

THE BURDEN OF SPACE EXPLORATION ON THE MENTAL HEALTH OF ASTRONAUTS: A NARRATIVE REVIEW

Alessandro Arone, Tea Ivaldi, Konstantin Loganovsky, Stefania Palermo, Elisabetta Parra, Walter Flamini, Donatella Marazziti

Abstract

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Space travel, a topic of global interest, has always been a fascinating matter, as its potential appears to be infinite. The development of advanced technologies has made it possible to achieve objectives previously considered dreams and to widen more and more the limits that the human species can overcome. The dangers that astronauts may face are not minimal, and the impacts on physical and mental health may be significant. Specifically, symptoms of emotional dysregulation, cognitive dysfunction, disruption of sleep-wake rhythms, visual phenomena and significant changes in body weight, along with morphological brain changes, are some of the most frequently reported occurrences during space missions.

Given the renewed interest and investment on space explorations, the aim of this paper was thus to summarize the evidence of the currently available literature, and to offer an overview of the factors that might impair the psychological well-being and mental health of astronauts.

To achieve the goal of this paper, the authors accessed some of the main databases of scientific literature and collected evidence from articles that successfully fulfilled the purpose of this work.

The results of this review demonstrated how the psychological and psychiatric problems occurring during space missions are manifold and related to a multiplicity of variables, thus requiring further attention from the scientific community as new challenges lie ahead, and prevention of mental health of space travelers should be carefully considered.

Key words: space missions, space travel, astronauts, mental health, mental well-being

Alessandro Arone¹, Tea Ivaldi¹, Konstantin Loganovsky³, Stefania Palermo¹, Elisabetta Parra¹, Walter Flamini¹, Donatella Marazziti^{1,2}

¹Department of Clinical and Experimental Medicine Section of Psychiatry, University of Pisa, 56100 Pisa, Italy

²Unicamillus—Saint Camillus International University of Medical and Health Sciences, 00131 Rome, Italy

³Department of Radiation Psychoneurology, Institute for Clinical Radiology, State Institution "National Research Centre for Radiation Medicine, National Academy of Medical Sciences of Ukraine"

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Corresponding author

Dr. Alessandro Arone,
Department of Clinical and Experimental
Medicine, Section of Psychiatry
University of Pisa,
Via Roma, 67
56100 Pisa, Italy
Phone: +39 3270299017
E-mail: alessandroarone@libero.it

Introduction

Since its first steps on Earth, the human species has evolved by adapting and shaping the surrounding environment to its needs. Yet nowadays, in a modern era marked by pandemics, social inequalities, wars and in which men still have much to discover despite enormous advances in science and other fields, some environments represent a huge challenge. This is due to some of their features, to the point of being defined as "extreme environments", as they often require challenging physical and mental efforts (Paulus et al., 2009; Ilardo & Nielsen, 2018). Extreme environments are manifold, and they include prolonged and marked isolation experiences on Earth, such as polar environments and submarine explorations, but they can also be found beyond our planet's boundaries, in the case of space. The adjustment from Earth to an environment

characterized by the lack of gravity naturally raises the need for physical adaptation primarily, but it may also lead to the search for new horizons and to stimulation of creative thinking (Amabile & Gryskiewicz, 1987; Runco & Charles, 1993), thus determining the exploitation of mental resource that, however, in this process as fascinating as rich in implications, must be preserved. Over the decades, the public and scientific interest in space missions has progressively revealed the risks and dangers to health behind this project, in particular in the case of long-duration space missions, as several space hazards, such as microgravity and radiation, can sharp different organs and systems by altering the human physiology (Clément & Slenzka, 2006). From cell damages (Huang et al., 2009; Kawahara et al., 2009) to the alteration of the processes maintaining the health of bones and muscles (Ilyina-Kakueva & Burkovskaya, 1991; Kaplansky et al., 1991; Davidson

