eccentric earl and his wife such a pleasant lovers' tour of the Moon and planets.

The mechanics of intercourse in space will, in fact, be challenging. In space, a kiss is not just a kiss: the couple would have an extremely hard time keeping their lips together, let alone the rest of their bodies. Meanwhile, because sweat doesn't drip off, the earl of Redgrave and his wife would soon be covered in perspiration.

If the Earl and Missus succeeded in procreating, then what? We already know that success is possible–or at least, we know it would be possible if the couple were a Medaka fish.

In 1994, in one of the best known experiments in modern space biology, four Japanese killfish (Oryzias latipes or Medaka) traveled aboard the space shuttle for fifteen days as part of the second International Microgravity Laboratory mission. Their journey was filmed by biologist Kenichi Ijiri. The film is as silent and trace-inducing as a Charlie Chaplin movie. Two fishes, a male and a female Medaka, swimming around a plastic flask, mark what is possibly the most famous image on Ijiri's footage.

The male performs his ritual dance swimming in circles around the female, in an orbit that slowly shrinks and ends near her body. First their heads touch briefly. Then, using his dorsal and ventral fins, he embraces her. Their bodies engage in a tension that maintains their positions fixed in space. They look like one big-head fish with two end fins. Their bodies curl as his body seems to momentarily engulf her. And soon their conjoined figure takes the shape of an X –a figure with two heads and two fins joined at one point. For a moment they seem to just float. The entire process lasts thirty seconds. Mating has ended. The belly of the female bears the newly fertilized eggs.

What Ijiri's silent footage has recorded were the first vertebrate animals to mate successfully in space. They mated and laid eggs every day during the first week of the mission. All eggs laid were able to develop normally. Eight fish hatched in space looking like they should: two giant, black pigmented eyes attached to a round body, itself attached to a very long tail propelling them out of their developing membrane into a world of microgravity. Back in the ground, they would produce a second generation of Medaka, proving that however difficult the enterprise, and at least for some species, it seems possible to reproduce and develop successfully in space.

The common fruit fly, *Drosophila melanogaster,* has proved that besides its skills at being a pest, it, too, can successfully reproduce during a space flight. Bacteria, yeast, cell cultures, frogs, sea urchins, and nematodes have also had their opportunity on board NASA's space shuttles, and space station facilities. Even tropical freshwater hermaphrodite snails have added themselves to the list. Rid of the earthly constraints keeping it attached to the walls, in space, *Biophalaria glabrata,* can dislodge itself from the walls of its aquarium floating freely through the water to meet another snail and produce embryos. Frogs' first experiences regarding fertilization in space have not been as romantic as that of the snails, but they, too, have been successful, as have been crickets, and salamanders.

Nonetheless, things are not everywhere as bright, or as clear as the ritual dance of a Medaka male around its female, or as easy as the floating of a hermaphrodite snail in search of a partner. April Ronca's experiments have shown that we can expect other consequences, affecting our sensory perception, for example, and that these effects have special consequence for mammals that are reproducing. Her conclusions have been borne out by other experimenters. Not surprisingly, then, a disruption of that reliable gravitational signal has effects. When male rats are mated five days after space flight with female rats that have not left Earth, their offspring show retarded growth, hydrocephaly, out of place kidneys, and enlargement of the bladder. Rat fetuses' exposed to microgravity lag in their skeletal development formation of neurons and muscle fibers, and their retinas (and thus, their vision) are disturbed. As if that's not enough, the weight of the male rats' testes and their levels of testosterone dramatically decrease as a result of space flight. Microgravity also reduces their energy consumption, while hyper-gravity has the opposite effect. Frogs exposed to similar gravity loss see degenerated muscles, and small lungs; their tadpoles are strange, altered creatures with enlarged heads and eyes.

Our planet has changed in many ways during its existence. Its atmosphere was decidedly very different from the one we enjoy today, and so were its oceans. Its temperature, its climate, the distribution and shape of its continents –they have all changed. The only constant influencing the development of every organism on the planet is gravity: it has not changed since the dawn of life roughly 3.8 million years ago. Gravity is the condition Earth organisms are most adapted to, relying on its steadiness to orient themselves in their environment as well as to survive. Gravity may even play a role in evolution; at the least, our evolution has occurred to exploit and accommodate gravity's constancy.

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Five years ago, Ralf Anken considered dropping an aquarium full of fish out of his office window. "I can tell you the fish probably wouldn't have liked it, especially the landing" he says, but however the fish felt, science would have been served.

As head of the section Microgravitational Biology of the Biomedical Science Support Center at the Institute of Aerospace Medicine that is part of the German Aerospace Center (DLR) in Cologne, Germany, Anken supports space experiments related to biomedical issues. In parallel, he holds a Professorship of Zoology at Hohenheim University near Stuttgart.

