Article

Is Human Enhancement in Space a Moral Duty? Missions to Mars, Advanced AI and Genome Editing in Space

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Abstract: Any space program involving long-term human missions will have to cope with serious risks to human health and life. Because currently available countermeasures are insufficient in the long term, there is a need for new, more radical solutions. One possibility is a program of human enhancement for future deep space mission astronauts. This paper discusses the challenges for long-term human missions of a space environment, opening the possibility of serious consideration of human enhancement and a fully automated space exploration, based on highly advanced AI. The author argues that for such projects, there are strong reasons to consider human enhancement, including gene editing of germ line and somatic cells, as a moral duty.

Keywords: Human mission to Mars; human deep space missions; human enhancement; gene editing; moral duty; AI

Introduction

Long-term deep space human missions are no longer only the subject of science-fiction stories and literary fantasies. There is little doubt that in the near future—despite many obstacles and risks and an unclear rationale—humans will attempt deep space missions. The most likely first target will be Mars. Such a project would involve relatively obvious and broadly discussed challenges, primarily in the fields of human medicine and technology. The human species is physically and psychologically adapted to terrestrial geophysical parameters. This paper discusses conditions in space that constitute a challenge to human life and health, and argues that the combination of hazardous space environment and human biological limitations will require new ethically radical solutions. Those solutions, it suggests, could include purely robotic missions based on advanced artificial intelligence (AI) on one hand, or on implementing human enhancements, including both germline and somatic genome editing, on the other. Indeed, there may be strong reasons why planners of space missions might consider such procedures our moral duty. As Martin Rees recently noted, "Because [space adventurers] will be ill adapted to their new habitat, the pioneer explorers will have a more compelling incentive than those of us on Earth to redesign themselves."[1]

The Challenges of Space for Human Life and Health

Since the '50s, significant efforts have been made by space agencies to determine what threats, and risks, space represents, and then to prepare human astronauts in the best possible ways for the challenges they would encounter. However, current health and public policies of spacefaring countries are still too conservative. Some of the challenges of the space environment are described below, before turning to a discussion of new space policies that might be needed.

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Although the presence of humans on Mars is the main focus here, issues raised in discussions of a Mars mission might be relevant to other possible long-term human space missions as well. The basic obstacle for long human spaceflights is the harmful impact of the space environment on human health. This environment is challenging in a broad and complex way, since it simultaneously adversely affects all human systems.

One of the most difficult challenges is space radiation, including primarily galactic cosmic rays (GCRs), solar energetic particle events (SEP), and radiation trapped in Van Allen Belts. For example, the rate of radiation on Mars is estimated to be about 91 times higher than the average radiation experienced on Earth.[2] Space radiation may cause direct harms, effected mostly by short but strong doses of SEP. But the more challenging kind of space radiation is GCR, that permanently affects human astronauts throughout the entire mission, and may cause delayed effects in human health. The current policy of space agencies in spacefaring countries is based on the protocol of sending older, rather than younger, astronauts into space. The rationale for this procedure lies in the fact that some harmful effects of space radiation occur several years after the mission is completed. Because younger astronauts have a longer lifespan, the late radiation effects may appear earlier in their lives than is the case for older generations of astronauts.[3] It is worth remembering that the impact of space radiation on human health is challenging, not only for astronauts who currently serve short missions at the International Space Station (ISS) but, because of the delay in its effects, might cause extra challenge for the idea of a deep-space human mission designed to make humans a multiplanetary species. In a possible future scenario in which the mass-scale human spaceflights to Mars—and possibly to other space destinations—become a reality, not only older but mostly younger generations of astronauts and space settlers may necessarily be involved; the idea of humans as a multiplanetary species requires a succession of generations. But having successive generations necessitates reproduction in space, which will be challenging for human reproductive biology, and may fail in a space environment.[4]

Space radiation can be classified as one of the most harmful environmental conditions in space, but it is not unique. Mark Shelhamer argues that one of the biggest health challenges during and after spaceflight is on the molecular biology of strength and balance, such as the effect on muscle coordination due to the lack of tonic otolith stimulation in an environment without an appropriate gravitational force.[5] The basic countermeasure used in current space programs to cope with muscle and bone atrophy is physical exercise, which remains a challenge even for those in good condition.