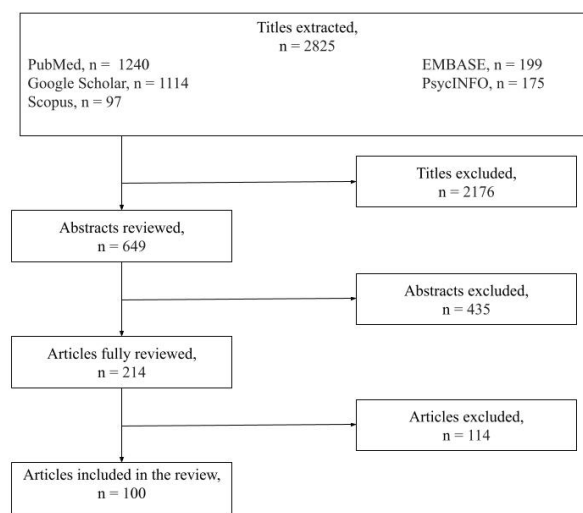
et al., 1999; Willey et al., 2011), the immune system (Gridley et al., 2009), heart and vessels (Fritsch-Yelle et al., 1996; Diedrich et al., 2007; Boerma et al., 2015) and central nervous system (CNS) (Souvestre et al., 2008), space also increases the risk of carcinogenesis (Kennedy, 2014), thus urging the search for drugs and compounds able to prevent or mitigate it (Burns et al., 2001; Zhang et al., 2006; Kennedy & Wan, 2011). Space missions, particularly of long duration, can put a strain on maintaining an adequate mental well-being, and the role of some personal and interpersonal factors has long been discussed (Kanas, 1998; Flynn, 2005; Barr et al., 2007; Kalb & Solomon, 2007; Trappe et al., 2009;

and case reports if published in indexed journals. All the authors equally contributed in identifying potential information specific to this topic amongst the titles and abstracts evaluated.

Results

The first selection excluded 2176 titles because: a) duplicates; b) not concerning the scope of the paper; c) not informative enough. The second selection excluded 435 abstracts after being read and reviewed, as the information presented did not fulfill the scope of our paper and/or did not appear to be relevant to the topic

Figure 1. Flowchart



Fitts et al., 2010; Kandarpa et al., 2019; Marazziti et al., 2021). Both individually and in synergy, such factors may determine the onset of mood symptoms (Gushin et al., 1993; Tafforin et al., 2015), cognitive issues (Britten et al., 2012; 2016; Rabin et al., 2014; Acharya et al., 2019; Cacao & Cucinotta, 2019; Moore et al., 2019), sleep disturbances (Putcha et al., 1999; Barger et al., 2014; Wotring, 2015) and others. Finally, space missions may cause some significant neuroanatomical effects, with most of the data available coming from magnetic resonance imaging (MRI) studies, and will then be briefly discussed herein.

Therefore, this paper was conceived as a narrative review with the aim of commenting on the current literature on the main psychological conditions affecting astronauts in the course of space missions. We also investigated the possible aetiology of such issues, with a focus on the psychosocial and physical factors involved.

Materials and Methods

The following databases were accessed in order to research and gather data from articles that were published only in English language from 1 January 1963 to 31 August 2021: PubMed, Scopus, Embase, PsycINFO and Google Scholar. Free text terms and MeSH headings were combined as follows: “(space missions OR space travels OR astronauts) AND (psychological OR psychiatric OR psychosocial OR issues OR symptoms)”. All the authors agreed to include in the review conference abstracts, posters

of interest. Subsequently, 114 more publications were excluded after further reading and evaluation, as they did not provide enough information and/or resulted sufficiently in line with our review. Finally, 100 papers were included in this paper (figure 1).

Discussion

Health issues

It has long been known that the health of space travelers can be endangered by various space factors, to the point that the National Aeronautics and Space Administration (NASA) recognized the existence of a new branch of science called “bioastronautics”, aimed at the study of the biological effects on the astronauts’ bodies (Charles, 2005). In particular, most of the gathered evidence to this day suggests that space microgravity and radiation stand among the most known space perils (table 1).

