The Impact of Space Missions on Humans1

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Abstract *From Yuri Gagarin's first manned spaceflight, the focus has been on investigating the function and changes in the human body across the full spectrum of spaceflight during all missions. Space travel impacts the whole body and affects all our organs and psyche without exception. As soon as we are exposed to microgravity and the Earth's gravity ceases to act on our bodies, we will notice changes such as osteoporosis (spaceflight osteopenia), a decrease in red blood cells (space anemia), and various symptoms observed during the missions, and the list goes on. Although many people are unaware that the benefits of space programs have affected almost everyone on Earth, the truth is that there is a wealth of inventions and discoveries that have come about solely because of space programs.*

INTRODUCTION

Human spaceflight has evolved significantly since its inception. Early space missions focused primarily on survival, as astronauts faced the challenges of launching into orbit, enduring the harsh space environment, and safely returning to the Earth. The first human spaceflight in 1961 marked the beginning of an era of exploration beyond our planet. Over the years, space agencies like NASA, Roscosmos, and others developed more advanced technology allowing longer missions and more complex tasks, such as spacewalks and docking at space stations. The creation of space stations like Skylab, Mir, and especially the International Space Station enabled humans to live and work in space for extended periods, advancing scientific research in microgravity. Today, human spaceflight is moving toward sustainability and permanence in space. The ISS (International Space Station) serves as a model for continuous human presence in low-Earth orbit. At the same time, upcoming missions aim to establish long-term habitats on the Moon (via NASA's Artemis program) and eventually Mars. These efforts require advancements in life support systems, radiation protection, and sustainable energy sources, as humanity pushes toward living and working in space indefinitely.

Researchers are using the data to develop even more effective procedures and equipment to help astronauts perform their tasks in a healthier manner. Engineers are also using the information to develop spacecraft and other life-support equipment that will ensure the long-term success of future missions. Ongoing research helps to improve and evaluate health standards, physical fitness programs, nutritional health protocols, and miscellaneous training standards. It is essential to understand the impact of space on humans, as we are about to leave the International Space Station in low-Earth orbit and head towards our next destination, the Moon. Missions lasting longer than a year have been carried out aboard the International Space Station to give researchers an even more detailed picture of what happens to our bodies when we live in this hostile environment for longer periods of time. Research has shown that a one-year mission has a different effect on humans, which is why exploring this area is essential if we are looking towards our even more distant goal of Mars.[1] NASA (National Aeronautics and Space Administration) is conducting continuous research on the risk factors for a trip to Mars and has grouped them. It is called RIDGE, which stands for Space Radiation, Isolation and Confinement, Distance from Earth, Gravity fields, and Hostile/Closed Environments.[2]

GO THERE AND COME BACK

From the very first moment, space travel is a stressful experience for the human body. Even the launch of a rocket is already an extreme load, while the body is subjected to several times the normal gravity. On Earth, under normal, resting conditions, we experience an acceleration of 1G (gravitational force). During the launch of a rocket, the human body can be subjected to an acceleration force of up to 4G. An unexercised person can tolerate approximately 3G, but above that, they may lose consciousness. The vertical G-force is harder to withstand than the force applied in a direction to the spine, as blood drains away from the brain and eyes. A significant G-force can have negative effects, such as the heart no longer being able to deliver blood efficiently to the organs, resulting in poor circulation and insufficient oxygen to the brain and other parts of the body. In more extreme cases, loss of consciousness may occur, often preceded by a deterioration in vision, such as tunnelization, or loss of color vision. Most spacecraft are designed so that the effect of the G-force is spread over a comfortable spectrum

*Figure 1: Inside the capsule (*https://www.russianspaceweb.com/soyuz-ms-09.html *Downloaded: 19.08.2024.)*

1 Cranford, Nathan, Turner, Jennifer: *The Human Body in Space.*

2 Johnson, Doug: *We don't know why, but being in space causes us to destroy our blood.*

using more favorable chest-back acceleration in the direction of the X-axis, instead of the traditional Gz overload in the head-foot direction, shifting blood from the head to the trunk and lower extremities.[3]

