Biological and social challenges of human reproduction in a long-term Mars base

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Authors: Konrad Szocik, Rafael Elias Marques, Steven Abood, Aleksandra Kędzior, Kateryna Lysenko-Ryba, Dobrochna Minich

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Biological and social challenges of human reproduction in a long-term Mars base

Konrad Szocik & Rafael Elias Marques, Steven Abood, Aleksandra Kędzior, Kateryna Lysenko-Ryba, Dobrochna Minich

The first author, the corresponding author

Konrad Szocik (born in 1985), Doctor of Philosophy,

Assistant Professor at the University of Information Technology and Management in Rzeszow, Poland (Department of Philosophy and Cognitive Science),

Sucharskiego 2 Street, 35-225 Rzeszów, Poland;

tel.: +48 17 866 11 11

fax.: +48 17 866 12 22

E-mail: kszocik@wsiz.rzeszow.pl; konrad-szocik@wp.pl

tel. +48 692 020 370

&

The first author

Rafael Elias Marques, PhD

Researcher

Laboratório Nacional de Biociências - LNBio

Centro Nacional de Pesquisa em Energia e Materiais - CNPEM

Campinas, Brazil

rafael.marques@lnbio.cnpem.br

Co-authors

Steven Abood

Department of Biological Sciences,

Florida International University,

11220 SW 8th Street, Miami, FL, 33199, USA

saboo001@fiu.edu

Aleksandra Kędzior, MA

University of Information Technology and Management in Rzeszow, Poland

Chair of Administrative Law,
akedzior@wsiz.rzeszow.pl

Kateryna Lysenko-Ryba, MA
University of Information Technology and Management in Rzeszow, Poland
Chair of Process Engineering,
klysenko@wsiz.rzeszow.pl

Dobrochna Minich, PhD
University of Information Technology and Management in Rzeszow, Poland
Chair of Theory of Law,
dminich@wsiz.rzeszow.pl

Highlights

- The idea of the human base on Mars will generate many various challenges.
- One of them is the successful maintenance of such a base in terms of human medicine and biology.
- Human reproduction in human constant space settlement is supposed to be a necessary but extremely hard to achieve project.
- Human reproduction on Mars will affect not only serious medical and biological challenges but also big ethical and social ones.

Abstract:
A manned mission to Mars and the establishment of the first human settlement in outer space was once a mere figment of science fiction but is now being planned and expected to take place in the following twenty years. Mars is under consideration as the next planet beyond Earth to support continuous human exploration. Unfortunately, such an endeavor comes with titanic challenges in various disciplines, from space travel technology to medical, biological, social and ethical challenges. Reproduction involves many aspects of human life, and is also the subject of various disciplines. We assume that human reproduction in a Mars settlement will be necessary for the long-term success of an outer space mission. Thus, here we explore and discuss the challenges involving the likely scenario of human reproduction in Mars. To anticipate the many issues

associated with human reproduction outside Earth, we applied multidisciplinary approaches to discuss possible social, ethical, medical and biological challenges of human reproduction on Mars.

Keywords:
Long-term Mars base; human reproduction; challenges; ethics.

Introduction

The idea of a manned mission to Mars is becoming actualized by both governmental and private enterprises and may become a reality in the next 20 years. Motivations behind deep-space missions include the search for natural resources, the expansion of the human civilization (Impey, 2015), and the search for other forms of life (National Aeronautics and Space Administration n. d.)). These motivations are closely related to environmental, economic and social issues taking place on Earth, notably the dispute for land and other territories (Shelhamer, 2017). An analysis of the planning of a manned mission to Mars may consider short-term and/or long-term perspectives. . In our paper, we focus on a long-term mission that will include building a stable human settlement on Mars. For obvious technological and medical reasons, such a stable settlement will likely be achieved long after the first team of astronauts land successfully on Mars. If the mission planners decide at some point in the future to settle on Mars, reproduction will be necessary to enable the long subsistence of such a community. We assume that current plans of manned missions to Mars will necessarily result in the establishment of a human colony on Mars, regardless of the many required technological advances yet to be made. Therefore, it is worth discussing and predicting cultural, social and biological challenges that may appear on a future Martian colony (Szocik, 2016). As pointed out by our group and others, establishing a Martian outpost is likely to bring many of the same societal problems we face on Earth (Nature, 2016). Such problems include all the axiology which defines the life of people living in a colony (Lipiec, 2016; Becker, 2016).

Space exploration is constantly increasing in popularity. So far, governmental institutions such as NASA, Roscosmos State Corporation, China National Space Administration, the European Space Agency and private companies such as MarsOne, Blue Origin or SpaceX are actively involved in sending human astronauts to Mars. The technological advances to be achieved in the next decades to successfully establish the means for Mars exploration are expected to boost several sectors of the global economy and change society. Stephen Hawking once stated, “I believe that the long-term future of the human race must be space and that it represents an important life insurance for our future survival, as it could prevent the disappearance of humanity by colonizing other planets” (Hawking, 2015). There is no doubt that humans as a species face significant challenges

for their own survival on Earth. Overpopulation, war, climate change and the shortage of essential resources such as water, comprise a threatening but plausible reality for the next decades. Although space exploration will result in human progress and in a reassessment of our values and priorities, we must not use space exploration as an excuse to neglect our home planet.