Additionally, consideration of further space exploration is challenging because of the unpredictability of the space environment, and only limited testability. The fact is that no human astronaut has ever experienced the conditions of an interplanetary environment. Currently, there are only two sources of knowledge and data regarding conditions of life in space. The first main source of information is from astronauts whose space missions were experienced in spacecraft at the ISS. These data have limited applicability for the purposes of any future Mars missions, because they were conducted in the Low Earth Orbit (LEO), a circumstance with different parameters than interplanetary space. LEO offers relatively effective protection against the cosmic radiation because of the protective impact of the magnetosphere, and atmosphere of the earth.

The second main source of current knowledge about the impact of space on humans is provided by earthly Mars-analog experiments. These experiments attempt to simulate the behavioral and psychological conditions of living in space, and are an important source of knowledge about the potential effect on the human psyche of that extreme environment.[6] However, they are not able to simulate physical conditions of spaceflight or living on Mars. The two basic factors missing in these experiments are reduced gravity and space radiation. Because it is impossible to overcome these two limitations before the first astronauts are sent to Mars, the full panorama of challenges cannot be predicted.[7]

The Limited Efficacy of Currently Available Countermeasures

So far, the only current countermeasures are designed to cope primarily with the aforementioned immediate challenges for human health and life in space: space radiation, as described above, and microgravity. Paradoxically, the best means of coping with the negative effects of microgravity is an artificial gravity.[8] Invention and simulation of terrestrial gravity in spacecraft would be able to substantially reduce, or perhaps even eliminate serious health threats such as bone loss, muscle atrophy, or cardiovascular problems.[9] But the technology needed is well beyond the current state of the art, and—while it is considered in general as a safe, and the best possible countermeasure to microgravity—the possible side effects of intermittent or continuous artificial gravity for a space crew are unknown.[10] The currently most effective countermeasure to the damage caused by microgravity in space is physical exercise. Other countermeasures include special pressure suits for blood circulation[11] and drugs used to cope with the negative effects of microgravity.

Similar difficulties and challenges are presented by the negative impact of radiation. Perhaps the best countermeasure to the extreme radiation in space would be appropriately thick walls for spacecraft. However, the advantage of thickness of a spacecraft's walls is counterbalanced by the added weight, which is necessarily limited by the requirements of flight.[12] Heavier spacecraft require stronger engines and increased fuel. Because of this coefficient of weight to antiradiation efficacy, the effectivity of antiradiation protective shielding provided by walls of spacecraft does not exceed 30 percent. This relatively low rate of effectivity of antiradiation protection is counterbalanced by the fact that the human space missions at the ISS usually do not last longer than six months. They are also conducted within the relatively safe borders of LEO, in contrast to interplanetary space without the protective atmosphere and magnetosphere of Earth. Currently applied countermeasures to space radiation include drugs, diet, and the mentioned shelters.[13] Shelters include equipping the entire spacecraft with appropriately thick walls, and the construction of special rooms or cabins inside any future interplanetary spacecraft. Such antiradiation cabins could be designed to protect the crew, in case of emergency, against the flares of SEP.

In short, nutrition, exercise and antiradiation shielding are only partially protective—and that is in the limited context of Low Earth Orbit. The total dose of the space radiation experienced during a mission to Mars would far exceed the limits of exposure to radiation experienced during missions at the ISS. Currently available countermeasures to the dangers of deep space exploration are of limited efficacy.

Is there any Rationale for Sending Human Astronauts to Space?

This brief overview of currently available measures to counter the risks of space in the context of a harmful and, to some extent, unpredictable space environment, leads to a rather pessimistic prospect for successful human missions to Mars. First, previously used countermeasures have been applied only in LEO, which offers different parameters in regard to space radiation than interplanetary space. A second issue is the longevity of the mission. The shortest possible human mission to Mars would require approximately three years. This period is about six times longer than the standard missions at the ISS. These two factors introduce new kinds of threats and risks for astronauts performing the first long-term deep space missions. Thus, such a mission may be dangerous in ways that are incomparable with previously experienced rates of danger for human health and life in space. So why should we still consider sending human astronauts to deep space?