SPACE AS A HABITAT

The environmental effects of space are lethal to living organisms unless proper protection is applied. In a vacuum, there are a number of threats, the most obvious of which are oxygen and pressure deficits, but we must not forget extreme radiation and temperature fluctuations. Exposure to space can lead to hypoxia, decompression, and other diseases like hypocapnia. The effect of hypobaria (during decompression) might be hypocapnia (decreased pCO_2) but onboard the ISS, the main threat is hypercapnia (elevated CO_2 level) due to the exhaled air pockets without convection and less effective CO_2 absorption. There is about a 10-fold increase in ambient CO_2 levels, which might be a significant cause for SANS (Space-Associated Neuro-ocular Syndrome, involving headache, blurred vision, and decreased visual acuity). The top of these symptoms is experiencing cell mutation and deformation due to high-intensity photon impacts, which pose a constant threat to those in space.[4]

RADIATION

Radiation is nothing more than the propagation of particles in space or materials in the form of SPE (Solar Particle Events) and cosmic radiation. Radiation is one of the most dangerous effects humans can face during space travel. It poses a threat at the cellular level, as it can significantly affect the structure of DNA (deoxyribonucleic acid), thus deforming and destroying cells. There are acute symptoms, which can be classified as mild, from which recovery is almost guaranteed: diarrhea, some changes in the blood, and vomiting. These symptoms are not expected to occur if the astronaut is exposed to normal radiation, but if a solar flare were to occur while in space, much more serious problems would be expected due to the high levels of radiation. When confronted with this eventuality, astronauts on the International Space Station currently orbiting overhead will implement a pre-rehearsed and safe protocol to regroup in a shelter that offers the greatest protection against radiation and wait for the danger to end. The primary concern about space radiation is its long-term impact on astronauts. The long-term effects may include cataracts, increased cancer risk, and infertility. Certain health effects can skip a generation and may mutate through mutated genes in the descendants of the exposed person. The development of po-

3 Forster, Estrella M.: *A database to evaluate acceleration (+gz) induced loss of consciousness (g-loc) in the human centrifuge.*

4 Pilmanis, Andrew A., Sears, William J.: *Physiological hazards of flight at high altitude.*

tential health problems is influenced by the level of exposure, the sensitivity of the astronaut to the adverse health effects of radiation, and various other factors. These other factors include the altitude of the spacecraft above the Earth, the length of the mission, the protection of the spacecraft, the type of radiation, and the conditions of exposure.

The human body, as an object exposed to radiation, also has parameters that influence the extent of damage. These key parameters include age and gender, as well as overall health, which is closely monitored in astronauts to ensure they are free of any issues.[5] NASA experts have pointed out that a possible mission to Mars could result in a particularly high radiation load during the journey, based on measurements from a probe sent there in 2011.[6] If the first mission arrives on the surface of Mars in the future, they will not be able to fully relax there either, as the radiation measured on the planet is massive, often twice the normal level.[7] Even long-term, low-energy levels of radiation can provoke DNA damage, possibly leading to carcinogenesis or fetal malformations without a real threshold. Based on the Radiation Assessment Detector measurements of NASA's Curiosity rover during its transit to Mars, the astronauts would be exposed to a minimum of 660 ± 120 millisieverts during a full mission. NASA's career exposure limit set for astronauts is around 1000 millisieverts (as analog to nuclear industrial plant workers, maximizing the dose at 100 mSv for any 5 consecutive working years, aiming to keep it ALARA [as low as reasonably achievable]). Powerful ionizing radiation particles can target living tissues within the body throughout the mission, so presently the unpredictable radiation burden might be even showstopper from ethical aspects.[8]

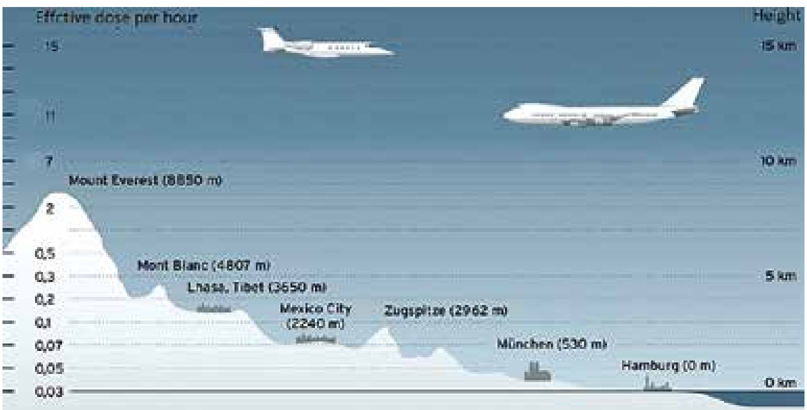

*Figure 2: Aircrews' radiation exposure (*https://www.bfs.de/SharedDocs/Bilder/BfS/EN/ion/radiation-protection/aircrews-radiation-expose.jpg?__blob=poster&v=2 *Downloaded: 10.09.2024.)*