Organizations involved in space travel so far have envisioned different strategies to reach Mars. SpaceX is planning a "one-way ticket" journey for their first astronauts, similar to the mission plan in development by Mars One (Sydney et al., 2016, p. 192). Conversely, NASA is planning a return trip for the astronauts, which poses an incredible technical challenge. NASA's solution is the Mars Ascent Vehicle (MAV), which will be sent to Mars a few years before the astronauts so that they have the means to return to Earth (National Aeronautics and Space Administration, 2012). Nonetheless, human reproduction on Mars, or during the journey to Mars, will eventually take place. We should anticipate the challenges associated with such an important aspect of human life.

Human reproduction combines medical, biological, social and cultural aspects. In this paper, we will discuss the main challenges of human reproduction on a future Mars colony. We consider that the logistics of human reproduction should be carefully determined to conciliate resources and colony growth on Mars. The central issues are how a Martian colony should maintain a balance between reproductive rights and the need for reproduction in the inhospitable Martian environment. Also, little is known about pregnancy in outer space. We discuss possible answers for the following questions: how could we ensure the success of human reproduction? Could we sustain continuous human generations in a Mars colony? How (if any) will these biological and medical challenges affect our moral thinking and moral intuitions?

Human reproduction in Mars is necessary for long-term colony establishment

The predicted organization of a Martian colony, as well as current knowledge on human population dynamics, suggests that reproduction on Mars will be necessary for colony survival and subsequent expansion. Until a Martian colony is established as a self-sustainable population, immigration from Earth will also be necessary, but eventually should become complementary. Chris Impey and colleagues have calculated that a minimum viable human population for an extra-terrestrial colony to survive throughout time should include about 5,000 individuals (Impey, 2015). This calculation considers possible and unpredictable catastrophes, illnesses and other demographically deleterious phenomena. Other calculations estimate a minimal viable population (MVP) of a given vertebrate species to be 5,816 adult individuals (Reed et al., 2003, p. 23), or approximate numbers (Flather, 2011). Such calculations refer to ecological studies on Earth, but consider all possible extinction

events. We suppose that in the extreme Martian environment the estimated human MVP is required to be greater.

It is very unlikely that a human colony on Mars would reach as many individuals in the decades following the first missions, although large-scale transportation to Mars is being conceived. Journeys to Mars, such as in Elon Musk' SpaceX Interplanetary Transport System, are expected to take 7-9 months, will be extremely costly, dangerous and will only be able to take a few astronauts at first. More importantly, it is unknown how many people would be willing to live permanently on Mars. We believe that humans born and raised on Mars will be better adapted psychologically and physiologically to life in the planet, and will be willing to accept ideologies, training and the culture of an extra-terrestrial colony. Therefore, we consider human reproduction on Mars to be an important means for the establishment of an enduring human community in Mars.

Social and ethical challenges of reproduction in Mars

The concept of reproduction on a Mars colony is challenging. Before we consider medical and biological objections, we must enumerate selected ethical and moral issues that are strictly correlated with sexual policy and regulation of fertility rate. Human history provides examples of control and regulation of human reproduction. Ethical and legal systems, both secular and religious, include rules for dating, mating/sex, and reproduction. Human sexuality and reproduction were and still are a fierce matter of debate on Earth. Below we discuss four challenging topics, describing how these issues have been treated on Earth and how they may be raised in the Martian context:

1. Value of human life,
2. Abortion policy,
3. The problem of value – Mars as a place beyond moral values,
4. Sexual selection and artificial genetic engineering.

Value of human life

The Western civilization evaluates human life as the most important value and human good (Giezek, Kokot, 2002, p. 101). A demotion of the status of an individual human life from invaluable is hardly discussed. We do not practice individual sacrifice for the benefits of our community. The idea that human life should be protected has been expressed in legal documents of Western civilization throughout centuries. In the modern era, philosophers talked about this in terms of three basic natural rights: the rights to life, liberty, and property. Among declarations published in the 18th century, the right to life was mentioned only in the American Declaration of Independence together with the rights to freedom and happiness (Declaration, 1776; Kędzia, 1991, p. 169). The

United Nations Human Rights Declaration (1948) states that every human has a right to life, freedom, and security. According to the Convention of Children's Rights published in 1989, every child has a right to life. Policies aimed at the protection of early life may extend to the prenatal period, which has led to conflicts between conservative and liberal segments of western societies regarding the right to abortion.

