Pol J Aviat Med Bioeng Psychol 2022; 28(2): 19-26
DOI: 10.13174/pjambp.23.05.2025.02

REVIEW ARTICLE

POTENTIAL OPHTHALMOLOGICAL PROBLEMS DURING PLANNED CREWED MISSIONS TO MARS

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Source of support: Own sources

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Abstract: The three unmanned rover missions to Mars carried out in 2021 have raised expectations for manned flights to this planet. However, recently published reports and a NASA report indicate that changes in the during these flights may be one of the most important factors limiting their conduct.

The purpose of this presentation is to discuss ocular changes that occur during long--term space missions.

During flights, astronauts often experience disc swelling, the development of retinal and choroidal folds, focal retinal ischemia, flattening of the eyeball and hyperopia, which may cause temporary and permanent visual disturbances during the flight as well as after returning to the Earth.

Conducting long-term space flights will be possible after developing methods that will allow elimination of the negative effects of microgravity on the human body, including the vision system.

Keywords: prolonged space missions, manned flights to Mars, ocular changes

Cite this article: **Prost M. Potential Ophthalmological Problems During Planned Crewed Missions to Mars. Pol J Aviat Med Bioeng Psychol 2022; 28(2): 19-26. DOI: 10.13174/pjambp.23.05.2025.02**

INTRODUCTION

In February 2021, landers appeared on the surface of Mars within a few days of each other: the orbiter and the rover Hope developed by the United Arab Emirates (9 February 2021), the rover, lander, and orbiter Tianwen-1 from China (10 February 2021), and the rover Perseverance sent by NASA from the USA (18 February 2021). There were more countries that attempted to deliver their probes to Mars or to its orbit. The highest number of orbiters, landers, and rovers has been sent to Mars by the American space agency NASA, which, however, experienced both successes and failures in this regard. Perhaps the greatest success was India's only mission, namely the spacecraft Mangalyaan (Mars Orbiter Mission). Since 2014, it has been orbiting Mars and conducting research on its atmosphere and surface. It was the cheapest mission in history, with costs amounting to just under 100 million dollars (less than the budget of Hollywood science fiction films). India became the first country to succeed in a Mars mission on the first attempt. In contrast, earlier Martian missions carried out by Japan and Russia ended in failure. In 2022, the Mars rover Rosalind Franklin, built within the framework of the international ExoMars program conducted by the European Space Agency and the Russian Roskosmos, was scheduled to launch, but due to the Russian invasion of Ukraine, the project was suspended. All missions were unmanned. However, they revived expectations regarding crewed flights to the planet. The most ambitious crewed Mars mission currently underway is the SpaceX mission, being developed by Elon Musk's company. It has generated strong interest among both supporters and critics of the project. The technological obstacles to carrying out such a crewed mission to Mars appear solvable within a predictable timeframe. However, the real challenge lies in the fact that, unlike the robotic missions completed so far, living beings — humans — must travel to and survive on the surface of Mars. This presents a far greater challenge than technical issues alone. NASA and SpaceX are planning crewed missions around the year 2037. What are the realistic chances that we will be able to travel to and colonize Mars in the near future?

ISSUES RELATED TO SPACEFLIGHT AND LIFE ON MARS

The challenge of the duration of a crewed Mars mission

Mars is a superior planet (it lies farther from the Sun than Earth). It is the second closest planet to Earth (after Venus, where surface temperatures reach nearly 500°C [932°F], and atmospheric pressure is almost 100 times that of Earth). Mars travels at a different orbital speed than Earth. Earth completes its orbit around the Sun in 365.25 days, while Mars takes 687 days. The orbits of the planets are elliptical rather than circular, meaning that each planet is sometimes farther from Earth and