5 Canadian Space Agency: *How does radiation affect the human body in space?*
6 Kerr, Richard A.: *Radiation Will Make Astronauts' Trip to Mars Even Riskier.*
7 Scott, Jim: *Large solar storm sparks global aurora and doubles radiation levels on the Martian surface.*
8 Townsend, Lawrence W.: *Implications of the space radiation environment for human exploration in deep space.*

VACUUM

Decompression sickness, which occurs as a result of exposure to a vacuum, develops when the human body experiences a rapid and drastic decrease in atmospheric pressure. Although gas exchange continues for a very limited time period in the vacuum of space, all gases, including oxygen, are eventually purged from the body. If the body does not receive enough oxygen beyond a certain point, the astronaut may lose consciousness and, in the worst-case scenario, their life. During decompression sickness, the nitrogen that is normally dissolved in the body tissues and blood comes out as a solution due to the sudden drop in pressure, forming bubbles throughout the body. These small bubbles can lead to various symptoms, including a feeling of numbness, aching joints, and even death if a person is exposed to a vacuum for at least 90 seconds. In practice, the process is more rapid. In 10 seconds, the subject would be unconscious. After 60 seconds, not only the nitrogen bubbles but also the evolving ebullism (vaporization of fluid water at body temperature) can demolish effective circulation due to the boiling effect.[9]

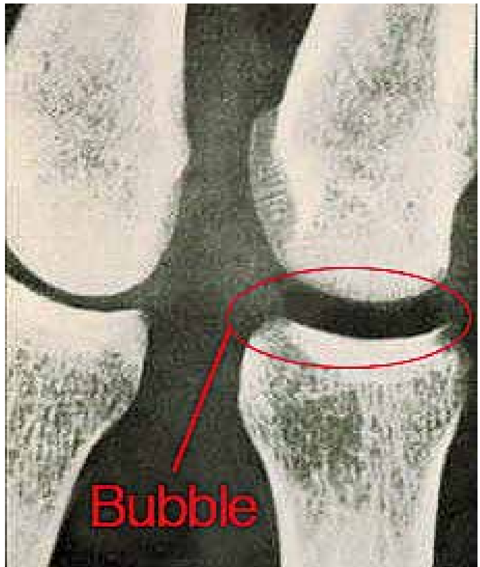

Figure 3: Visible effect of peripheral decompression sickness (bends symptoms) (https://www.asc-csa.gc.ca/eng/astronauts/space-medicine/decomp.asp *Downloaded: 19.08.2024.)*

Another present and unavoidable problem is hypoxia. We refer to this condition when there is not sufficient oxygen circulating in the blood, tissues, and cells to maintain normal bodily functions. Humans are not designed to exist at the altitudes where today's research takes place. The lungs lack the capacity and ability to function adequately in high-altitude, low-oxygen-density environments.[10] The main danger of hypoxia lies not only in the obvious functional problems but also in the fact that people generally do not feel or notice the onset of the condition. As a result, the decline in cognitive and physical performance may go unnoticed for a time. One method of preventing hypoxia is to pressurize the aircraft cabin, artificially increasing air pressure. Another method is to increase the amount of oxygen inhaled, such as by using an oxygen-generating system, which may involve wearing an oxygen mask. Modern Russian and American space suits fully perform both functions, making the likelihood of any vacuum-related incident during spacewalks very low.[11]

9 Landis, Geoffrey A.: *Human Exposure to Vacuum.*
10 Balog László et al.: *Bevezetés a sportdiagnosztikába.*
11 Southern Wings: *Hypoxia in aviation.*