Independent of current legal systems, ecological factors and "fight for survival" situations reveal a broad spectrum of possible human behaviors, from pure selfishness to heroic altruism and self-sacrifice. Judgments regarding the value of human life may be affected by conditions of resource scarcity and survival. The case of Lawrence Edward Grace Oates who participated in the South Pole expedition commanded by Robert Scott in 1911-1912 is noteworthy. Oates is known as a man who decided to leave camp during a return trip from the South Pole to increase the chances of survival for his companions. His decision is often interpreted as a suicidal, self-sacrificial act (Limb & Cordingley 1997). Another kind of terrestrial analogy for the challenges of future Martian missions are cases of team climbing at high summits where individual survival often depends on the support of others. Despite this necessity of help from those who are in a superior physical condition, often those in this superior position place a primacy on their own survival in lieu of helping companions in need (Simpson 1988).

The idea to protect life at every stage of development (Orzeczenie, 1997) may not be suited to a Mars colony. Values and the axiological framework that support legal regulations on Earth may not be valid in a Martian environment. First, an inhospitable environment and a small mission crew may result in the elevation of the value of group over individual. We suppose that in deep-space missions, such an axiological approach would be implemented and allow policies in such matters such as abortion, euthanasia of terminally ill persons, or sacrifice of individual life that would the benefit the entire community. Like in the case of the expeditions on Earth that we mentioned, we cannot always predict the possible behaviors of particular individuals in fight for survival situations, and we have much less opportunity to do the same in regard to the future living in Martian base. Obviously, space psychologists will do their best to select the most appropriate candidates for that mission. However, new ecological conditions that cannot even be simulated on Earth including high radiation exposure, microgravity, or long distance from Earth, just to mention a few, introduce some level of unpredictability into the mental framework of Martian astronauts (Wickman, 2006; Kanas et al. 2009; Torre et al. 2012).

Abortion policy

Nowadays, despite the action of conservative groups, abortion is often considered to no longer be a crime, but a matter of freedom, personal values and health, and a right of women. However, legislation on abortion varies greatly among countries, and is associated with economic development, religion and culture. For example, within Europe, Poland and Ireland are characterized by legislation restricting abortion, whereas Sweden, Germany and Belgium (and other countries) have liberalized abortion policy including the right to abortion upon request up to 12 weeks of gestation (Berer, 2017). Discussion on the ideological aspect of abortion is often rooted in our religious past, whereas the philosophical and axiological aspects of abortion evokes the basic values of life and freedom.

In the context of Martian colony, we expect that the abortion policy would be liberal in comparison to Earth, and should evolve to a further liberal concept. Abortion should be acceptable in cases where pregnancy poses a high risk to the mother and when the fetuses display severe conditions unsuitable for life, *in utero*. We assume that the Martian colony environment would favor these liberal pro-abortion policy because the birth of a disabled child would be highly detrimental to the colony. Increases in the consumption of resources and extended time and effort from parents/ crew necessary to raise a disabled child wouldn't result in development of the colony and its community. A Martian community may set new or higher criteria for valuable offspring, and may evolve to favor the preservation of personal and physiological traits more suitable to Martian residents.

We will not discuss the alternative of prohibition to reproduce because – even if reproduction would be deleterious for the colony – contraception is largely dependent on compliance. Sterilization prior to the journey to the Mars colony, as performed by couples that do not want (more) children, could be considered, but shouldweighed against the needs to facilitate the birth rate necessary to establish a stable colony of adequate population size.

The problem of value – Mars as a place beyond moral values

Human life is regulated and affected by moral values in at least two ways: by a set of external obligations and limits, and by moral intuitions that are, at least partially, deeply rooted in our human evolutionary past. Studies on the origin of moral values may be found elsewhere (Haidt, 2001; Waal, 2008). The main sources of morality are human culture (Creanza et al., 2017) and evolution, as in the theory developed by Charles Darwin. In addition to human culture, biological traits and behavior contribute to the establishment of moral values and later, to change throughout time. Unfortunately, it is not yet possible to predict how moral patterns in a Martian colony would evolve.

If life on Mars – as we suggested above – requires such a dramatic change in the value of human life, it suggests that human moral patterns developed on Earth may not be suitable in a Mars colony. Thus, the colony may be considered a place beyond moral values, and with reduced privacy. People willing to have children could be enrolled in projects for thorough genetic and phenotypical screening, so that any risks are minimal, or anticipated. We suppose the moral and ethical challenge will be the definition of which members of the colony should be encouraged to have children, and which members should not. Moreover, members with the intent of reproducing should understand the considerable possibility of abortion and, if necessary, to comply. If we are correct in our prediction that the Martian concepts of ethics and morality will be wider and more flexible than Earth's, abortions will apply to a variety of cases far surpassing those described in current abortion policies in Earth. A strategy to establish a set of moral standards may be - as previously discussed (Szocik et al., 2016; Szocik, 2017) – an educational program based on a Martian religion that could explain the ontology of living on Mars, promote integration and acceptance of science and technology, encourage prosocial behavior and conciliate cultural and moral concepts from astronauts with different backgrounds. We expect a Martian colony to require a cultural system that will further motivate and strengthen prosocial and pro-cooperative patterns, even though they may result in individual compromise and respect individual rights.

