Exploring Space Medicine: Human Health Hazards in Space Exploration

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The National Aeronautics and Space Administration (NASA) has designated five hazards to human health. Further research and development in the field of aerospace medicine is just as important as other critical areas within aerospace, such as hypersonics and space domain awareness. Continuation of successful space exploration missions will depend on engineering solutions that address the physiological limitations of the human body. The five hazards are already present in low Earth orbit (LEO), and as we extend missions beyond LEO, these hazards will only amplify. NASA's five hazards include: gravity fields, space radiation, isolation and confinement, distance from Earth, and hostile/closed environments. Challenges associated with gravity fields include microgravity and hypergravity, and the medical conditions and performance limitations that arise from both. Space radiation poses a significant risk to astronaut health, requiring special engineering solutions such as shielding to protect the crew. Isolation and confinement contribute to psychological stress, which in turn may contribute to other health issues. Distance from Earth signals communication delays and the need for crews to remain self-sufficient. Self-sufficiency includes the ability to perform complex medical procedures and treat themselves if an emergency arises. Finally, the hostile/closed environment includes all the characteristics above and specifically focuses on the risks of living in a closed environment. Closed environments contribute to increased susceptibility to illness. All five of these hazards overlap significantly, and an understanding of these hazards is critical since these are the challenges we encounter within the field of aerospace.

I. Nomenclature

NASA	=	National Aeronautics and Space Administration
LEO	=	Low Earth Orbit
1g	=	Microgravity
SAS	=	Space Adaptation Sickness
SABP	=	Space Adaptation Back Pain
ANOVA	=	Analysis of Variance
mSv	=	Mili-Sievert
VR	=	Virtual Reality
A.I.	=	Artificial Intelligence
ISS	=	International Space Station

II. Introduction

The future of space exploration is interdisciplinary because the intersection of medicine, human performance, and engineering will require further research and development to enable elaborate, deep, and long-duration missions in space. Spaceflight poses several significant challenges to human health. NASA has identified five hazards that pose significant challenges within the field of aerospace medicine, and the designation of these five hazards can serve as starting points for understanding the risks associated with them [1]. The five designated hazards are gravity fields, space radiation, isolation and confinement, hostile environments, and distance from Earth. It is important to note that

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there is significant overlap between all five hazards; for example, immune dysfunction can be clearly linked to isolation and confinement. The extreme environments that will be explored during long-duration and deep space missions are characterized by several environmental stressors, such as microgravity and radiation. These unique qualities contribute to several human health repercussions within several systems in the human body, including, but not limited to, the cardiovascular system, neurological, psychological, and musculoskeletal systems. The application of the human factor is critical to better understand how we can design extensive medical operations and vehicle systems for optimal human efficiency. Integrating human factors into engineering solutions will also need further research and development as manned exploration continues in new environments.

III. Gravity Fields

A. Microgravity

The phenomenon of microgravity is a fundamental driver for several research studies regarding the life sciences in space. The significant change in the measure of gravity in outer space compared to Earth produces several unique and potentially harmful situations. An understanding of microgravity is essential to better understand the challenges that arise from a microgravity environment. Microgravity is the condition in which the systems in the environment, whether people or objects, appear to be weightless [2]. The experience of microgravity is created whenever a person or an object is in free fall and is measured as 1 g [2]. It is well documented that microgravity leads to significant physiological changes within the human body. This is largely due to the unnatural environment the human body must adapt to after entering an environment with a significant change in the force of gravity.

Microgravity effects on human health can be divided into two categories: short-term exposure and long-term exposure [3]. An example of a short-term effect would be space adaptation sickness (SAS). SAS is one of several medical conditions astronauts may suffer from due to the microgravity environment. NASA has documented that the medical condition affects up to 73% of crew members during the first two to three days of flight. Symptoms include headaches, back pain, drowsiness, and genitourinary issues [4]. Fluid shift and redistribution can lead to an increase in intracranial pressure on vascular structures in the brain, which can result in migraines and headaches. An additional symptom associated with SAS is space adaptation back pain (SABP) [4]. SABP occurs in 52% of space travelers during the first two to three days of flight [4]. The usual back curve straightens due to microgravity reduction, potentially leading to degrading spine stability and pain. While most cases resolve after two to three days of flight, hence "short-term" effects, further research and development is needed to understand the exact causes of SAS, as microgravity appears to be a contributing factor [4].