When he isn't collecting Sumerian-Babylonian Cuneiform scripts, looking for fossils, searching for stone-age artifacts, classifying Roman coins, exploring the cathedral of Cologne, or pretty much gathering any bizarre thing he can find himself with, Anken tries to understand how exactly gravity works on vertebrates. Instead of rats, he works with fish.

There are many reasons for that. Fish are robust creatures, despite their frail appearance. Some species don't care if it's a bit too cold or a bit too warm. "That's why one cannot use every species of fish for such experiments," Anken says. "Cichlid fish are just great, zebrafish are probably not. And one cannot use fish living in salty sea water. Maintenance in space would be then a very severe logistic problem as sea-water aquaria are even hard to handle on Earth."

Fish are also widely available; they reproduce readily, are easy to raise, and are cheap. Less than a hundred thousand dollars can get you a space aquarium with fifty larval (that is, small) fishes. "We are talking here about an aquarium for 50 fish for spaceflight, not about an aquarium to be set up in your living room on Earth," he says. Sending one human being to space may cost several million dollars.

According to Anken, fish subjects as experimental models have another advantages. "Mice and rats are beautiful. They have red or nice and soft brown eyes. So if you send one into space, everybody will say 'ah! poor, poor animal!'" It's different with fish. "You send fish into space and they turn, they tumble, they cannot orient themselves anymore, and people see that and they love it."

Most importantly for Ralf Anken, fish, because they float freely in water, are highly sensitive to alterations in gravity conditions. What's more, their balance system is similar to that of higher vertebrates, including humans. Our balance is regulated by a squid shaped labyrinthine set of organs called the vestibular system. The overall balance system in the brain collects information from our eyes, inner ear, and position sensors in the joints and muscles. It determines our body's position, stabilizes us, makes our movements smoother, and prevents us from stumbling over our feet when walking or running. Its functioning also explains why the Earth seems to keep moving when you stop spinning: a compensatory vestibular reflex has continued to move your gaze in the opposite direction of your movement.

Inside the vestibular system are a pair of semicircular canals and a collection of small structures called otoliths, located within sac-like cavities. The semicircular canals stabilize vision during motion. They respond to how fast you rotate your head; but they don't sense gravity. The otolith organs –tiny sacs filled with fluid and crystals (the oto- or statoliths), lying on the sensory portions of the inner ear– are the main gravity sensors. Their inner walls are covered with sensory cells that have hair-like projections reaching in towards a mass of dust-sized crystals – tiny stones- that rest on them when gravity is present and your head is straight.

Just a small tilt of your head and the fluid filling these sacs will shift following gravity's pull. The stones will drift too, bending the hair-like projections, which inform the brain of the repositioning of your body, or the body of a tiny pup inside the womb of a pregnant rat.

In the weightlessness of space flight, the otoliths lose their orienting ability because they lose their continuous input from gravity. A single inner ear stone consisting of several hundred thousand mini crystals, in the inner ear of humans, weighs about 10 micrograms. In a fish weighting five grams and measuring two inches long, otoliths are made of only one single crystal, but a large one: it would weigh about 20 micrograms. In a fish the size of a human, that inner ear stone would be the size of a ping-pong ball. "So you can see that in fish, otolith stones are easy to spot. You can dissect them without problem. It's good to work with them," Anken says.

His experiments have involved sending aquariums aloft inside space shuttle orbiters, satellites, Brazilian suborbital sounding rockets, modified commercial planes, and drop-tower capsules, providing him with microgravity times ranging from days to seconds. "And you're thinking, 'how many fish will return alive?' " That's the most important question for Anken because many support systems tend to fail during the missions. Small details like the aggressiveness of individual fish become relevant. "It´s larval fish. They eventually fight and kill each other," he says.

When a spacecraft returns bearing one of his experiments, and the module containing the fish is opened, the first thing Anken does is count the survivors. "It's stress, stress, stress. You're awake for about 30 hours without sleep. All you can do is wait to receive the next order, and then you rush to get the fish, and then dissect them trying not to make a single mistake," he recounts, "It's a lot of stress because these fish are expensive: roughly $2,000 per fish! "You can't make a mistake".

Eventually, though, frozen fish samples are prepared and distributed between Florida scientists and Anken's colleagues back in Germany. The ones headed to Germany make it home in the most efficient and simple way conceivable: inside Anken's own luggage. "Fully approved by authorities of course."