Sexual selection and artificial genetic engineering

Sexual selection describes and interprets patterns of behavior that affect dating, mating, and reproduction. Sexual selection indicates that mating is an assortative, non-random process. In human history, marriages often were arranged by parents for obvious political, social, and/or economic reasons. We suspect that the practice of genetic counselling, careful selection of partners and restriction of reproductive rights may be a necessary strategy, to prevent traits incompatible with life in Mars from emerging in subsequent generations. Such strategy should not be mistaken for eugenics, which describes practices and intent to improve the genetic "quality" of human populations (Aultman, 2006). Eugenic projects of racially pure human communities are based on discriminatory and controlled mating, and have emerged repeatedly in history and condemned for their terrible consequences to humanity. Miscegenation is a key factor for a healthy and long-lasting human colony in Mars.

Should couples on Mars discover that their developing baby possesses a condition unsuitable for life on Mars, and abortion is not an option, genetic engineering may represent an alternative to generate viable children, but such technology and its ethical implications has yet to be fully developed (Matthew, 2005). In any case, establishing families will be important inlight of

expanding the colony population to MVP, and to promote psychological and physiological health among residents. Kinship is frequently a unique and important source of personal support. Kin ties exert influence in biological (Hamilton, 1964) and cultural theories (Crespi, Summers, 2014) as a main factor in human evolution. There are many cases in human cultural and social life in which so called fictive kinship appears spontaneously (or is intentionally provided) to enhance human relations and to motivate cooperation and altruism.

The moral and ethical challenges mentioned above cannot be fully tested or predicted before the mission will be launched. The unique opportunity that may be and should be managed now on Earth is to prepare – technologically, medically, and psychologically - the future deep-space astronauts as best as possible for all possible scenarios. For that reason, thought experiments and science-fiction-like speculations, obviously rooted in scientific background and earthly parallels, are probably the prudent methodology to attempt to elucidate the future scenarios in space. One such inspiration that may be applicable for the topics of reproduction and artificial sexual selection that we discussed can be found in "Noumenon", written by Marina Lostetter (2017). The book addresses the issue of population management during the long deep-space journey. Obviously, the voyage itself is not parallel to a 6-9 month long journey to Mars but it works as a good parallel for staying on Mars, and as a good starting point for thought experiments on possible ethical challenges. Ethical dilemmas discussed by Lostetter (2017) include reproduction and population policy that is determined by the specific environment and future benefits of the mission. Population management issues seem to be crucial in such a confined , narrow space like the future long-term Martian base, encompassing a condition of scarcity resources resulting in a highly endangered chance for survival. That science-fiction scenario shows how challenging for our current moral intuitions and ethical standards such a deep-space mission can be.

Biological and medical challenges of reproduction in Mars

Pregnancy is the sole mean of human reproduction, and is key to long-term colonization of Mars. Unfortunately, pregnancy is risky and may pose serious hazards to women's health, especially in an extraterrestrial environment. Deep-space missions require astronauts to be at peak physical condition and perfect health (Hackney, Scott et al. 2015; Crucian, Babiak-Vazquez et al. 2016). During travel, astronauts may experience motion sickness, headaches, body pain, diseases and genitourinary problems, among several other pathologies (Ertl, Diedrich et al. 2002) (Rummel, Michel et al. 1976). On their return to Earth, astronauts stationed at the ISS presented with muscle and bone loss (Chang, Healey et al. 2016), immunosuppression (Mukhopadhyay, Saha et al. 2016) and even temporary blindness (Zwart, Gregory et al. 2016), which required astronauts to recover for

months. Microgravity has been described as an inducer of significant changes in the cardiovascular system of astronauts both during and after flight (Otsuka, Cornelissen et al. 2016). Changes in the nervous system, hearing and eyesight are also significant and related to the physiological adaptation/stress to microgravity (Ertl, Diedrich et al. 2002; Strewe, Feuerecker et al. 2012; Cassady, Koppelmans et al. 2016). The life-supporting environment of a Martian colony won't facilitate astronaut recovery to a necessary healthy status, and is likely to require the most of astronauts' physical capacities. Mars gravity is 0.38g (Lacquaniti, Ivanenko et al. 2017), which indicates that astronauts will remain in hypogravity for the whole mission, or lifetime. Without the opportunity to return to an environment at 1g (Earth gravity), we assume that most astronauts will never recover to a pre-journey healthy state, and may have to adapt to new parameters of health and well-being, as made possible in the Mars colony infrastructures. Moreover, astronauts will have to tolerate lower oxygen tension (Fogg 1995) and the risk of chronic exposure to radiation. NASA's human habitats on Mars are being designed to prevent or mitigate most of the health hazards associated with long-duration missions, and are invested with new technologies for health monitoring and diagnostics, in association with exercise systems (NASA's Journey to Mars – Pioneering Next Steps in Space Exploration, 2015). Other governmental and private enterprises have not detailed their efforts to maintain a healthy environment for astronauts, and have focused on the primordial aspect of transporting the first colonizers to Mars and providing a minimal environment compatible with human life. Overall, it is unknown how pregnancy would be influenced by microgravity symptoms, for better or worse.