A long-term effect includes bone loss. Bone loss has been well documented as early as 1965 [5]. Microgravity specifically reduces loading on bones, leading to a decrease in the weight-bearing function and subsequently a decrease in bone density [5]. Long-duration space missions will increase the risk of bone degradation; therefore, special solutions will be required to ensure astronauts are able to decrease risk of bone loss. Medications, exercise, and nutrition serve as countermeasures to bone loss; however, advanced techniques will be needed for missions to extend beyond the LEO [5]. For example, a mission to Mars would require medications to be specially designed and curated, so they last for long periods due to extended travel time. Food would also need to be specially contained, so it does not expire, or special methods to grow food must be developed. These are not the only conditions created in the microgravity environment. Several limitations within research and challenges remain within this field of space medicine due to a small sample size and a lack of research for deep space missions.

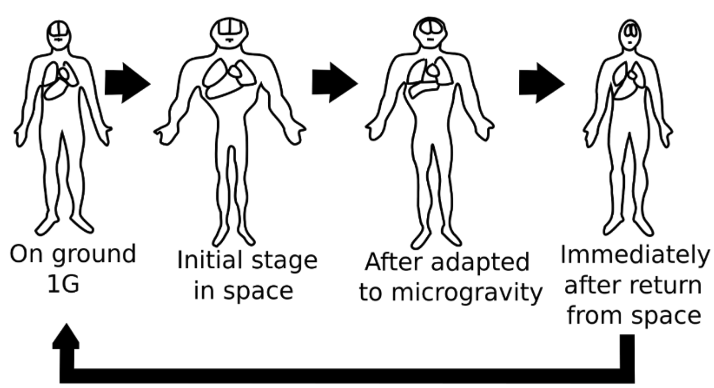

Fig. 1.1 Fluid Redistribution [6]

B. Hypergravity

Hypergravity, greater than Earth's standard of 1g (9.8 m/s), also poses significant challenges to human health during space exploration. During standard launch and reentry of space vehicles, humans are exposed to hypergravity. Hypergravity presents challenges that human sensorimotor systems are unable to solve in the long term [7]. The surrounding force fields characterize the amount of force needed to move our limbs and perform the same tasks. Hypergravity actions may be produced under the guise of normal gravity; therefore, the actions are not sufficient to reach targets. A major finding was that final reach errors were greater in hypergravity than in normal gravity [7]. A 3x2x2 analysis of variance (ANOVA) revealed a significant effect on the environment. Fig. 1.2 reveals endpoint errors on the Z-axis were greater in hypergravity, which was at 2.2 cm +/- 1.2 cm [7]. In contrast, microgravity was at 0.1 ± 0.6 cm and normal gravity at 0.6 ± 1.0 cm. No other interaction or main effect was significant [7].

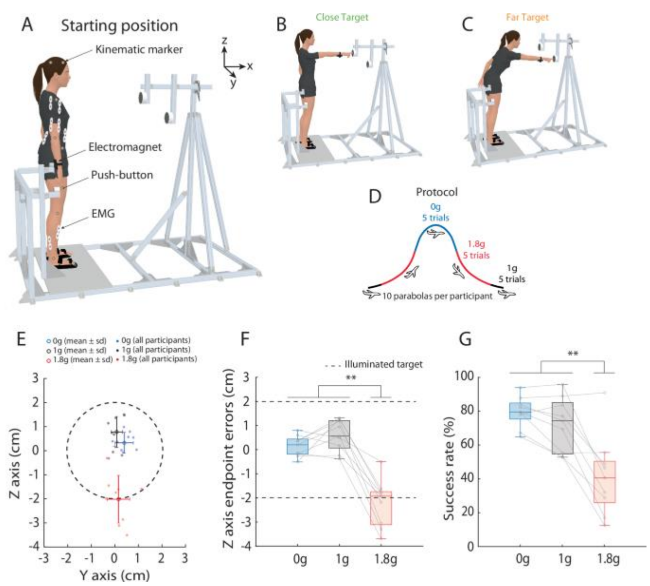

Fig. 1.2 Set up of Experiment and Demonstration of Motor Performance [7]

This study encompassed three days in parabolic flight. Standing participants were tasked with reaching towards one of two visual targets by means of upward arm movements. Participants did this during three different phases: microgravity, hypergravity, and monogravity, also known as normal gravity. Major results show significant degradation in final accuracy in the environment of hypergravity compared to microgravity and normal gravity [7]. Training must be specially designed to prepare the crew for perceived difficulty during hyper gravity. Mission environments, such as the cockpit, must be designed ergonomically to ensure optimal human performance and to ensure successful missions extend beyond LEO.