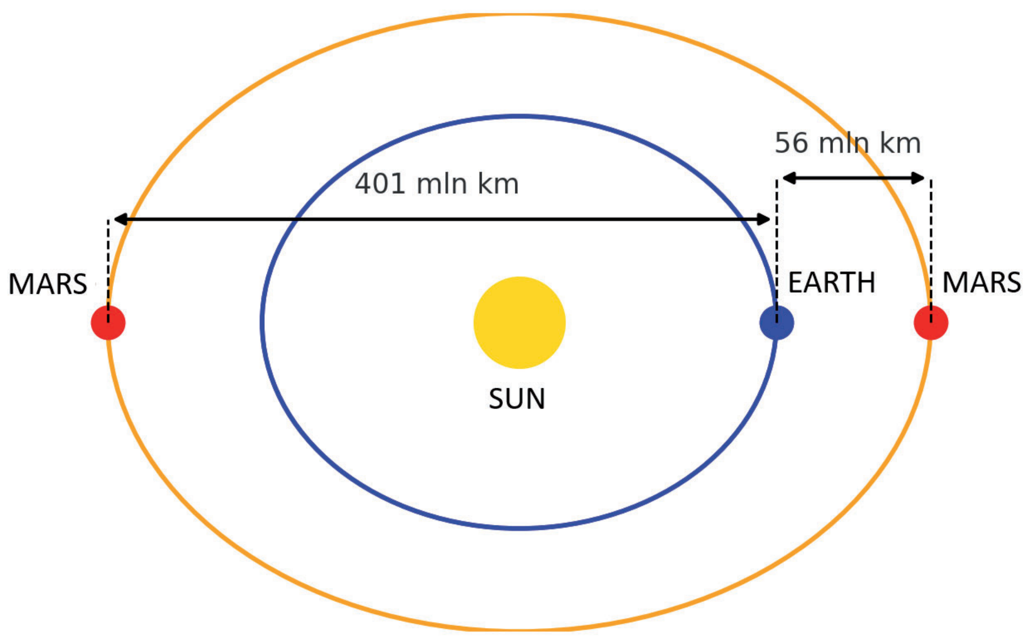

Fig. 1. Positions of Earth and Mars relative to the Sun.

sometimes much closer (during which it appears brighter and more visible in our sky). The average distance from Mars to the Sun is just under 228 million kilometers, and the distance from Earth to Mars ranges from 56 million kilometers to 401 million kilometers (Fig. 1).

For this reason, it is only feasible to travel to Mars roughly once every two years, when both planets are relatively close to each other. At their closest approach, the distance between Earth and Mars is a minimum of 56 million kilometers. One year later, when Earth returns to the same position in its orbit, Mars is on the opposite side of the Sun, and the distance increases to 401 million kilometers. With the use of the best theoretical propulsion systems, a spacecraft could potentially cover the 56 million kilometer distance in 43 days. However, this is purely theoretical. The Curiosity rover took 254 days to reach Mars. A Mars mission therefore must be carefully timed so that both the outbound and return flights occur when the planets are at their closest points. It is estimated that a round-trip mission could take approximately 950 days. This would involve an extended stay on the surface of Mars. However, the supplies necessary for surviving two years on Mars could be sent ahead of time by uncrewed spacecraft, well before humans even board the rocket on Earth.

Technical Challenges of a Mission to Mars

Until now, orbiters, landers, and rovers sent to Mars have had relatively low mass. In the case of crewed missions, it will be necessary to transport a large amount of equipment, instruments, life-support systems to protect living beings from galactic radiation, microgravity, and other hazards, as well as supplies for the journey — and of course, the astronauts themselves. As a result, the mass of such a spacecraft will be significantly greater. This means a large quantity of fuel will be required to ensure the journey to Mars, a safe landing on the planet's surface, and the return trip.

Medical Challenges During a Human Mission to Mars

The primary medical issues involve protection from galactic radiation and the effects of microgravity. Radiation exposure will increase the risk of developing cancer, central nervous system disorders, cardiovascular diseases, acute radiation syndrome, and irreversible DNA mutations. So far, our technological capabilities provide only partial protection for astronauts from this radiation, but it remains a technical issue that could potentially be solved. Microgravity will cause a range of physiological disturbances that will significantly affect astronaut health and performance (Table 1).

Challenges Related to Human Survival on Mars

A. Galactic Radiation

Both during the flight and while staying on Mars, astronauts are exposed to increased levels of galactic radiation. The Martian atmosphere is extremely thin, with a density of about 7 hPa — approximately one hundred times thinner than Earth's atmosphere. Unlike Earth, Mars does not have its own magnetic field (magnetosphere) to protect it from the solar wind. As a result, harmful cosmic radiation reaches the surface of Mars directly. This leads to a heightened risk of developing cancer, central nervous system disorders, cardiovascular diseases, acute radiation syndrome, and irreversible DNA mutations. So far, our technological capabilities only partially protect astronauts from this radiation, and it remains a challenge that must be addressed.