The aspects of Martian life that could influence the process of reproduction are many (Urbaniak and Reid 2016). For instance, it is not known if reduced gravity would affect the production of reproductive cells in both males or females, or the success rate of fertilization (Jones, Jennings et al. 2005). The effects of reduced gravity on the embryonic development and delivery are also unknown (Urbaniak and Reid 2016). Radiation is known to be deleterious for adults and especially for reproductive cells, developing embryos and fetuses, and is already considered a major health hazard to astronauts (Northum, Guetersloh et al. 2015; Shirazi-Fard, Alwood et al. 2015).

This plethora of health hazards that may be associated with extraterrestrial life requires the establishment of a healthcare system on a Martian colony. In the context of pregnancy, healthcare will be essential from the first months of pregnancy up to the beginning of an infant's life, to ensure mother and child survival and proper recovery. Pregnant women are known to develop a transient immunosuppressed condition (Cheng and Sharma 2015). Briefly, this condition is associated to placental development, which actively suppresses the immune system of the mother so that the immune system doesn't respond aggressively to the developing fetus. This immunosuppressive

state requires that mothers be extra careful regarding certain infections, especially those affecting the genitourinary tract and belonging to TORCH (Toxoplasma, Other, Rubella, Cytomegalovirus and Herpes simplex) (Racicot, Kwon et al. 2014; Coyne and Lazear 2016). Such microorganisms may capitalize upon this impaired immunological condition and cause severe disease, malformations and abortions (Racicot, Kwon et al. 2014). Immunosuppression is frequently developed by astronauts on (and after) missions (Crucian, Babiak-Vazquez et al. 2016) (Stowe, Mehta et al. 2001), and such a state may aggravate the risks of infection-induced abortions and facilitate the dissemination of diseases among pregnant and non-pregnant individuals.

Common practices adopted for a healthy pregnancy also includes constant monitoring and the modification/supplementation of the mother's diet, to ensure key nutrients are sufficient (WHO. Guideline: Daily iron and folic acid supplementation in pregnant women. Geneva, World Health Organization, 2012). In parallel, concern has been raised on the age-related fertility decline of female astronauts (Jones, Jennings et al. 2005). The average age of an incoming female astronaut is 32, and many choose to delay pregnancy until after their first spaceflight. Pregnant astronauts are not allowed to train in most installations, which results in just a few astronauts conceiving children before the age of 40. Thus, Jones and colleagues suggest the creation of a NASA-sponsored program for assisted reproductive technology for astronauts, which would provide services such as cryopreservation of gametes and embryos. The success rates of gametes and embryos are dependent on the age of the patient at the time of collection, so such a program would be a way that young astronauts could preserve their means to reproduction and avoid complications of pregnancy later in life (Jones, Jennings et al. 2005). Such a program could be adapted in the future to assist astronaut reproduction in Mars. Moreover, the process of having children can be overwhelming, especially in a dangerous Martian environment (Jacubowski, Abeln et al. 2015). Thus, psychological support to families should increase success not only in giving birth to healthy children, but also would assist families in the process of raising children. In long-term planning, when reproduction on Mars may become a reality, astronauts certified in different areas of medicine will be necessary.

Fortunately, we believe that many questions regarding human pregnancy on Mars can be investigated before any attempt at human reproduction on the red planet. Biomedical research is already performed at the ISS and other spaceflight missions (Mukhopadhyay, Saha et al. 2016), including mammalian cell culture, bacteriology and genome sequencing (Checinska, Probst et al. 2015). Several aspects of space travel are being modelled on Earth, notably those related to human physiological changes (Rodman, Almeida-Porada et al. 2016). Experimental models of embryonic development could be adapted for preliminary studies in outer space, which could answer whether reduced gravity is deleterious or not. Examples of *in vitro* models to be used are induced pluripotent

stem cells (iPSC) of various organs, obtained from adult human tissue. *In vivo* experimental models of embryonic development, such as embrionated chicken eggs, are desirable but more difficult to study in a restricted space station environment. Likewise, *in vivo* experiments in space using a mouse model of pregnancy would be difficult, but would bring invaluable insight into mammalian reproduction. Human reproduction in a Moon colony, or in a space station, does not seem necessary, but would certainly help our understanding how human reproduction would take place in Mars.

Another biological issue that may take place in a long-term Martian colony is consanguinity. Consanguinity may be harmful in subsequent generations in a small population, which increase homozygosity and the chances of offspring being affected by recessive or deleterious traits (Dahdouh, Taleb et al. 2016). Consanguinity can be avoided by maintaining a large and unrelated sexually-active population. Thus, miscegenation is a positive aspect for a Mars colony on both social and biological aspects. Impey and colleagues calculate that a group of 500 adults should be sufficient to avoid consanguinity (Impey, 2015). Continuous reproduction in Mars should be recommended after the adult population reaches a safe threshold, or if immigration is constantly complementing the genetic pool of the population. NASA plans for the colonization of Mars (NASA's Journey to Mars – Pioneering Next Steps in Space Exploration, 2015) are based onreducing the degree of reliance on Earth, which would allow Mars colonies to become self-sufficient, independent of technological or populational input from Earth.