One of the reasons might be increased efficiency. Taking into account the current state of the art in space robotics, human astronauts outperform space robots. This argument is explored by, among others, Ian A. Crawford.[14] He argues that human astronauts are still superior to their robotic counterparts in areas such as flexibility, mobility, effective sample collection, and maintenance and deployment of technological equipment on the surface of space bodies, to mention a few. Human astronauts are more effective than either autonomous robots or another alternative, teleoperations. This advantage of humans over robots in space has direct impact on scientific effectiveness and academic productivity. As Crawford points out, the number of published academic papers using the data obtained during manned *Apollo* missions is higher than all the academic papers published on the basis of data provided by all the robotic space missions conducted throughout the history of space exploration.[15]

When compared in terms of the quantitative amount of information gained, and the quality of the results, human missions offer more benefits than comparable robotic missions. The question arises: If human presence in space offers such benefit, what would justify its financial costs, and risks for human health and life? If one assumes that the human presence in space is needed and profitable, there is no doubt that human astronauts perform better in the field than space robots; the problem is the rationale for human space missions in light of the costs and risk. The currently discussed justifications, in fact, only include scientific reasons. This is the main goal of the human mission to Mars planned by NASA. While profitable for the academic and scientific community, is progress in space science sufficient to justify the high financial cost and real threat for human health and life? This question requires serious debate.

In short: in the field of performance and effectivity, human astronauts still win the competition with space robots. But it is not clear if the current rationale for human presence in space, which has only scientific justification, would justify the risk for human life.

What other factors might enter into consideration? Another reason justifying human space exploration centers on the issue of space as a refuge in post-catastrophic Earth scenarios. Should a time come when Earth is no longer able to sustain human life, in order to survive, humans will have to become a multiplanetary species. Advocates of this idea include: Stephen Hawking, Robert Heinlein, Isaac Asimov, and Elon Musk.[16] Although this idea is worth study and effort, it is not clear if refuge in space is able to really offer an advantage over analogical subterranean or aquatic refuges on Earth. Arguments against the comparative efficacy of space refuge are discussed elsewhere;[17] but on the other hand, it is hard to deny that multiplying human presence in space would serve as an additional protection for the species against a possible catastrophic event on Earth.

The Rationale for Human Enhancement in Space

If robotic or other teleoperatically mediated projects are less satisfactory, are there other alternatives to be considered? The current state of human spaceflight and human achievements in space does not require human enhancement; but it is possible that there are ways of enhancing ISS astronauts which would increase their ability to perform their tasks. Space exploration limited to LEO, while not necessarily friendly for humans, is not as hazardous as interplanetary space. Their relative short duration and short distance from Earth make rapid evacuation and reentry of astronauts in LEO feasible without augmentation. In contrast, human enhancement as a public policy should be considered seriously as an important—and possibly necessary—protocol for spacefaring countries for missions in excess of three years. The current lack of alternative efficient countermeasures to space hazards including space radiation, microgravity, and reduced gravity would be the main reason for the application of a biological human enhancement program, if the risk to the humans involved could thereby be minimized.

Due to our biological limitations, it is a safe assumption that long-term human presence in space is probably impossible without specially enhanced humans. As stated by Christopher S. Allen and colleagues, "The most carefully selected and well-trained crewmembers will never be superhumans."[18] Although natural biological variation in human genotype and phenotype currently does not include individuals who would be adapted better than others to live in microgravity, or who would be more resistant to high doses of space radiation, this need not continue to be the case if enhancement were possible. Human astronauts could and should become 'superhumans' if the deep space human missions are expected to be safe, efficient, and reasonable.

Because of the degree of intervention or reversibility, different methods of human enhancement to be considered for space astronauts raise different ethical issues and controversies. Relatively uncontroversial is pharmacological enhancement, because the changes involved are reversible and non invasive. This type of enhancement for astronauts would have something in common with the enhancement of soldiers. This practice has a long history, in which pharmacological cognitive enhancement improves the cognitive performance of soldiers or other professionals who require focused alertness over a period of time.