Anken's experiments' outcomes have ranged from the successful to the tragic. His fish were aboard space shuttle Columbia when it disintegrated before landing in 2003. "Everybody remembers where they were the day the terrorists attacked the twin towers in New York City," recounts Anken. "I remember where I was; and I also remember where I was and what I was doing the day Columbia exploded." He was with his children playing in the snow in his back yard. "My father came to the balcony and called out saying the shuttle had crashed. And I said '*merda*, shit, don't joke that way'," he remembers, "and my father said, 'I'm not joking', so I went to the living room, turned on the TV and checked…" Anken grieved over the loss of the astronauts. But he also had a professional loss. "I was so in need of those results," he says. "So much work, so many logistic constraints, so much paperwork, so much money; and it crashed! I went into some sort of down," he says.

"Once I had learned to believe that Columbia in fact had crashed, I made some phone calls to colleagues. It was within about two hours after the crash that we had a plan how to proceed," Anken remembers. He decided to try for bargain ways to simulate gravity-less or extra-gravity conditions. "I didn't need to get perfect weightlessness, but something… cheap," he says.

"Once upon a time, I thought about riding a roller coaster with my aquarium." He hasn't done that yet, but he found something better. "I thought, well, actually, we can get free fall if we open the window, take the aquarium with the fish, and throw it out the window. If the building is twenty meters high, we can get two good seconds of free, cheap, fall." But how could he succeed in keeping both the aquarium and the recording camera from breaking into pieces with the fall?

"Ideally with a bungee rope," he says. And, instead of a building, a three-story crane.

Anken took a rubber rope, hooked it to the crane, secured the aquarium to the end of the rope, and threw it from the crane. That produced intervals of changing accelerations. "The thing went down, we'd pull it up again, it went down, we'd pull it up, and so forth. We did that for twenty minutes, three days in a row."

What they produced was some sort of diminished gravity, quite close to microgravity, though not exactly. Every time the ropes caught the payload, Anken would get approximately 2 g of hypergravity. And as soon as the payload was freed from the power of the ropes, entering "a sort of small parabola," the simple procedure would offer him a single second of free fall.

Eventually, Anken abandoned the experiment. "Too short, too imprecise free fall, just changing accelerations." No particularly interesting response by the animals. He turned to a slightly more expensive drop-tower in Bremen, Germany, providing him with a free fall, at true microgravity, lasting exactly 4.7 seconds at 150 meters.

Anken's experiments have taught him and his colleagues interesting things about the workings of the vestibular system. They have noticed that otolith stones grow more slowly under conditions of hyper-gravity. This increased strength in the force of gravity, such as would be experienced on the surface of a planet with greater mass than our own, can also be replicated in a centrifuge. "When we place a fish in a centrifuge, producing a gravity force of three times that of the Earth, 3g, and leave the animals there for two or three weeks, or even just five days," explains Anken, "we've seen the growth of the otolith stones proceed slower than in normal gravity." In microgravity, the opposite seems true. Otolith stones grow faster and heavier than they do under gravity conditions on Earth. "It's as if the system was saying, 'oh oh, I don't feel anything. What's happening? Do I have stones?' and so it grows them faster to compensate'."

These findings apply regardless of the asymmetry of the otolith stones. "There is one inner ear on the right and one inner ear on the left of a vertebrate animal. Most individuals (fish and human) have asymmetric otolith. That means that a left otolith, for instance, either in a fish or in a human, may be heavier or larger than a right otolith, or the other way around," Anken explains.

"In some cases, asymmetry is high, in other cases, it is low," he says. "It depends on the individual." In some individuals, this asymmetry is so high that the brain cannot compensate for the difference, especially in weightlessness.

"In particular individual cases, a high asymmetry does not pose a problem to the individual, because the brain and other sensory organs simply work great and can compensate," Anken adds. In cases where the brain or the other sensory organs do not work that well, however, an otolith asymmetry turns out to be a problem. "It is not known why the brain and the sensory systems work great or not that great in individuals," he says.

Anken believes this might account for the motion sickness that people experience inside a moving boat, a car or a plane. "So far, it´s a theory," emphasizes Anken. He says the theory is most heavily backed up by his research on fish, "but there are even some experiments on humans, not related directly with our fish studies, which indirectly also speak in favor of it."

How exactly does it explain motion sickness?

At Earth's gravity, the brain uses many sensory organs to understand our postural control, judging which one of the sensory entities works correctly and which one makes mistakes. “Let´s say that your left stone weighs 1 gram, whereas the right one has two grams. The brain sort of “knows” that and corrects the incoming messages by one gram (difference),” explains Anken. “In Space, there would not be that one gram difference on physical ground,” because both stones do not have any weight, i.e., their weight is equal. “The brain – stupid as it is – would continue compensating for the one gram which actually is not anymore an issue. Meanwhile, other sense organs would be smarter than the inner ear. They would tell the brain ‘We are weightless!’”