Some consider that a human population on Mars could evolve and differentiate from the human population on Earth. We believe that this event is extremely improbable assuming the exclusion of genetic engineering. Physical separation of a given population on Earth could result in speciation, that is, the differentiation of populations into separate species. However, there are several other mechanisms to be considered besides sole physical isolation, which are reviewed elsewhere (Seehausen, Butlin et al. 2014). Studies on human evolution indicate that human populations remained in long-term isolation on several occasions throughout history, for example in Oceania (Kayser 2010) and the Americas (Pickrell and Reich 2014). Although differences between human populations accumulated, they were not sufficient to result in speciation. The window of the most efficient transit between Earth and Mars occurs every 26 months. SpaceX has estimated the journey to Mars to take between three and six months. Therefore, distance or inaccessibility would not lead to the separation of human populations on Earth and Mars. Even if we forecast that a time will arise when the technology necessary for a Mars colony will be completely developed, and that Mars colonies will become self-sufficient, contact with Earth would still be required and/or desired. Complete isolation, that is, in physical, cultural and ecological aspects, is unlikely to take place

between Earth and Mars, and thus, speciation of humans is a remote possibility. However, let us consider another evolutionary scenario that opens up the possibility of speciation within human populations living in a deep-space colony. As mentioned earlier, although ethical challenges will need to be overcome, human reproduction on Mars could be improved through genetic engineering. The method of CRISPR makes possible adaptive genetic engineering (Ran F. A. et al. 2013; Kleinstiver et al. 2016). We should consider the idea of genetic human enhancement before and during that mission (Szocik et al. 2018a, 2018b). Genetic engineering and deep-space isolation can result in speciation of Homo Sapiens. In such a scenario, new ethical challenges arise from theevolution of a new kind of human species who will possess a new nature and, consequently, possibly new moral duties and rights when compared with people living on Earth.

Final remarks

In our paper, we argue that one of the most important long-term challenges associated with Mars colonization is human reproduction on site. Our purpose was to enumerate aspects that may be overlooked in the attempts to colonize Mars, but nonetheless should be discussed and addressed to maximize the chances of establishing a successful Martian colony in the next decades. The subject of human reproduction in the extraterrestrial environment is complex and involves every aspect of human life. We suggest that human reproduction is necessary for maintaining a successful long-term colony on Mars, and while we consider it to be an overall positive, this subject brings challenges to our moral thinking.

The consequences of successful human reproduction on Mars will be significant. The birth of a healthy human being outside Earth is by itself a statement of our abilities as a species, and indicates our potential to successfully explore the universe. Astronauts must be physically and psychologically prepared for missions, and we understand that preparation in a moral sense will be necessary to deal with dilemmas and decisions pertinent to a lifetime on Mars. We suggest that psychological training of astronauts should include preparation to withdraw moral intuitions that – even if deeply rooted – may need to be revised to build a new world. We expect reproduction on Mars to lead to the creation of new moral/ethical concepts, and to remarkable advances in medicine, biology and biotechnologies. Ultimately, these technological advances will improve human reproduction, with reverberations in our understanding of disease, treatment and human lifespan, both on Mars and Earth. Reproduction is an intimate aspect of human life. Life on Mars will be distinct from our life on Earth, and so will be the reproduction that engenders it.

References

Aultman, J. M. (2006). “Eugenomics: Eugenics and Ethics in the 21st Century.” Genomics, Society and Policy, Vol.2, No.2, 28-49

Becker, G. (2016). Tractatus Ethico-Biologicus, Gdańsk University Press.

Berer, M. (2017). “Abortion Law and Policy Around the World: In Search of Decriminalization.” *Health and Human Rights*, 19(1), 13–27.

Cassady, K., V. Koppelmans, et al. (2016). "Effects of a spaceflight analog environment on brain connectivity and behavior." Neuroimage 141: 18-30.

Chang, D. G., R. M. Healey, et al. (2016). "Lumbar Spine Paraspinal Muscle and Intervertebral Disc Height Changes in Astronauts After Long-Duration Spaceflight on the International Space Station." Spine (Phila Pa 1976) 41(24): 1917-1924.

Checinska, A., A. J. Probst, et al. (2015). "Microbiomes of the dust particles collected from the International Space Station and Spacecraft Assembly Facilities." Microbiome 3: 50.

Cheng, S. B. and S. Sharma (2015). "Interleukin-10: a pleiotropic regulator in pregnancy." Am J Reprod Immunol 73(6): 487-500.

Coyne, C. B. and H. M. Lazear (2016). "Zika virus - reigniting the TORCH." Nat Rev Microbiol 14(11): 707-715.