Several studies have pointed out how microgravity may alter cell physiology by compromising its structure or its survival (Crawford-Young, 2006; Huang et al., 2009; Kawahara et al., 2009). Furthermore, a relationship has been described between microgravity and the immune system (Woods & Chapes, 1994; Sonnenfeld, 2002; Gridley et al., 2009) that might lead to the onset of infections, immune disorders and CNS alterations that might affect the health of astronauts, with the consequent impairment of the positive mission’s outcome. Microgravity may also negatively impact the mechanisms of tissue repair in skeletal muscles and bones (Ilyina-Kakueva & Burkovskaya,

Table 1. Physical factors in space and their effects on health

Microgravity	Radiation
Changes in cell structure and differentiation Altered immune response Impaired tissue repair Cardiovascular dysregulation Sensory-motor alterations Space adaptation syndrome Cognitive dysfunction Eye diseases	Bone loss and fractures Cardiovascular dysfunction Carcinogenesis CNS changes Learning and memory impairment Altered executive functions Visual disturbances

1991; Kaplansky et al., 1991; Davidson et al., 1999). The cardiovascular system may be affected as well, since several studies showed an important decrease in heart rate during spaceflights (Fuller, 1985), the possible onset of potentially fatal dysrhythmias (Fritsch-Yelle et al., 1996) and several changes in blood and plasma volume (Bao et al., 2007; Diedrich et al., 2007). Post-flight orthostatic intolerance has been frequently reported in astronauts (Fritsch-Yelle et al., 1996). Finally, the sensory-motor system appears to be deeply affected by microgravity. Indeed, the CNS needs to adapt to microgravity since different spatial information, such as somatosensory, visual and vestibular stimuli, has to be elaborated (Souvestre et al., 2008). A syndrome known as space adaptation syndrome (SAS) may occur as a consequence of a sensory conflict between inputs from visual and tactile senses and vestibular organs (Lackner & Dizio, 2006). The eye is another organ that may be affected by the effects of microgravity, with damages to either its structure and/or its functions. Optic nerve swelling, flattening of the posterior globe, periorbital edema and increased intraocular pressure have all been reported (West, 2000; Kramer et al., 2012). Hypobaric hypoxia, a microgravity-induced condition caused by a decreased partial pressure of oxygen in space, may also occur, potentially causing further eye diseases such as retinal and vitreous hemorrhages or papilledema (Russo et al., 2014).

Health professionals have long been warned about the negative and potentially catastrophic consequences for the human body following radiation exposure (Meyers, 2000) and, in the course of space missions, different organs may be deeply affected by radiation. Bone loss and fractures may occur as a consequence of a disruption of the skeleton (Willey et al., 2011). The cardiovascular system is also at risk, since it was found to be particularly sensitive to the effect of ionizing radiation (Boerma et al., 2015). Nevertheless, when it comes to radiation, the focus is primarily on the risk of carcinogenesis, with the focus being shifted over the years to the search of potential surrogate endpoint biomarkers (SEBs) to explain this phenomenon (Kennedy, 2014). Regardless, it has been suggested that radiation exposure may lead to oxidative stress, which in turn may be behind the mechanisms of carcinogenesis (Kennedy & Wan, 2011). Therefore, unsurprisingly, antioxidants, along with protease inhibitors and retinoids, have been proposed as chemopreventive agents to oppose the risk of carcinogenesis (Burns et al., 2001; Zhang et al., 2006; Kennedy & Wan, 2011), albeit further studies on the field are required to draw definitive conclusions.