As Anken tells it, the inner ears say “this is nuts” but the brain would not match the info that’s coming in from the other sensory organs. The brain then would face an intersensory conflict. “‘Who the heck is telling me the correct information regarding postural control? The brain cannot solve, at least not immediately, the problem. It will then decide that it, itself, is not working correctly,” Anken says.

“This must be due to poisoning, thinks our stupid brain. Then, it would order that a particular brain part be activated to execute vomiting of the organism…” A person’s feeling of dizziness on boats, cars, or planes, might be a result of this. It could even account for a fish’s own motion sickness. “Yes, fish can get motion sick. They can even vomit,” Anken says.

Some studies suggest that people with asymmetric otoliths experience ‘lighter’ motion sickness symptoms compared with people who do not. “You can’t directly measure otolith asymmetry in humans, though. That´s why we take fish”.

In 2007, Anken sent his fish on a parabolic adventure over the Atlantic Ocean in an Airbus A-300 ZERO-G. The journey was reminiscent of those roller coaster rides at the local Fair, but this time not only people were subjected to all the excitement: fish too. And just like many a roller coaster rider, they got motion sick.

When fish get motion sick their movements go berserk. They swim in spirals resembling a screwdriver, and even loop. “We wanted to know if this turning could be understood as a consequence of the asymmetry of the otolith stones,” explains Anken. “What we saw was that animals with a particular high asymmetry went motion sick, animals with comparably symmetrical stones did not go motion sick.”

In microgravity, despite the fact that there is no weight difference in the otoliths from one side to the other, and though they are not loaded, there is still a compensation mechanism taking place. The asymmetry of the otolith stones is what produces that compensation: The bigger the asymmetry the greater the compensation."

Disturbance of the vestibular system was also the cause of the disorientation of April Ronca's rat pups. As such, it may provide one opportunity to explore the question of gravity's role in the evolution of life on Earth.

Sensory systems follow a number of general principles. As April Ronca tells it, in all species ever looked at, birds, and different kind of mammals, the sensory systems begin to function in the same order. It's an evolutionary conserved order: first come the chemical sensors, then the somatosensors and vestibular sensors, and lastly, the auditory and visual sensors develop.

The key is in the timing. The formation of these sensory systems occurs at different times relative to birth. In humans, for instance, all of these sensory systems are functioning before a person is born. "In rats, only the very early senses are functioning at birth. "This makes rats a very good model to study these systems in isolation before having all other systems interact with one another," Ronca says.

During STS-66, the crew of astronauts filmed the pregnant rats in their animal housing. The footage of the flight revealed movements of the dams' bodies corresponding to pitch (z), yaw (y) & roll (y). When Ronca and her colleagues looked at the differences between flight rats and their earthbound counterparts, they found no discrepancy in the vertical movements displayed by both groups, but they did observe seven times more y-movements among the rats in flight.

Wondering what effects, if any, this would have on the developing pups inside the rats' wombs, Ronca designed another set of experiments. She didn't know if the fetuses could detect and respond to biological stimuli normally present in the uterine and perinatal environments. She decided to observe the sensory environment around the pups before they are born, to establish a sense of what sensory 'normalcy' feels like for them inside their mother's uterus. Then, Ronca and colleagues created simulations of prenatal and birth stimuli and presented them to fetuses that had been externalized from the womb so they could be monitored, but that had intact umbilical connections to the dam.

Ronca's team simulated the mother rat's contractions by putting pressure on the fetuses with a balloon placed against their mother's uterine horns. "We simulated the mother's rearing by tilting the pup," she says. "And we measured the pup's heart rate response by tiny electrodes attached to the front and back of the animal."

The response was immediate. “Each time we tilted them we got a heart rate response; when we compressed them we also got a heart rate response,” says Ronca. “This tells us there’s a detection of a maternally produced event.” In other words, what the mother is normally doing has an influence on fetal development, and possibly, on the development of the sensory systems.

Ronca set out to make an experiment that only tests the vestibular system. “We were able to separate two subdivisions of the vestibular system: the otolith organ and the semicircular canal,” Ronca explains. “With this kind of a model, because developing in space will form an otolith that is deprived, the function of the semicircular canal is going to increase.” This means that anything stimulating the semicircular canal will have a bigger impact. “The result was a large deceleration of the heart rate in the flight animals.”

These results were distinguished from the previous ones by the age of the pups involved. While in the first experiment the pups were one to a few days old, the second experiment observed younger pups – pups still in development inside their mother’s womb. “And here the flight animals are showing a response but the controls are not. This suggests that greater stimulation due to the mother’s seven times more head-to-tail rotations, or rolling movements, in the weightlessness of space increases the development of that sensory system –the component of the vestibular system called the semicircular canal.”