IV. Space Radiation

Radiation is a form of energy emitted in light-emitting rays, waves, and/or particles. Space radiation poses a unique challenge because it is different from the radiation experienced on Earth [8]. The three types of radiation that comprise space radiation include particles emitted from solar flares, particles trapped in Earth's magnetic field, and galactic cosmic rays, which originate from outside our solar system [8]. All of these are representative of ionizing radiation. These types of radiation are high-energy and difficult to avoid; special methods and procedures will need to be created to shield the crew from damaging radiation.

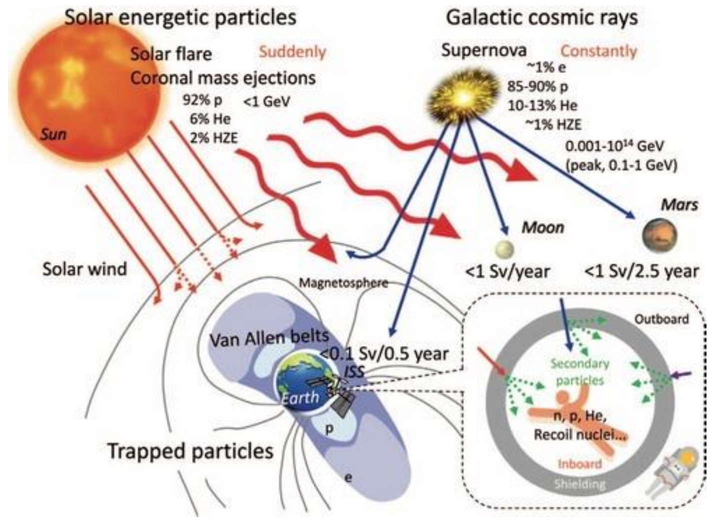

Fig. 2 Components of the Space Radiation Environment [9]

Mili-Sievert (mSv) is used to measure radiation. 1 mSv of ionizing radiation is equivalent to 10 chest X-rays, and astronauts are exposed to doses ranging from 50 to 2,000 mSv. Although to date no astronaut has been diagnosed with cancer related to ionizing space radiation, it is presumed that exposure to space radiation increases risks of astronauts developing cancer and other detrimental health effects. It is important to note that cancer latency comprises years to decades [9]. Three primary factors exist to determine the amount of radiation received by astronauts. Altitude above Earth, solar cycle, and individual susceptibility are all constraints we must design in order to ensure better health outcomes for crew [8]. These factors contribute to the likelihood of an astronaut's exposure to radiation; as a result, medical implications may develop. Primary health risks developing from space radiation include degenerative vascular changes, genetic mutations, and cancer [10]. The space radiation problem cannot be avoided; designing this challenge will produce certain limitations and tradeoffs. For example, if we choose to use special shielding that is significantly heavier than another type of shielding, there is a tradeoff of mass for launch capability. An increase in mass could impact transportation costs and propulsion systems. This is just one tradeoff in a sea of tradeoffs to be explored.

V. Isolation and Confinement

A key concern during long or deep space exploration missions is the fragility of the human psyche. Psychological stress has been linked to the dysfunction of the human immune system [11]. NASA astronauts undergo rigorous training to ensure they can safely complete missions in space and to prepare for an environment that is psychologically and physically taxing for humans. There is an increased risk of depression and anxiety due to the stressful environment in which the astronauts find themselves. Prolonged isolation and confinement contribute to cultural issues between crew members and sleep disturbances, which, as a result, can all contribute to stress for an astronaut [12]. All these risks may contribute to the development of immunological processes such as pathogenesis and inflammation because these processes have been linked to psychological stress [13]. The crew must possess certain amicable qualities, for example, teamwork and critical thinking, to ensure successful missions. Space missions have increasingly included crew from different walks of life, so cross-cultural sensitivity is also an important factor when designing and planning missions. Team dynamics, although not inherently a technical challenge, will be a challenge, nonetheless. Crews must be able to accommodate the cultural differences that may be present.

Antarctica is used as a testbed for analog missions. Analog missions are where the environment mimics conditions in space. Research on Antarctic crews revealed increased psychological stress and symptoms such as fatigue, sleeping difficulties, and impaired cognitive function [14]. A condition referred to as winter-over syndrome was characterized by tension between crew, cognitive impairment, and sleep disorders [14]. These conditions and symptoms have already been perceived in astronauts from past space exploration missions [14]. Longer duration of space missions extending beyond LEO will require special precautions regarding isolation and confinement. Use of Virtual Reality (VR) is one of many solutions currently being tested for astronaut crew health. For example, if an astronaut misses home, they could use the VR to escape the isolated space environment for a while. This may prove especially beneficial for astronaut mental health in the long run. Additionally, special lighting configurations will need to be integrated in space exploration missions extending beyond LEO. Since the normal day and night cycle will be absent, this can lead to changes in sleep patterns, or worse, disturbances.