TEMPERATURE

The temperature in space is either extremely high or extremely low for the human body to withstand. During a spacewalk, astronauts are exposed to a temperature fluctuation of 240 degrees Celsius. When they are on the sunlit side of the Earth, the temperature is +120 degrees Celsius, while on the shaded side, it drops to an equally extreme –120 degrees Celsius.[12] In space, heat loss occurs through radiation, as there is no suitable medium for heat conduction. Of course, astronauts venture into the harsh environment of space wearing appropriate suits, so there is no risk of freezing. The other factor is the unfiltered, direct sunlight to which a person could fall victim, as it causes significant heating of various surfaces. Additionally, ultraviolet radiation can inflict serious harm on a person in this hostile environment. Based on the experiences of past missions, specialists and engineers have developed the essential tool for staying in space: the spacesuit. This suit can be seen as a miniature spacecraft, as it performs the same vital function—keeping a person alive. Among its features, the spacesuit effectively handles extreme temperature fluctuations thanks to its multi-layered material. Additionally, a special liquid cooling system ensures a comfortable temperature for the astronaut inside the suit.

ZERO GRAVITY

We experience the sensation of weightlessness when gravity has little or no effect on our bodies. In practice, according to the laws of physics, gravity exists everywhere, as it is the force that keeps celestial bodies in their orbits. However, in Earth's orbit, a person does not perceive this force at all.[13] This sensation is similar to what we experience on a roller coaster during a sudden change in direction in an amusement park.

In fact, it is not just the feeling that is the same; it is also the underlying factor that causes it. The International Space Station, for instance, is in a constant state of freefall around the Earth. However, its forward velocity perfectly matches the rate of its fall toward the planet, resulting in the astronauts inside not being pulled in any specific direction. As a result, they float. At first glance, this might sound quite comfortable, but in reality, this condition leads to numerous health issues. The most discussed are bone density and muscle loss, but many other problems also arise during a long-term mission. One of the primary missions of the ISS, for example, is to study these effects so that, armed with valuable data, we can embark on future long-term and distant missions more safely as we continue our explorations beyond Earth.

We are well-adapted to Earth's surface conditions, so in response to weightlessness, various physiological systems start to change and, in some cases, deteriorate. While most of these changes are

12 NASA: *Spacewalk Spacesuit Basics.*

13 Howell, Elizabeth: *Weightlessness and its effect on astronauts.*

Figure 4: Floating in weightlessness
*(*https://phys.org/news/2016-10-flight-gravity.html *Downloaded: 10.08.2024.)*

temporary, some can have lasting effects on human health. After a certain period of time, these effects impact astronauts' performance and lead to a decrease in their ability to work. This happens as the risk of injury increases, the circulatory system weakens, and oxygen intake deteriorates.[14] Since 65–72% of our body is made up of fluids (more variation in organ level), gravity tends to force them into the lower regions. However, humans have perfectly adapted to this and are able to compensate for this phenomenon. If we disrupt this fluid flow by eliminating gravity, we can induce an overall cephalad shift, leading to changes in the fluid content of the inner ear, as well as issues with vision, taste, and smell.[15]

SPACE SICKNESS AND SPACE ADAPTATION SYNDROME (SAS)

The very first and most common symptom that astronauts notice during the initial period of weightlessness is SAS (space adaptation syndrome), as well as space motion sickness. It is the reverse of terrestrial motion sickness, arising when the environment and the individual seem to be moving relative to each other visually, even though the vestibular system does not provide a matching

14 NASA Glenn Research Center: *Exercise Physiology and Countermeasures Project (ExPC): Keeping Astronauts Healthy in Reduced Gravity.*

15 Shamei, Arian et al.: *Postural adaptation to microgravity underlies fine motor impairment in astronauts' speech.*

sensation of bodily movement. Symptoms of space sickness include nausea, vomiting, dizziness, headaches, fatigue, and general discomfort. The first incident of space adaptation syndrome was reported by astronaut Gherman Titov in 1961.[16] Space motion sickness is slightly different, lasting for 4 days and affecting even 60–70% of astronauts (in the Apollo program as well). Space adaptation syndrome comprises mainly the cephalad shift-induced cardiovascular alteration, with less effective blood volume and "puffy head, birdy legs" shape. Spaceflight Associated Neuro-ocular Syndrome (SANS) is also a recognized effect, which can generate eye and brain changes during long-duration spaceflight. The long-term health effects are uncertain, but they are being actively monitored and studied. In weightlessness, blood and cerebrospinal fluid shift toward the head, which is thought to be the root cause of structural changes in the eyes and brain. Long-duration astronauts may experience some or all of these changes, with individual biological differences. These vision changes can affect an astronaut's performance during flight, and the longer they remain in space, the more they may be affected. While many astronauts experience these effects only during their time in space, some changes may be permanent. Researchers are exploring solutions, including fluid shift countermeasures, to prevent SANS and to assess any long-term health effects.[17]