Creanza, N., Kolodny, O., Feldman, M. W. (2017). Cultural evolutionary theory: How culture evolves and why it matters. *PNAS* 2017 114 (30) 7782-7789; published ahead of print July 25, 2017, doi:10.1073/pnas.1620732114

Crespi, B., Summers, K. (2014). "Inclusive Fitness Theory for the Evolution of Religion.” Animal Behaviour 92: 313-323.

Crucian, B., A. Babiak-Vazquez, et al. (2016). "Incidence of clinical symptoms during long-duration orbital spaceflight." Int J Gen Med 9: 383-391.

Dahdouh, A., M. Taleb, et al. (2016). "Genetics and psychotic disorders: A fresh look at consanguinity." Eur J Med Genet 59(2): 104-110.

Ertl, A. C., A. Diedrich, et al. (2002). "Human muscle sympathetic nerve activity and plasma noradrenaline kinetics in space." J Physiol 538(Pt 1): 321-329.

Nature. (2016) Fed up of Earth? Try Mars. Nature 539, 7629. https://www.nature.com/news/fed-up-of-earth-try-mars-1.20982

Flather, C. H., Hayward, G. D., Beissinger, S. R., Stephens, P. A. (2011). "Minimum viable populations: is there a ‘magic number’ for conservation practitioners?” Trends in Ecology and Evolution 26, 6: 307-316.

Fogg, M. J. (1995). "Terraforming Mars: conceptual solutions to the problem of plant growth in low concentrations of oxygen." J Br Interplanet Soc **48**(10): 427-434.

Giezek, J., Kokot, R. (2002). "Granice ludzkiego życia a jego prawna ochrona" in B. Banaszak, A. Preisner (eds.), Prawa i wolności obywatelskie w Konstytucji RP, Warszawa.

Hackney, K. J., J. M. Scott, et al. (2015). "The Astronaut-Athlete: Optimizing Human Performance in Space." J Strength Cond Res 29(12): 3531-3545.

Haidt, J. (2001). "The Emotional Dog and Its Rational Tail: A Social Intuitionist Approach to Moral Judgment." *Psychological Review*, 2001, Vol. 108, No. 4.

Hamilton, W. J. (1964). "The Genetical Evolution of Social Behavior." Theor Biol. 7(1): 1-16.

Impey, Ch. (2015). Beyond: Our Future in Space, W.W Norton & Company.

Jacubowski, A., V. Abeln, et al. (2015). "The impact of long-term confinement and exercise on central and peripheral stress markers." Physiol Behav 152(Pt A): 106-111.

Jones, J. A., R. Jennings, et al. (2005). "Genitourinary issues during spaceflight: a review." Int J Impot Res 17 Suppl 1: S64-67.

Kanas N., Sandal G., Boyd J.E., Gushin V.I., Manzey D., North R., Leon G.R., Suedfeld P., Bishop S., Fiedler E.R., Inoue N., Johannes B., Kealey D.J., Kraft N., Matsuzaki I., Musson D., Palinkas L.A., Salnitskiy V.P., Sipes W., Stuster J., Wang J. (2009) Psychology and culture during long-duration space missions. *Acta Astronautica* 64, 7-8, April-May, 659-677.

Kayser, M. (2010). "The human genetic history of Oceania: near and remote views of dispersal." Curr Biol 20(4): R194-201.

Kędzia, Z. (1991). "Prawo do życia" in R. Wieruszewski (ed.), Prawa człowieka. Model prawny, Wrocław Warszawa Kraków.

Kleinstiver B. P., Pattanayak V., Prew M. S., Tsai S. Q., Nguyen N. T., Zheng Z. and Joung J. K. (2016) High-fidelity CRISPR–Cas9 nucleases with no detectable genome-wide off-target effects. *Nature* 28 January, 529: 490-495.

Lacquaniti, F., Y. P. Ivanenko, et al. (2017). "Human Locomotion in Hypogravity: From Basic Research to Clinical Applications." Front Physiol **8**: 893.

Limb, S. & P. Cordingley. (1997). *Captain Oates: Soldier and Explorer*, Pen & Sword Paperbacks.

Lipiec, J. (2016). Filozofia miłości, Fall: Kraków.

Lostetter, M. (2017). Noumenon, Harper Voyager.

Matthew, L. (2005). The ethics of using genetic engineering for sex selection. *Journal of Medical Ethics*, *31*(2), 116–118. http://doi.org/10.1136/jme.2003.005983

Mukhopadhyay, S., R. Saha, et al. (2016). "A systems biology pipeline identifies new immune and disease related molecular signatures and networks in human cells during microgravity exposure." Sci Rep 6: 25975.