VI. Distance from Earth

Challenges associated with distance from Earth will become more prevalent the further humans travel from Earth. Deep space exploration will be characterized by profound delays in communication. For example, a one-way transmission to Mars could take up to twenty-two minutes to receive [15]. Astronauts will need to be self-sufficient in the case of delayed transmissions. Remote health care must be carried out by the crew, as there would be too many risks associated with returning to Earth, such as time and reentry. Complex medical systems integrating telemedicine will be essential for ensuring future deep space exploration missions [16]. Since there is a possibility of communication delay or loss due to the distance from Earth, the crew must be able to perform and conduct complex medical operations and procedures. This constraint requires the crew to be reasonably knowledgeable about certain medical procedures, with the ability to perform the procedures on another crew. Autonomous systems and the use of artificial intelligence (A.I.) can help the crew to quickly diagnose and make medical decisions [17]. However, there is a possibility that the A.I., even with a robotic form, cannot perform complex medical procedures. There are limitations not only on humans, but also on A.I., and our engineering designs as well.

VII. Hostile/Closed Environments

Space is considered a hostile environment due to the extreme dangers present to humans. Therefore, a closed environment must be specially designed to mimic Earth; lighting, temperature, air, and several other factors must be carefully designed to encourage mental health and physical productivity [18]. The closed environment is designed to protect humans from the hostile environment; however, the closed environment also possesses certain limitations. The closed environment that astronauts are expected to stay in during space travel, for example, the ISS, can pose risks to the immune systems of the astronauts. When in a closed environment for an extended period, humans are more susceptible to illnesses and allergies due to the transferability of microbes. Bacteria, archaea, viruses, and eukaryotes that reside within the human body make up the human microbiome [19]. These organisms may well augment or diminish metabolic and immune functions [19]. Several unique stressors such as microgravity, radiation, isolation, and disruption in the normal night/day cycle may impact the microbiome [20]. Although these unique stressors are explored in other sections of this paper, it is important to highlight that there is significant overlap between the five hazards to human health.

VIII. Conclusion

The limitations of the human body will be a limiting factor as humans extend space exploration beyond low Earth orbit. Additionally, NASA's five hazards to human health can serve as a general guideline to understanding the factors that contribute to these limitations. Gravity fields significantly alter human physiology and human performance; microgravity contributes to fluid redistribution, and hypergravity leads to errors in certain activities. Space radiation affects human physiology because it can contribute to the development of genetic mutations, cancer, and more. Isolation and confinement can induce psychological stress, which can result in the increased likelihood of a compromised immune system. Distance from Earth poses communication delay challenges and the need for humans to remain self-sufficient, especially during deep space missions where there is no option to refuel. Hostile and closed environments possess certain qualities that increase the transferability of microbes and additional limitations, such as designing a space to live in, and not just survive in. These hazards overlap significantly, as they do not operate independently. For example, isolation and confinement may increase psychological stress, and psychological stress may in turn increase susceptibility to illness. The closed environment also induces susceptibility to illness. Further research and development within the field of aerospace medicine, with these hazards in mind, is critical to the success of future space exploration missions. There are still several limitations and gaps in research within the field; a higher budget and advocacy for the importance of space medicine and human factors engineering can help reduce the limitations and bridge these gaps. Ultimately, the future of space exploration will depend on our ability to survive, adapt, and overcome, and the field of aerospace medicine is at the forefront of this idea.

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References

[1]”5 Hazards of Human Health,” NASA, October 7th, 2025. [Online]. Available: https://www.nasa.gov/hrp/hazards/.

[2]”What is Microgravity?” NASA, February 13, 2009. [Online]. Available:https://www.nasa.gov/centers-and-facilities/glenn/what-is-microgravity/.

[3]"Mission Duration
https://www.nasa.gov/wp-content/uploads/2023/12/ochmo-tb-007-mission-duration.pdf?emrc=82ec36 ?