B. Microgravity

Gravity on Mars is much weaker than on Earth ($3.7\ m/s^2$ on Mars compared to $10\ m/s^2$ on Earth). This condition is referred to as microgravity. All human biological systems are adapted to function under Earth's gravity. Therefore, during a stay

Tab. 1. Sensory and Neuromotor Changes After Spending More Than One Month in Space

1.	Changes in the visual system (see further details below).
2.	Balance disorders (due to altered function of the otolith organs in microgravity).
3.	Difficulty assessing body position and head orientation in space (disrupted function of the semicircular canals).
4.	Spatial disorientation.
5.	Problems with concentration and memory.
6.	Cognitive difficulties, especially when performing two different tasks simultaneously.
7.	Impaired precision in hand movements — altered perception of hand weight.
8.	Muscle atrophy.
9.	Bone demineralization.
10.	Slowed speed and acceleration of limb movements.

on Mars, there may be a risk of developing intracranial hypertension, muscle atrophy, and bone demineralization.

C. Possibility of Breathing on Mars

The atmosphere on Mars is composed of approximately 95% carbon dioxide, 3% nitrogen, 1.6% argon, and only trace amounts of oxygen and water. Oxygen makes up just 0.13% of the Martian atmosphere. During the Perseverance rover mission, a device called MOXIE (Mars Oxygen In-Situ Resource Utilization Experiment) successfully produced enough oxygen to keep one astronaut alive for over three hours.

D. Dust Suspended in the Martian Atmosphere

Over billions of years, rocks on Mars have been ground down into fine dust, which continuously floats in the thin air. This dust contains perchlorates, which are harmful to humans. Mars experiences the largest dust storms in the entire Solar System — during these storms, sunlight is completely blocked from reaching the planet's surface.

E. Temperatures on the Surface of Mars

Due to its extremely thin atmosphere, daytime temperatures on Mars may reach a few degrees Celsius (and occasionally up to 20°C [68°F] on warmer days), but at night, they can drop to –90°C to –100°C (–130°F to –148°F).

F. Presence of Water on Mars

Water on Mars exists only in the form of solid ice caps at both poles. All of the above problems mean that long-term human habitation on Mars would require living permanently in underground tunnels carved into the rock.

OPHTHALMOLOGICAL PROBLEMS ASSOCIATED WITH CREWED MISSIONS TO MARS

Recent reports and publications, including those from NASA, indicate that changes in the visual system during crewed missions to Mars may be one of the major limiting factors for carrying out such missions. This assessment is based on the results of studies conducted during long-duration stays by astronauts aboard the International Space Station (ISS). The duration of those missions was approximately 180 days — shorter than any potential future flight and stay on Mars. Astronauts underwent examinations on Earth prior to the mission, during their stay on the ISS, and after returning to Earth. The list of ophthalmological diagnostic equipment used to examine astronauts aboard the International Space Station is presented in Table 2.

The results from these measurements were compiled in NASA reports (Table 3) and in numerous publications [1–10, 12–26].

Physiological and pathological changes occurring in astronauts' bodies in the visual system and musculoskeletal system are referred to as Spaceflight Associated Neuro-ocular Syndrome (SANS). These changes have also been the subject of numerous publications on the topic [1–10, 12–20].

Changes in the visual system following long-duration spaceflight are presented in Table 4.

Tab. 2. Ophthalmological Equipment on the International Space Station

1.	OCT (Spectralis model)
2.	Tonometer (Tonopen model)
3.	Ophthalmic ultrasound
4.	Direct ophthalmoscope
5.	Visual acuity test charts
6.	Amsler grid test
7.	Contrast sensitivity test
8.	Transcranial Doppler device

Tab. 3. NASA reports on changes in the visual system of astronauts.

1.	The Visual Impairment Intracranial Pressure Summit Report, NASA, October 2011 [21].
2.	Risk of Spaceflight-Induced Intracranial Hypertension and Vision Alterations, NASA, July 12, 2012 [17].
3.	Prospective Observational Study of Ocular Health in ISS Crews (Ocular Health). http://www.nasa.gov/mission_pages/station/research/experiments/204.html. May 13, 2015 [15].
4.	Risk of Spaceflight Associated Neuro-ocular Syndrome (SANS) November 30, 2017 [16].

Tab. 4. Changes in the visual system caused by long-duration spaceflight.

1.	Optic disc edema.
2.	Cotton wool spots in the retina.
3.	Retinal and choroidal folds.
4.	Flattening of the posterior globe.
5.	Hyperopia.
6.	Dilation of the optic nerve sheaths and optic nerve kinking.
7.	Impaired stereopsis – difficulties in depth perception and spatial orientation.
8.	Increased intraocular pressure.
9.	Cataracts.
10.	Decreased visual acuity.

A. Optic disc edema

Optic disc edema was observed in nearly all astronauts following long-duration stays on the International Space Station [3, 8–10, 23]. After returning to Earth, the edema subsided, but the resolution time varied between individuals. Prolonged optic disc edema may lead to damage of the nerve fibers that make up the optic nerve.