SPACEFLIGHT SARCOPENIA AND OSTEOPENIA

A significant consequence of long-term weightlessness is the loss of bone and muscle mass. In zero gravity, astronauts exert little to no pressure on the back or leg muscles used for standing, causing these muscles to weaken and shrink over time. As a result, some muscles deteriorate quickly, and without regular exercise, astronauts can lose up to 20% of their muscle mass within just 5 to 11 days. The muscle fiber composition also changes, with slow-twitch endurance fibers, essential for maintaining posture, being replaced by fast-twitch fibers, which are inadequate for heavy labor. Advances in research on exercise, hormone supplements, and medication may help preserve muscle and body mass. The functional inactivity of "antigravitational muscles" results in muscle atrophy, up to 50% muscle mass loss, and a decrease in muscle strength. The muscular atrophy seen in astronauts is very similar to deconditioned bed-rest patients, and upon return to Earth, some astronauts experience difficulty simply maintaining an upright posture with muscle soreness and tightness. Major postflight impairments require a proper rehabilitation program after returning to 1G gravity on Earth: the full recovery of muscle mass and strength can exceed 2 months.[18] [19] Bone metabolism also changes in the absence of gravity.

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16 Delft University of Technology: *Why do astronauts suffer from space sickness?*
17 Fong, Kevin: *Moon landing: space medicine and the legacy of Project Apollo.*
18 Payne, Michael-Williams et al.: *Space Flight Rehabilitation*
19 Springel, Mark: *The human body in space: Distinguishing fact from fiction.*

In a typical Earth environment, calcium is deposited, and bone is built where the skeleton experiences stress. However, in a microgravity environment, where there is no such stress, bone metabolism significantly decreases.

Astronauts on Mir experienced an average bone loss of 1–2% per month. By comparison, the elderly typically lose 1–1.5% of bone mass annually, while postmenopausal women experience a loss of 2–3% per year.[20] The degree of bone loss is so dramatic that the risk of fractures is significantly increased, and symptoms similar to osteoporosis can be observed. In Earth's gravity, bones continuously regenerate through an advanced system that involves signals from specialized bone-building cells, known as osteoblasts and bone-degrading osteoclasts. These systems are interconnected, ensuring that whenever bone is broken down, new layers are formed to replace it—both processes occur together in a healthy adult. However, in space, microgravity leads to increased osteoclast activity. This becomes problematic because osteoclasts break down bones into minerals that are then reabsorbed by the body. These two cells do not respond properly to each other's presence, preventing bone formation. As a result, bone loss continues without regeneration. The abnormal behavior of these specialized cells was observed around the pelvic bones, as this area typically bears the most weight. Studies on mice have shown that just 16 days without gravity are enough to cause bone degeneration. Increased blood calcium levels from bone loss can lead to hazardous calcification of soft tissues and the possible formation of kidney stones. It is still unclear whether full bone regeneration occurs after returning to Earth. Observations of astronauts have shown that after spending 3–4 months in zero gravity, it takes approximately 2–3 years to regain nearly full bone density.[21] To prevent and minimize the effects of this undesirable phenomenon, the International Space Station is equipped with several tools. They have installed two specialized treadmills, to which astronauts are secured with elastic bands, a stationary exercise bike, and weight machines that use springs to achieve the desired effect.

Figure 5: Load-bearing treadmill exercise with gravity-simulated resistive straps (https://www.newscientist.com/article/dn11538-even-in-space-running-a-marathon-is-an-uphill-battle/ *Downloaded: 17.08.2024.)*

20 Hullander, Doug, Barry, Patrick L.: *Space Bones.*

21 Rodan, Gideon A.: *Bone homeostasis.*

Astronauts are required to exercise for at least 2 hours daily to minimize muscle loss. During long-term missions, astronauts wear compression trousers to help reduce the process of bone loss. Compression trousers mainly prevent fluid shift to the lower body in the reentry phase, minimizing orthostatic tolerance. Suits with resistive straps or GLCS (Gravity Loading Countermeasure Skin) suits apply Earth-like loading to help maintain bone mass.[22] We can also help reduce bone thinning through our diet by increasing calcium and vitamin D intake, which is controversial, regarding kidney stone risks. Various drug treatments currently used or proposed for osteoporosis, such as hormone therapy (estrogen or progestin), selective estrogen receptor modulators, bisphosphonates, teriparatides, and human parathyroid hormone are also powerful osteoanabolic agents. However, it is not yet known if they will offer the same benefits in space as they do for osteoporosis. Currently, space agencies are also deploying advanced computational systems to understand how muscle atrophy can be reduced in the state of weightlessness.[23]