National Aeronautics and Space Administration. (n. d.) *Overview***.** Retrieved from NASA Mars Exploration Website: https://mars.nasa.gov/programmissions/overview/

National Aeronautics and Space Administration. (2012) Mars Ascent Vehicle. In-Space Propulsion Technology Program**.** Retrieved from NASA Space Flight Systems Website: https://spaceflightsystems.grc.nasa.gov/SSPO/ISPTProg/documents/MAV_Fact_Sheet_03_12_12.pdf

Northum, J. D., S. B. Guetersloh, et al. (2015). "Simulated Response of a Tissue-equivalent Proportional Counter on the Surface of Mars." Health Phys 109(4): 284-295.

Orzeczenie TK z 28.5.1997 r., K 26/96, OTK ZU 1997/2/19.

Otsuka, K., G. Cornelissen, et al. (2016). "Long-term exposure to space's microgravity alters the time structure of heart rate variability of astronauts." Heliyon 2(12): e00211.

Pickrell, J. K. and D. Reich (2014). "Toward a new history and geography of human genes informed by ancient DNA." Trends Genet 30(9): 377-389.

Racicot, K., J. Y. Kwon, et al. (2014). "Understanding the complexity of the immune system during pregnancy." Am J Reprod Immunol 72(2): 107-116.

Ran F. A., Hsu P. D., Wright J., Agarwala V., Scott D. A. and Zhang F. (2013) Genome engineering using the CRISPR-Cas 9 system. *Nature Protocols* 8: 2281-2308.

Reed, D. H., O'Grady, J. J., Brook, B. W., Ballou, J. D., Frankham, R. (2003). "Estimates of minimum viable population sizes for vertebrates and factors influencing those estimates." Biological Conservation 113: 23-34.

Rodman, C., G. Almeida-Porada, et al. (2016). "In vitro and in vivo assessment of direct effects of simulated solar and galactic cosmic radiation on human hematopoietic stem/progenitor cells." Leukemia.

Rummel, J. A., E. L. Michel, et al. (1976). "Medical experiment M-171: results from the second manned Skylab mission." Aviat Space Environ Med 47(10): 1056-1060.

Seehausen, O., R. K. Butlin, et al. (2014). "Genomics and the origin of species." Nat Rev Genet 15(3): 176-192.

Shelhamer, M. (2017). Why send humans into space? Science and non-science motivations for human space flight. *Space Policy*, Vol. 42, November 2017, 37-40.

Shirazi-Fard, Y., J. S. Alwood, et al. (2015). "Mechanical loading causes site-specific anabolic effects on bone following exposure to ionizing radiation." Bone 81: 260-269.

Simpson, J. (1988). *Touching the Void*, Perennial.

Stephen Hawking 's Interview in Independent, 19 February 2015.

Stowe, R. P., S. K. Mehta, et al. (2001). "Immune responses and latent herpesvirus reactivation in spaceflight." Aviat Space Environ Med 72(10): 884-891.

Strewe, C., M. Feuerecker, et al. (2012). "Effects of parabolic flight and spaceflight on the endocannabinoid system in humans." Rev Neurosci 23(5-6): 673-680.

Sydney, Do, Owens, A., Ho, K., Schreiner, S., de Weck, O. (2016). "An independent assessment of the technical feasibility of the Mars One mission plan – Updated analysis". Acta Astronautica 120: 192-228.

Szocik, K. (2016). "Unseen challenges in a Mars colony". Spaceflight 58: 20-23.

Szocik, K. (2017). "Is Religion necessary for a future Mars colony?" Spaceflight 3, 59: 92-97.

Szocik, K., Lysenko-Ryba, K., Banaś, S., Mazur, S. K. (2016). "Political and legal challenges in a Mars colony." Space Policy 38: 27-29.

Szocik, K., Campa R., Rappaport B. M., Corbally Ch. (2018a). Changing the Paradigm on Human Enhancements. The Special Case of Modifications to Counter Bone Loss for Manned Mars Missions. *Physics Today* (under evaluation).

Szocik, K., Wójtowicz T., Rappaport B. M., Corbally Ch. (2018b). Mission to Mars: A Challenge for the Ethics of Human Biology. *Science and Engineering Ethics* (under evaluation).

The unanimous Declaration of the thirteen united States of America, 4 July 1776.

Torre G. G. De La n, Baarsen van B., Ferlazzo F., Kanas N., Weiss K., Schneider S., Whiteley I. (2012) Future perspectives on space psychology: Recommendations on psychosocial and neurobehavioral aspects of human spaceflight. *Acta Astronautica* 81, 587-599.

Urbaniak, C. and G. Reid (2016). "The potential influence of the microbiota and probiotics on women during long spaceflights." Womens Health (Lond) 12(2): 193-198.

Waal, F. B. M. de. (2008). "Putting the Altruism Back into Altruism: The Evolution of Empathy." Annual Review of Psychology, 2008, 59.

Wickman, L. A. (2006) Human Performance Considerations for a Mars Mission. *IEEE Aerospace Conference Proceedings*, January.

Zwart, S. R., J. F. Gregory, et al. (2016). "Genotype, B-vitamin status, and androgens affect spaceflight-induced ophthalmic changes." FASEB J 30(1): 141-148.