Recent rapid advancements in science raise the possibility of more radical and less reversible forms of enhancement—gene editing. Gene editing raises serious ethical issues, and thus engenders more debate. It can include gene editing of somatic cells, which consists in editing genes identified as responsible for particular skills and capabilities, or associated with certain illnesses. Changes as a result of somatic editing are not heritable, and editing some cells to reduce the chances of astronauts becoming ill in space seems ethically unproblematic. Editing germline cells, deliberately changing the genes to be passed on to future generations, is a more distant prospect than gene editing of somatic cells, but it is worth pondering the possibility of a spacefaring country debating the editing of germline cells as one option, if it becomes available.[19] For example, there might come a time when humans become a multiplanetary species and settle beyond Earth, perhaps on Mars. There could be benefits for a space colony from editing germline cells to prevent illnesses or enhance the embryos of future children born on Mars in order for them to be better adapted to their new environment. Such procedures could substantially decrease the number of damaged genes in the gene pool of a new space community, and better ensure their successful establishment.

Currently, it is still unclear if any kind of gene editing would be able to provide antiradiation and antimicrogravity protection for astronauts in space. Deleterious side effects of spaceflights might include not only medical hazards, but also decreases in performance. Genetic modifications open space for the risk of conflicting pressures: while gene editing may increase performance in one function or capacity, it may decrease performance in another one.

Another argument for enchantment might be for the purpose of aiding the recovery of returning astronauts after their interplanetary journey. Here, the distinction between therapy and enhancement become less clear; and there are good reasons to treat enhancement procedures more in terms of therapy than in terms of enhancement. Because humans are not adapted biologically to live in space, any enhancement procedure applied to the future astronauts—despite the fact that it will be applied to healthy individuals—will possess some therapy-like features.

The rationale for human enhancement in space is a resultant of the rationale for human space missions and space settlement. The stronger the rationale for human spaceflight, the stronger the rationale for human enhancements in space. But the opposite —the less the rationale for human spaceflights, the less rationale for human enhancements in space—is not necessarily' true. Even if the rationale for human spaceflights is weak, it does not mean that humans should be sent to space without augmentation. The inherent value of human life requires that if there are good reasons to think that human health and life are threatened in space, and currently known countermeasures are not sufficient, mission planners have the moral imperative to enact enhancement procedures that could counteract the risks.

Another argument for human enhancement in space is associated with the moral duty to protect human survival as a species. As mentioned earlier, there may come a time when human life on planet Earth becomes unsustainable and, if our species is to survive, it might become necessary to establish permanent space settlements elsewhere. If human enhancement is the unique, or even one of the necessary, means to make adaptation to space communities possible, then humanity is obligated to apply human enhancement in space. This argument is similar to the argument for moral bioenhancement discussed by, among others, Ingmar Persson and Julian Savulescu. They argue that humanity is morally obliged to apply moral bioenhancement to follow their moral duties that are designed to increase the welfare of the entire community.[20] Human space settlement may be a particular means of ensuring human survival and increasing human welfare.

Human-like Robots in Space: The Challenge for Humanity

Because of the limitations of human biology, progress in space exploration may only be possible by robotic missions. Space robotics is currently the essence of space exploration, and remote locations in space that are beyond the scope of the piloted spacecraft can be approached only by robotic missions. Space robots have the advantage of being resistant to the harmful impact of space radiation and microgravity; are not affected by the longevity of interplanetary journeys; and have the added benefit of being less expensive than human missions.[21] The challenge arises in developing robotics capable of imitating the performance of human astronauts. Like many other functions and capacities in space, the advantage of robots over humans in some fields is counterbalanced by their disadvantage in others. It is assumed that space robots should possess locomotion and autonomy,[22] and be at least as intelligent as humans. Robot intelligence is not required in teleoperated missions in which robots conduct tasks managed by humans, and they do not have to be autonomous. The challenge arises for missions conducted in remote locations in which teleoperation becomes ineffective due to the communication delay.