FLUIDS (SPACE ADAPTATION SYNDROME)

In space, people experience continuous fluid loss, leading to a potential 22% reduction in blood volume. This effect becomes evident upon returning to Earth, where the decreased blood volume can cause problems, such as severe dizziness, while standing. The phenomenon occurs because Earth's gravity pulls fluids, including blood, toward the legs.[24] Consequently, the already diminished blood volume is further directed to the lower extremities, rather than being adequately distributed to the head. When gravity ceases, the hydrostatic pressure throughout the body also disappears. The resulting changes in blood distribution

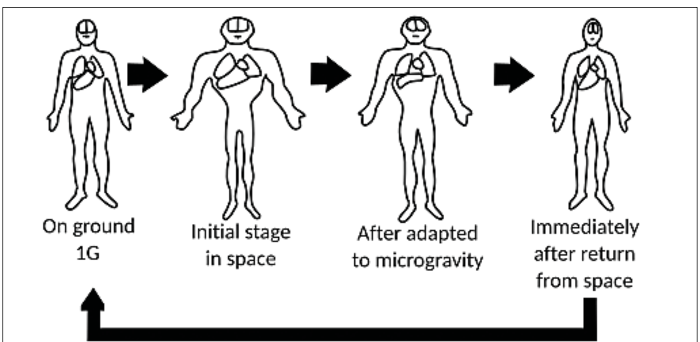

Figure 6: Fluid flow stages in microgravity (https://commons.wikimedia.org/wiki/File:Space_body_fluid.svg *Downloaded: 18.08.2024.)*

22 Waldie, James: *Astronaut Compression Skinsuits.*

23 Cavanagh, Peter R. et al.: *Exercise and pharmacological countermeasures for bone loss during long-duration space flight.*

24 Shibata, Shigeki et al.: *Impact of Prolonged Spaceflight on Orthostatic Tolerance During Ambulation and Blood Pressure Profiles in Astronauts.*

are similar to those that occur when a person transitions from a standing to a lying position.

A persistent redistribution of blood volume leads to facial edema, puffy head, birdy legs, and other undesirable side effects. Upon returning to Earth, the reduced blood volume may cause orthostatic hypotension, leading to circulatory insufficiency in the brain due to the sudden drop in blood pressure. Fluid-loading measures and salt re-supplement are applied by astronauts before landing and have significantly improved orthostatic tolerance after spaceflight. Both the quality and quantity of electrolytes critically affect how water is absorbed and distributed within the body.[25]

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25 Figliozzi, Gianine M.: *NASA rehydration technology has "the right stuff" for astronauts and athletes.*

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AZ ŰRMISSZIÓK EMBERRE GYAKOROLT HATÁSA 1.

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Kulcsszavak emberi test, űrrepülés, súlytalanság, hosszú távú hatás, izom, sugárzás, Artemis-program

Absztrakt *Jurij Gagarin első emberes űrrepülésétől kezdve, továbbá a soron következő valamennyi küldetés során hangsúlyt fektettek a tudósok az emberi test működésének és változásainak vizsgálatára, az űrrepülés teljes spektrumán. Az űrutazás hatással van az egész testre, és kivétel nélkül befolyásolja minden egyes szervünket, illetve a pszichénket. Abban a pillanatban, ahogy a súlytalanság hatásának vagyunk kitéve, és a Föld gravitációja megszűnik, olyan változásokat tapasztalhatunk, mint például az oszteoporózis (az űrrepülés okozta csontritkulás), a vörösvérsejtek számának csökkenése (űranémia), valamint különféle, a küldetések során megfigyelt rendhagyó tünetek. Sokan nincsenek tisztában azzal, hogy az űrprogramok előnyei szinte minden embert érintenek a Földön, számos találmány és felfedezés kizárólag az űrprogramoknak köszönhetően jöhetett létre.*