The effects seem to extend beyond the level of stimulation of a part of the vestibular system; Ronca and her team have even observed changes in the brain connectivity. Reared without gravity, the pups have brains that look different.

“We saw that in flight the branching patterns in the axons were much more limited,” she explains. “There were relatively few branches in the brain’s axons of the flight fetuses compared to the amount observed in the brains of controls. These are the axons of neurons moving from the otoliths into the midbrain, the area of medial vestibular nucleus in particular.” In an environment lacking in gravity, unloaded otoliths during development may be sending information leading to changes in neural architecture. Because the otoliths are unloaded, that part of the sensory system is not stimulated, “and the flight animals do not make these connections.”

Can the pups regain the capacity to make these connections? As of yet, Ronca doesn’t know. At least in the vestibular system, as both Ronca and Anken have shown separately, the effects of gravity are a structural part of our physiology. The question remains whether that is the end of the trail, or whether gravity is entertaining itself on an even more microscopic level within us.

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A little knowledge is a dangerous thing. That's a maxim originally formulated by Alexander Pope in "An Essay on Criticism", from 1709. It has been employed, with slight variations, ever since then, and implies that having little knowledge about something can tempt one to overestimate one's abilities. But overestimation can sometimes lead to amusing scenes, which can lead to very interesting ideas.

Two years ago Stephen Moorman, an Associate Professor of Neuroscience and Cell Biology at the Robert Wood Johnson Medical School in New Jersey was addressing a room crowded with undergraduate students. He started his lecture as always:

"The gravitational force has remained constant throughout all of evolutionary history."

"That's not true," yelled a cocky undergrad from his seat among the crowd.

And Moorman said, "Yes. It's constant. The mass of the Earth hasn't changed since that giant chunk from evolving Mars hit its surface, and the Earth threw off that big rock that became known as the Moon. Ever since then, which is 3 and a half or 4 billion years ago, its mass hasn't changed. And since the gravitational force of a planet depends directly on its mass, the gravitational force of the Earth hasn't changed".

The incident didn't stop there, however, because this was an undergrad very confident in *his little knowledge*. "But the gravitational force changes on a daily basis," the undergrad argued. "It's rhythmic. You see it in high and low tides."

Tides regulate the lives of sea urchins, of surf clams, and of fisherman whose knowledge of when to catch their prey depends on their cycles. They power the bore waves of great rivers like the Amazon or the Severn. For many people they are romantic: Standing on a wide, beautiful sandy beach, few people would ponder the role of the Moon somehow causing this display. They would just enjoy the Moon's lightly visible apparition over the sunset's horizon. And fewer still would realize tides are fundamental – the real signature of gravity, the part that cannot be removed by going into free fall.

Undergrad Ardon Shorr told the truth. The gravitational field around the earth isn't exactly uniform. It is changing all the time. In different places, it pulls with different force. This is due to the small cyclic changes everywhere on the surface of the Earth caused by the gravitational pull exerted by the Moon and the Sun. The pull caused by the Moon, for instance, on different parts of the Earth, depends on how far each part is from the former. The change is very small: about two millionths of the total gravitational force. As a result, its effects are more drastically seen on the oceans because they are wide and not rigidly connected to the surface.

When an ocean's *center* faces the Moon, its pull by the latter will raise its elevation, drawing it away from its shores– this is known as a low tide. When an ocean's *edge* is nearest to the Moon its water will rush towards the shore causing a high tide.

The same happens when the oceans are on the side of the Earth farthest from the Moon. They are pulled towards it, but not as strongly as the rest of the Earth so they lag behind relative to the center of our planet, creating high tides there as well. Where the gravitational field around the earth is strong there will be low tides; high tides will occur where the field is weak.

The big ocean and its tides gave Moorman a Eureka moment at the lecture. All of a sudden an image of a tiny structure came to his mind: the primary cilium.

Most people have never heard of a cellular appendage called the primary cilium. It was featured in the scientific literature as early as 1898. "But researchers had long considered it a vestigial organelle of little functional importance," says Moorman. Lately, however, the primary cilium has become a hot research topic in the fields of cell biology and physiology. Errors in the cilium's assembly and function have been associated with developmental defects, diseases, and disorders.

Primary cilia are non-motile sensory organelles that exist on the surface of differentiated mammalian cells –one per cell. "The vast majority of the cell-types in the body has this single solitary cilium," explains Moorman. "The cilium is rod-like, like a tiny thread sticking out from the body of a cell, and for a long time there was no known function for it."

According to Moorman, the problem has always been that it's "very difficult to find." If you use an electron microscope you don't see these cilia on every cell. Whether you're able to see it depends on whether or not you happen to be searching in exactly the right place.