One possible solution is an exploration telepresence which consists of human astronauts in orbit and robots on the surface of the space body.[23] Current space robotics involves semiautonomous robotic missions using scientific protocols implemented on earth. These programmed protocols are supplemented by commands received from ground control on Earth. The main disadvantage of robots here is their limited capacity for detecting and coping with unexpected situations and phenomena. Robotic 'cognition' is still very poor when compared with human cognitive capability, for qualitatively—not only quantitatively—detecting and evaluating perceived objects and facts. And while this proposal solves some problems, it does not mitigate the fact that human astronauts are still exposed to the harmful impact of the space environment.

Human-like intelligence and cognition in the field would substantially increase the effectiveness of robotic space exploration. Another scenario for the future progress in space exploration involves purely robotic missions based on autonomous and intelligent space robots; and there is no doubt that the effective scientific exploration of new, remote locations in space will require highly advanced robots equipped with advanced artificial intelligence (AI). This AI would have to go far beyond the algorithms and protocols implemented by scientists on Earth. But here again, one should ask if the scientific justification suffices to outweigh possible dangers of the alternative. There are good reasons to think that scientific exploration of space is not a sufficient rationale for implementation of advanced, theoretically dangerous, AI.

Highly advanced AI presents its own challengers for humanity. One of the challenges is the necessity to live in, and interact with, human communities. It is expected that space robots with advanced AI should possess abilities such as theory of mind and empathy that are crucial for the social dynamics of human groups[24]—a need recognized by engineers and programmers for an ethical framework for robots.

Scholars discuss various scenarios for the possible future development of AI in the context of the possible ethical issues.[25] While they underline a big technological gap between the current technological capabilities and future progress in AI, they argue for a need for special ethical protocols.[26] Nick Bostrom and Eliezer Yudkowsky discuss scenarios in which AI becomes more intelligent than humans. The issue arises if such intelligent machines will be able to follow only good behavioral patterns.[27] The aim of this paper is not to discuss in detail the ethical issues of the future progress in AI. The aim is to outline an unavoidable ethical dilemma which will appear in the future progress of space exploration: the dilemma between a need for genetic enhancement of human astronauts, and a need for autonomous and highly advanced AI in robotic space missions.

Conclusion

Harms and risks for human health, as well as high costs, make a rationale for current human interplanetary missions far from convincing. Possible alternative means of addressing these issues for a deep space mission program include human enhancement and/or fully automated space robots. The lack of human enhancement policies and protocols, including ethical consideration of the problems associated with invasive, irreversible, and heritable gene editing, coupled with the currently ineffective status of available countermeasures, might inhibit or even prevent the effective human exploration of deep space. In order for these options to be achievable, opening ourselves to considering controversial and theoretically risky solutions will be required. If human space missions are to be possible, human genome editing will not only be permissible, but required,[28] and space robots will need to be developed that are able to imitate human-like intelligence and cognition—that is, AI in a strong sense with all its possible pros and cons.