B. Cotton wool spots in the retina

Upon return to Earth, many astronauts were found to have cotton wool spots (Fig. 2) in the retina [2, 5, 7, 13]. These are fresh areas of ischemia (microinfarctions) in the retina caused by occlusion of capillary vessels. This results in a disruption of axoplasmic flow in the affected area and accumulation of axoplasmic material in and around the retinal nerve fibers, which appears as fluffy white spots on the fundus of the eye.

C. Retinal and choroidal folds

In many astronauts post-flight, horizontal light and dark lines were visible in the posterior pole of the eye. These are folds in the choroid and retina (Fig. 3). Their cause is congestion in the choroidal vessels and choroidal edema [5]. Choroidal and retinal folds are very clearly visible in OCT imaging [6].

Fig. 2. Cotton wool spots in the fundus of patients with diabetic retinopathy. Similar cotton wool spots were observed in some astronauts after returning to Earth.

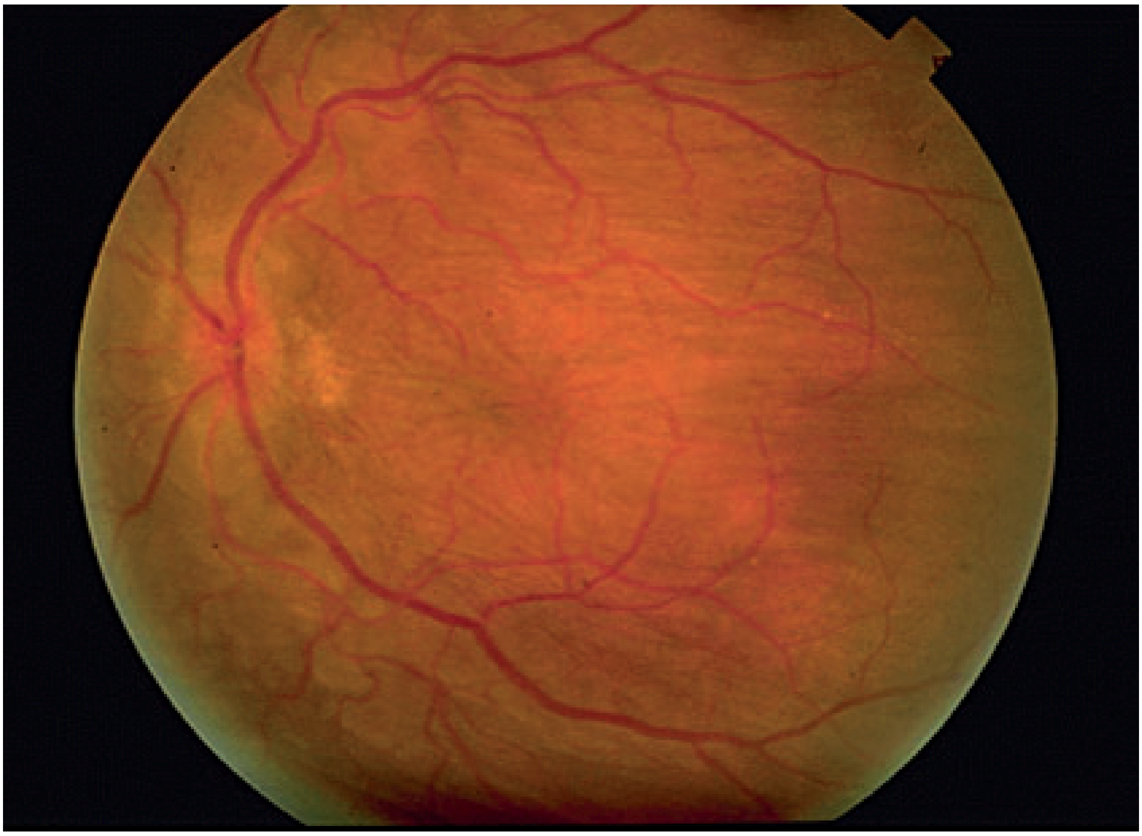

Fig. 3. Choroidal and retinal folds in a patient caused by compression of the eyeball by a retrobulbar tumor. Horizontal light and dark lines are visible in the posterior pole of the globe. A similar fundus appearance was found in some astronauts and was caused by choroidal edema in the posterior pole of the eye.

D. Flattening of the posterior pole of the eyeball

Choroidal edema causes the inner contour of the globe to become non-spherical—flattened or even bulging forward toward the lens.