The primary cilium is tethered to the centriole of a cell – a barrel-shaped organelle found in most animal cells that plays a central role in the process of cell division. "The cilium essentially holds the centriole off in one spot at the cell's surface preventing it from replicating, which it has to do when the cell starts to divide," Moorman says. "Some people started thinking that was the only role the cilium played – regulating the location of this centriole, and therefore regulating cell division".

Then, eight years ago, the mysterious cilium whose existence had been known for a hundred years or so but whose function continued to be elusive, was spotted, in an embryological structure known as the primitive node. The primitive node identifies which end of the primitive streak –the furrow in the midline of the embryonic disk that develops into a vertebrate– will produce all other tissues of the forming body.

"The primitive node is the first indication of where the head is going to be –what end of the embryo will develop the head," Moorman says. "What's interesting is that the primary cilia at the primitive node actually rotate! And when you prevent them from doing so, half of the embryos will show reversal of the sidedness of the organs. This means that the heart and liver, for example, will be on the wrong side of the developed body."

The cilium has been linked to diseases such as Polycystic Kidney Disease (PKD), which occurs when clusters of cysts (noncancerous round sacs containing water-like fluid) develop within the kidneys, and other parts of the body. PKD affects 600,000 Americans, roughly the population of the state of Vermont, and about 12.5 million children and adults worldwide. Defects in this organelle, moreover, have also been associated with many other ciliopathies, or disorders of the cilium, including cancer, obesity, diabetes as well as a number of developmental defects.

Primary cilium's role determining the right and left asymmetry in developing embryos, however, is what grabbed Moorman's attention. "It caught my eye! I wasn't working on primary cilia, but that caught my eye!"

It has caught other researchers' attention too; they are now studying its action on normal tissues, and on the kidney. In normal tissues, the cilium is thought to coordinate a series of important signal transduction pathways. In the kidney, researchers think the primary cilium may be working like an antenna probing the extracellular environment and transmitting signals to the cell via other messenger structures.

At the time of his encounter with the daring undergrad, Moorman was already acquainted with the way these "fascinating little creatures" help determine the asymmetry of the body's organs, aid in maintaining the integrity of the kidneys, and is involved with coordinating signal transduction pathways in mammalian development, health and disease. Not too shabby for a small, thread-like structure that seems to like playing hide and seek.

He was also aware of the work of a group of researchers, Resnick and Hopfer at Case Western University, who calculated the force-detection sensitivity of the primary cilium. The group had determined that the cilium could detect shear forces across the surface of its host cell of approximately five femto Newtons. (A femto is a 1 preceded by fourteen 0's, that is, a quadrillionth of a Newton – the unit of force.)

"When a fluid flows across the surface of a cell there are shear forces at the cell's surface," Moorman says. "Any force that causes the cilium to bend should have the same effects as shear forces."

A force like gravity, for instance. After the encounter at his lecture, Moorman started pondering whether the primary cilium was sensitive enough to detect the cyclic change in Earth's gravitational field. Could it be that the primary cilium was the body's gravity's sensor?

Taking a typical diameter of a cell to be about ten millionths of a meter, and modeling it as a sphere, Moorman calculated its volume. Assuming the cell has the same density as water, he determined its mass. With the mass, and the magnitude for the change in the gravitational acceleration of the Earth produced by the Moon and the Sun, Moorman determined the force that a typical cell would exert on its primary cilium.

"Think about the cell and its primary cilium as a cherry with its stem," Moorman explains. Holding the stem so that it is straight out –parallel to the ground– the mass of the earth will bend the stem. "If the cherry is the cell body," he says, "I was trying to calculate the fluctuation in the bending of the stem due to the fluctuation in Earth's gravity due to the moon."

As Moorman estimated it, if the primary cilium was sticking out at perpendicular to the direction of gravity, it would experience a maximum force of 1000 femto Newtons, well within its range of sensitivity.

But even if the cilium was gravity's sensor, what was the big deal? What could the primary cilium do with that information? "That's when the research we had already done, looking at the development of zebrafish in microgravity simulators, started to coalesce in my mind," says Moorman.

He had observed that exposure to simulated-microgravity causes changes in the expression of genes in many different developing organs in live zebrafish embryos. "There are periods of time when the embryos appear to be more susceptible to the effects," says Moorman. Different organs in the body display different periods of susceptibility. "Curiously, the organ systems that are usually affected in astronauts during their stay in space, are the same ones affected by microgravity conditions in zebrafish."

Of all the organs in the developing embryo, the heart and spinal cord show greatest susceptibility to microgravity conditions. Their changes in gene expression are the most dramatic. The heart, for instance, is most sensitive between 32 and 56 hours post fertilization. That is when folding is changing the beating tube's shape. The heart's atrio-ventricular septum is beginning to form. It is possible that at this moment the developing heart is being influenced by changes in shear forces associated with blood flow which, in turn, are being influenced by changes in gravitational force. These changes in shear forces could be causing the alterations in gene expression while in microgravity.