[4]”Space Adaptation Sickness,” NASA, September 25th, 2025. [Online]. Available:https://www.nasa.gov/wp-content/uploads/2025/09/ochmo-mtb-004-space-adaptation-sickness-sas.pdf?emrc=699fb68434d15

[5]”Bone Loss,” NASA, February 11th, 2026. [Online]. Available: https://www.nasa.gov/wp-content/uploads/2023/12/ochmo-tb-030-bone-loss.pdf?emrc=699ba45d68661
https://www.nature.com/articles/s41526-024-00452-x

[6]”Space Travel: How does Outer Space Affect Your Body?”, Marin Science Seminar, April 17th, 2016. [Online]. Avaliable: https://marinscienceseminar.com/space-travel-how-does-outer-space-affect-your-body/

[7]Chomienne, L., Sainton, P., Sarlegna F.R., and Bringoux, L., “Hypergravity is more challenging than microgravity for the human sensorimotor system,” npj Microgravity 11, 2 (2025). DOI: https://doi.org/10.1038/s41526-024-00452-x

[8]”Why Space Radiation Matters,” NASA, April 13th, 2017. [Online]. Avaliable:https://www.nasa.gov/missions/analog-field-testing/why-space-radiation-matters/

[9]Chancellor, J., Nowadly, C., Williams, J., Aunon-Chancellor, S., Chesal, M., Looper, J., & Newhauser, W. (2021). Everything you wanted to know about space radiation but were afraid to ask. *Journal of Environmental Science and Health, Part C*, *39*(2), 113–128. DOI: https://doi.org/10.1080/26896583.2021.1897273

[10]Chancellor JC, Scott GB, Sutton JP. Space Radiation: The Number One Risk to Astronaut Health beyond Low Earth Orbit. Life (Basel). 2014 Sep 11;4(3):491-510. DOI: 10.3390/life4030491. PMID: 25370382; PMCID: PMC4206856.

[11]Arone A, Ivaldi T, Loganovsky K, Palermo S, Parra E, Flamini W, Marazziti D. The Burden of Space Exploration on the Mental Health of Astronauts: A Narrative Review. Clin Neuropsychiatry. 2021 Oct;18(5):237-246. doi: 10.36131/cnfioritieditore20210502. PMID: 34984067; PMCID: PMC8696290.

[12]”Risk of Behavioral and Psychiatric Disorders,” NASA. [Online]. Availablehttps://www.nasa.gov/reference/risk-of-behavioral-changes-and-psychiatric-disorders/

[13]Marshall GD Jr. The adverse effects of psychological stress on immunoregulatory balance: applications to human inflammatory diseases. Immunol Allergy Clin North Am. 2011 Feb;31(1):133-40. doi: 10.1016/j.iac.2010.09.013. PMID: 21094928; PMCID: PMC2991159.

[14] Pagel, J. I and Choukèr, A., “Effects of isolation and confinement on humans-implications for manned space explorations,” *Journal of Applied Physiology* [online journal], Volume 120, Issue 1, DOI: https://doi.org/10.1152/japplphysiol.00928.2015 [retrieved 26 February 2026]

[15] Kintz, N. M., Chih-Ping, C., Vessey, W.B., Leveton, L.B., Palinkas, L.A., “Impact of Communication Delays to and from the International Space Station on self-reported individual and team behavior: A mixed-methods study,” Acta Astronautic [online journal], Vol. 129, pages 193-200, URL: https://www.sciencedirect.com/science/article/pii/S009457651630697X [retrieved 25 February 2026].

[16]Ganapathy, K., “Space Medicine: The Ultimate in Remote Healthcare,” Telehealth and Medicine Today [online journal]. doi: 10.30953/tmt.v5.178

[17] Buras WR, Hilmers DC. Developing artificially intelligent agents to support earth independent medical capabilities during human exploration-class space missions. NPJ Microgravity. 2025 Aug 2;11(1):51. doi: 10.1038/s41526-025-00503-x. PMID: 40753177; PMCID: PMC12317972.

[18]”Hazard: Hostile/Closed Environments,” NASA, [Online]. Avaliable: https://www.nasa.gov/hrp/hazard-hostile-closed-environments/.

[19]Ogunrinola GA, Oyewale JO, Oshamika OO, Olasehinde GI. The Human Microbiome and Its Impacts on Health. Int J Microbiol. 2020 Jun 12;2020:8045646. doi: 10.1155/2020/8045646. PMID: 32612660; PMCID: PMC7306068.

[20]Etlin S, Rose J, Bielski L, Walter C, Kleinman AS, Mason CE. The human microbiome in space: parallels between Earth-based dysbiosis, implications for long-duration spaceflight, and possible mitigation strategies. Clin Microbiol Rev. 2024 Sep 12;37(3):e0016322. doi: 10.1128/cmr.00163-22. Epub 2024 Aug 13. PMID: 39136453; PMCID: PMC11391694.