E. Hyperopia

Forward displacement of the retina leads to hyperopia in these individuals, which had not been observed before their space missions [2,7,20,25].

F. Dilation of the optic nerve sheaths and optic nerve kinking

MRI studies revealed widening of the optic nerve sheath and kinking of the optic nerve in many astronauts. These changes are reversible after returning to Earth [20,22].

G. Impaired stereopsis – difficulties in depth perception and spatial orientation

During space missions, stereoscopic vision can become impaired or even lost. This leads to difficulties in judging distances and spatial orientation, which may affect task performance [13,26].

H. Increased intraocular pressure

Eye examinations conducted in low Earth orbit showed elevated intraocular pressure in many astronauts. This is caused by impaired outflow of aqueous humor from the anterior chamber of the eye due to venous congestion in the drainage system [1,14].

I. Cataract

Prolonged exposure to space can lead to cataract development. This is attributed to galactic radiation exposure [4].

J. Decreased visual acuity

Reduced visual acuity was found in ¾ of astronauts after returning from the International Space Station. Typically, vision returns to normal within six months, but not in all cases. For example, in 2005, astronaut John Phillips experienced a drop in visual acuity from 1.0 to 0.2 after a six-month mission. His vision improved over time, but never fully returned to baseline [1]. It is believed that vision-related changes are the second most significant risk factor for human spaceflight—after cosmic radiation.

DISCUSSION

What causes the above-described changes in the visual system? The primary cause—apart from cataracts induced by galactic radiation—is microgravity. Under Earth conditions, blood flows to the upper body against the force of gravitational hydrostatic pressure. This requires increased cardiac effort. Additionally, gravity impedes the upward return of bodily fluids. Gravity also plays a key role in venous blood flow, particularly in the legs. When we stand or sit, gravity pulls blood downward—toward the legs and feet—making upward return more difficult. This is why prolonged standing or sitting contributes to the development of varicose veins in the lower limbs. The return of blood to the heart is assisted by rhythmic contractions of the smooth muscle in vein walls and by skeletal muscle contractions during movement. All of these mechanisms that counteract the effects of gravity in our body—whether in the heart, blood vessels, or muscles—evolved over a long period of time during life on Earth. In the case of microgravity in space, a shift occurs toward the upper body (including the brain) due to the absence of gravitational forces. Simultaneously, a shift of body fluids toward the head is observed, along with an increase in intracranial pressure [19]. This is accompanied by impaired lymphatic drainage and hindered circulation of cerebrospinal fluid. This situation is further exacerbated by hypercapnia on board the space station. It leads to changes in the pressure gradient between the cerebral vessels, the orbit, and the eyeball, as well as a shift of blood and lymph toward the head and eye [14,19,24]. As a result, swelling of the optic nerve and choroid occurs, as well as flattening of the posterior pole of the eyeball. Stagnation of cerebrospinal fluid in the subarachnoid space further intensifies optic nerve swelling and causes the expansion of the optic nerve sheaths and kinking of the optic nerve. Prolonged persistence of these conditions may lead to irreversible damage to the retina and optic nerve.

The above-mentioned changes in the visual system were confirmed in studies conducted during long-term astronaut stays on the International Space Station (ISS). These missions lasted approximately 180 days. It is currently unknown how extensive these changes may be after a return from a Mars mission lasting a minimum of 950 days. It is likely that they will be more severe than those described above. The long-term persistence of these changes may lead to permanent impairment of visual function (decreased visual acuity, visual field defects, reduced contrast sensitivity, loss of stereopsis). Will astronauts be able to carry out planned tasks after landing on Mars? Will they return to Earth with significant damage to the retina and optic nerve? How permanent will the changes be after a three-year mission to Mars? Will we be able to develop more effective methods of protection against cosmic radiation? These are questions to which we currently have no definitive answers.

Long-duration space missions will only be feasible once we develop effective strategies to eliminate the harmful effects of microgravity and cosmic radiation on the human body — including the visual system.

Advocates of Mars missions and potential colonization argue that one of the key goals is to assess whether humans could live on Mars if Earth's conditions deteriorate to the point where humanity must seek an alternative. However, if we are unable to prevent the degradation of Earth caused by our own actions, can we realistically hope to transform the extremely inhospitable Martian environment into one suitable for sustaining human life?

Would it not be more reasonable to direct our efforts toward restoring and preserving Earth's environment — while there is still time to act?

AUTHORS' DECLARATION:

Study Design: Marek Prost. Data Collection: Marek Prost. **Manuscript preparation:** Marek Prost. The author declares that they have no conflicts of interest.

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