Is the primary cilium informing the heart about these changes in gravity?

In order for a developing embryo to form the myriad cell types that will become the various organs and tissues that constitute its body, its cells must be able to respond to different concentrations of chemicals. This is what enables them to adopt their specific cell fates. In order to respond, cells must be able to regulate the expression levels of their genes.

The DNA of the cells' genes is used to make something called messenger RNA (mRNA). mRNA is used to make proteins. Proteins are what cells use to survive and to function. Everything in our bodies depends on proteins.

If you want to make, say, eight copies of a specific protein, how many copies of mRNA do you have to make? Certain cells might make two copies of mRNA, then use each copy to make four copies of the protein. Others might make three copies of mRNA, and then make either one, two or three copies of that same protein. The nucleus of the cell is what regulates this variability.

During development, it is the average number of copies made of mRNA that gets regulated to specify things like the fate of a cell. This is where the primary cilium comes back into the picture.

"The light switch protruding from the wall's surface of your room, say, is like a very small primary cilium sticking out of the cell's surface," Moorman says, "I flip that light switch, and the light in the ceiling is turned on. That is the cell nucleus. The primary cilium, like a switch, initiates a set of signals that are being sent to the nucleus." The nucleus uses *all* the signals it receives to say whether it needs to make five copies of mRNA from a specific gene, or wants to make six or seven. One of the signals from the primary cilium might allow the nucleus to tell the difference between needing to make five versus seven copies of mRNA.

The cell may be using the primary cilium to determine what it needs according to its gravitational environment. In the spinal cords of zebrafish embryos, for example, each segment initially has three different motor neurons that will innervate muscles. Each segment contains only one of each of the first two types of motor neurons. But of Cap, the third type of motor neuron, there can be one or two. Fifteen percent of the time, after a certain point during development, two Cap neurons remain in each segment.

In microgravity, however, two Caps remain 60 percent of the time. "So if you were to grow a zebrafish on the Moon, it might have Cap motor neurons in each spinal cord segment, and not fifteen, but perhaps 20 or 40 percent of the time," Moorman says. "Keep raising zebrafish on the Moon for a thousand years and maybe you will get zebrafish that always have two Caps in each spinal cord segment."

Removing the influence of the gravitational force does not seem to leave a lasting effect in the short term. "That has been seen in many cases, and with different organisms," Moorman asserts. "Chances are, though, that over evolutionary time scales, gene expression might get more variable when the stimulus it receives from gravitational forces is decreased."

"In that case," he says, "evolutionary changes might begin occurring more frequently… None of this seems like a big deal when we are referring to zebrafish. But remember that every cell in the human body also has primary cilia."

If primary cilia are the gravity sensors of our cells, and we begin spending more time in space, what could the consequences be for humans with primary cilia that are no longer stimulated by gravity?

Cells withdraw their primary cilia in order to divide. "Now suppose we move to another environment where primary cilia aren't stimulated, variability increases, and the cell fate adopted more frequently is that of a cancerous cell," Moorman says. "So if the levels of gene expression were to become more variable, there would be a higher probability that the cells become cancerous."

According to Moorman, there's a good probability that every cell in our body has the ability to stabilize the expression of the genes it contains to a certain level of variability. "Perhaps not in absolute terms, but maybe that's the one condition that would allow us to exist as we do," he says. But how is that information used? Is there any evidence that would suggest that it is used in everyday life?

Other animals might provide some information. "Take surf clams, for instance," Moorman says, "they mate at high tides, releasing their eggs and their sperm into the water. If you take surf clams and put them in a tank of water that is not connected to any large body of water, they will still release their sperm and egg at high tide, as if they could were able to detect the forces that are driving the tide."

Moorman thinks it might not be a coincidence that the average length of a menstrual period in a human female matches the lunar cycle. "Now, it is not in phase with the Moon, but the duration is the same on the average," he says. "I'm beginning to think that it might not be a coincidence. Maybe there are physiological processes that are fed by pathways that primary cilia are associated with." Perhaps cells, tissues, and maybe organ systems are able, after all, to monitor the gravitational force and use that information.

To date, there have been a lot of experiments exposing cells in culture to microgravity conditions. Researchers have noticed changes in gene expression patterns, "but nobody has taken the time yet to look for correlations between those changes and the activity of the primary cilium," Moorman comments. "It's on our to-do list," he confesses. If they did, they "might" be able to confidently assert that the primary cilium is the cell's gravity sensor.