Notes

1. Rees M. *On the Future. Prospects for Humanity*. Princeton and Oxford: Princeton University Press; 2018, at 150–1.
2. Sion N. Can astronauts survive radiation on prolonged space missions? *CRPA / ACRP Bulletin* 2011;31(4):22.
3. See note 2, Sion 2011.
4. Szocik K, Elias Marques R, Abood S, Lysenko-Ryba K, Minich D, Kędzior A. Biological and social challenges of human reproduction in a long-term Mars base. *Futures* 2018;100:56–62.
5. Shelhamer M. Trends in sensorimotor research and countermeasures for exploration-class space flights. *Frontiers in Systems Neuroscience* 2015;9:115.
6. Nelson M. Some ecological and human lessons of biosphere 2. *European Journal of Ecology* 2018;4(1):50–5.
7. Levchenko I, Xu S, Mazouffre S, Keidar M, Bazaka K. Mars colonization: Beyond getting there. *Global Challenges* 2018; doi: 10.1002/gch2.201800062.
8. Impey C. *Beyond: Our Future in Space*. New York, NY: W.W. Norton and Company; 2015.
9. Braddock M. Artificial gravity: Small steps on the journey to the giant leap. *Journal of Space Exploration* 2017;6(3):137.
10. Allen SC, Burnett R, Charles J, Cucinotta F, Fullerton R, Goodman JR, et al. Guidelines and Capabilities for Designing Human Missions. NASA Center for AeroSpace Information 2003.
11. Ian MM, Rhodes RA, Davis KN. *Performance of the Z-2 space suit in a simulated microgravity environment*. 48th International Conference on Environmental Systems ICES-2018-71, 8–12 July 2018, Albuquerque, New Mexico.
12. Durante M. Space radiation protection: Destination Mars. *Life Sciences in Space Research* 2014; 1:2–9.
13. Clancy P, Brack A, Hornick G. *Looking for Life. Search the Solar System*. Cambridge: Cambridge University Press; 2005.
14. Crawford IA. Dispelling the myth of robotic efficiency: Why human space exploration will tell us more about the Solar System than will robotic exploration alone. *Astronomy and Geophysics* 2012;53:2.22–2.26.
15. See note 14, Crawford 2012.
16. Arroyo IH. Do space travel benefits for humanity outweigh the investments made? Analysis of the scientific, historical and moral reasons used to justify investments in space travel; available at https://itslide.net/document/space-travel-investment-and-benefits (last accessed Aug 5 2019).

17. Szocik K. Should and could humans go to Mars? Yes, but not now and not in the near future. *Futures* 2019;105:54–66.
18. Allen SC, Burnett R, Charles J, Cucinotta F, Fullerton R, Goodman JR, et al. Guidelines and Capabilities for Designing Human Missions. NASA Center for AeroSpace Information 2003.
19. The Chinese researcher He Jiankui conducted genetic modification of embryos, and then twins have been born. This experiment has been widely criticized; see: Cyranoski D, Ledford H. International outcry over genome-edited baby claim. *Nature* 2018;563:607–8; Savulescu J, Singer P. An ethical pathway for gene editing. *Bioethics* 2019;33:221–2.
20. Persson I, Savulescu J. The art of misunderstanding moral bioenhancement. *Cambridge Quarterly of Healthcare Ethics* 2015;24(2):48–57; Persson I, Savulescu J. The Duty to be Morally Enhanced. *Topoi* 2017, doi: 10.1007/s11245-017-9475-7.
21. Chien SK, Wagstaff L. Robotic space exploration agents. *Science Robotics* 2017; 2:eaan4831.
22. Gao Y, Chien S. Review on space robotics: Toward top-level science through space exploration. *Science Robotics* 2017; 2:eaan50742017.
23. Lester DF, Hodges KV, Anderson RC. Exploration telepresence: A strategy for optimizing scientific research at remote space destinations. *Science Robotics* 2017; 2:eaan4383.
24. Yang G-Z, Bellingham J, Dupont PE, Fischer P, Floridi L, Full R, et al. The grand challenges of *Science Robotics*. *Science Robotics* 2018; 3:eaar7650.
25. Dignum V. Ethics in artificial intelligence: Introduction to the special issue. *Ethics and Information Technology* 2018;20:1–3, https://doi.org/10.1007/s10676-018-9450-z; Wang W, Siau K. Ethical and Moral Issues with AI – A Case Study on Healthcare Robots. *Emergent Research Forum (ERF)*, Twenty-fourth Americas Conference on Information Systems, New Orleans 2018.
26. Torresen J. A review of future and ethical perspectives of robotics and AI. *Frontiers in Robotics and AI* 2018;4:75, doi: 10.3389/frobt.2017.00075.
27. Bostrom N, Yudkowsky E. The ethics of artificial intelligence. In: Frankish K, Ramsey WM, eds. *The Cambridge Handbook of Artificial Intelligence*. New York: Cambridge University Press; 316–34.
28. Gyngell C, Bowman-Smart H, Savulescu J. Moral reasons to edit the human genome: Picking up from the Nuffield report. *Journal of Medical Ethics* 2019. First published online: 24 Jan 2019, doi: 10.1136/medethics-2018-105084.