"It would support the effects seen in cells in culture, like the fact that cells divide at higher rates in microgravity environments," Moorman says. "If cells divide, the cilium must have been absorbed. It the cilium has been absorbed, it might mean it hasn't been stimulated. This could be evidence supporting the solitary cilium's role as gravity sensor."

If this is true, if a gravity sensor has been found, does this mean that the one factor we always thought we had depended on was never really constant because we were equipped, after all, to sense its variations? Was the rate of our evolution and that of all other species on our planet influenced by tiny variations in Earth's gravitational field? Maybe it was those variations rather than its constancy that shaped us. Perhaps that is why we find the tides so romantic after all: because every single cell of our body, literally, can sense them.

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Some call it a factor of physical restriction. A baby will not be able to walk until all the bones that articulate with other bones inside his little body learn to negotiate with the muscles they are paired with, flexing and extending, trying and failing, refining his falling, until he succeeds in standing. And some day, when this baby's body has grown old, although by then he will have had a lifetime of practicing these negotiations with nature, gravity will pull him down, the strength of his bones and muscles no longer able to win the fight.

All ancestors of all living things have had to counter the gravitational force and win the battle to earn the freedom of movement over the surface of the Earth or within seas. From skeletal bones to actin, they have devised a variety of ways to overcome the force that shapes their form or limits their size. They have managed to sense gravitational information around them transforming any kind of acceleration into a biological signal that allows them to make sense of their world, and to survive within it.

Multi-cellular organisms, like April Ronca's rats, or Ralf Anken's fish, or humans, make use of the otoliths –their balance system- in organs like the inner ear to transform gravitational input into a body-own signal. Insects employ body extensions like club-shaped halters or sensilla. In vertebrates, sensing of gravity begins with the bending of hair-like cilia on sensory cells within the inner ear. Its apparently innocuous swaying opens and closes ion channels within the sensory cells, altering the electrical current passing through it, transporting it to the brain as a potential, received and interpreted there. Informed by this input, in cohesion to tactile, proprioceptive and visual cues, the brain understands the organism's orientation in space, helping it to control its posture, and to survive. Even unicellular organisms, like the *Paramecium*, possess a membrane-body with channels that open and close, interpreting changes in water pressure inside as a result of its orientation with respect to the direction of gravity. It can detect gravity magnitudes of 0.32g and above.

Despite measurements and studies, however, bone loss, atrophied muscles, nausea, salmonella, herpes, or very big-head tadpoles, humans will sometime soon return to the Moon, and will most likely engage fully in the project of reaching Mars with manned missions that will physically place a few earthlings on the surface of the red planet, no matter the consequences; in spite of any ubiquitous little cilium trying to influence our chances to escape.

One can speculate that trying to tweak our interaction with space is witnessing evolution in all its exotic splendor. Some organisms will probably be genetically better equipped than others to deal with the new environment we seek outside of our earthly home. Some would survive the transition process, while others, naturally, would not. The earthling that escapes Earth will become part of a new species: free to live beyond our earthly boundaries; bounded by its inability to return. Breaking the umbilical cord will require a transformation beyond the physical level, beyond the phenotype that defines a species. No longer tied to the earth, earthling no more, he will become an orphan, a nomad of sorts.

The ones who go further, those who even manage to reproduce in space will realize it isn't them surviving, but perhaps a slightly altered species –an altered version of themselves. Perhaps only an astronaut can at least try to fathom what it would feel like not to be tied to our planet anymore. Maybe only he or she can begin to ponder such melancholy – or excitement. It would be only pondering, though, because an astronaut, like all of us, is tethered still to our planet.

We need earth's gravity to move as we do, from the rhythm of our gait to its style to the specific muscles we use; we need gravity to look as we do, for our body's development to follow its plan, and our bodies to each take on the shapes that are so familiar to us, and so uniquely distinctive, from the distribution of organs inside a human body to the size and position of the head in a tadpole; we need earth's unique gravity strength even to be what we are, to recognize ourselves and our universe, and our place in it, as we do and always have.

Our identity as humans, as people, as earthlings, as inhabitants of the universe itself is linked to earth, tethered to it. Even the way in which we look at a tiny spider at work spinning its web is irrevocably linked to earth's gravity; we use its precision and symmetry on Earth as reference to what the outcome of its labor must be everywhere else, under any alternative condition. Earth itself is our reference inside the rest of the Cosmos. Earth's gravity is our context.

We do not seem to know how to escape. For now only one prescription for gravity has been written –the alternative, if it exists, appears to have been rendered with an invisible ink we are not yet able to read. Perhaps we will be able to attempt our exit, but we don't know how yet. Maybe we will venture into the moon and Mars; most surely, we'll try. For now, though, we remain tethered to Earth, because to be what we are, what we've always known we are, even if we stray, we must return.

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