Psychological and psychiatric problems

Emotional and interpersonal issues

Emotion regulation seems to need appropriate countermeasures during long-duration space flights, as emotion training can play an important role in the success and safety of missions (Liu et al., 2016). Mood issues of the astronauts have long been reported, and they may also compromise the fulfillment of the mission task, as in the case of the abrupt abort of the Soyuz T14-Salyut 7 mission in 1985, which was suggested to have been partly caused by crew's depression (Morris, 2014). Symptoms of reduced resilience may occur, ranging from decreased drive and energy levels to passiveness (Gushin et al., 1993). Anxiety symptoms have been reported and linked to negative interpersonal interactions, as well (Tafforin et al., 2015). Indeed, the heterogeneity of the space crew in terms of size, ethnic background, languages and roles may result in tension and communication issues among the crew members (Kanas, 1998). Prolonged isolation from loved ones and routine on Earth also pose a risk for the mental well-being of cosmonauts (Kandarpa et al., 2019), along with sharing a confined environment with the same people around (Harrison et al., 1989). Indeed, isolation may lead to monotony, which has been conceptualized as a three-fold model of spatio-temporal, sensory and social isolation and has been proven to be potentially detrimental for the success of the mission (Peldszus et al., 2014). Evidence from space analogues would also suggest that such factors may be responsible for a wide range of symptoms, including fatigue, altered circadian rhythms, sleep disturbance and neurocognitive impairments (Pagel & Choukèr, 2016; Deming & Vasterling, 2017). Moreover, the features of the spacecraft, which constitute the so-called “habitability” (Musso et al., 2018) represent a fundamental element of space missions, for reasons exceeding far beyond its sole role as a means of transport, and may represent another stressor to the overall well-being of the astronauts. According to Kanas and Manzey (2008), these include light, noise, vibration and temperature. As for the light, since it represents the main stimulus of the circadian rhythms, its excessive exposure may then lead to a deep alteration of the latter. Therefore, it has been suggested how either its removal from the settings and the spaces dedicated to sleep or the creation of an environment where alternating light and dark in the spaces shared by the astronauts may be desirable (Caddick et al., 2017). Excessive exposure to noise, mainly due to the equipment and the crew activities, may represent a further stress factor for cosmonauts. Both wakefulness and sleeping may be compromised, to the point that cosmonauts have been instructed to wear protection devices to counteract the potential

damages induced by high levels of noise (Limardo et al., 2017).

Finally, habitability includes the need for privacy that, considering the spaces available and the peculiar environment, may not be always sufficiently respected, thus leading to possible psychological effects (Winisdoerffer & Soulez-Larivière, 1992).

Cognitive problems

Although fascinating, space poses as a seriously stressful environment, and may therefore represent a danger to cognitive functions that, along with motor performances, have long been known to undergo some kind of deterioration under stress conditions (Hockey, 1983; Albery & Goodyear, 1989; Lieberman et al., 2002).

Space radiation is one of the factors most involved in the onset of these issues, and its potential biological effects are broad, even at a low-dose rate exposure, that has been demonstrated to induce significant neurocognitive complications associated with an impairment in neurotransmission (Acharya et al., 2019).

Originally, back to the 1960s, the general assumption was that the brain is not sensitive to the effect of cosmic radiation, and even the consequences on other body areas, such as the lens of the eye, were thought to be minimal (Curtis, 1963). However, a few decades after the original assumptions of Curtis (1963), it was demonstrated that high linear energy transfer (LET) particle irradiation of the brain may cause capillary hemorrhages, and that both neuroglia and blood-brain barrier may be vulnerable to damage following ionizing radiation. Since DNA repair in neural cells has a certain amount of mispair, such damages may produce different notable effects, including myelin degeneration, a reduction in local metabolism, and alterations in both synaptic density and microcirculation. Scientists and health professionals have long warned about adverse consequences following radiation exposure (Meyers, 2000), as well as many secondary effects in cognition and mood due to a decrease in neuronal structural complexity (Parihar et al., 2015; 2016).

As a result, it is not surprising that the radiation matter has gone under the lens of NASA, since the safety of space travellers and the success of missions may indeed be compromised by the neurocognitive effects induced by radiation (Cucinotta et al., 2014). Indeed, radiation exposure is massive during space missions. The estimated average astronaut's radiation exposure to Mars per year is equivalent to a cumulative dose of 672 millisieverts (mSv), and, in International Space Station (ISS) orbit, around 182.5 mSv. In order to get an estimate of the extent of such numbers, it should be highlighted that the average background radiation exposure on Earth per year is, instead, of 3 mSv (Jones et al., 2012).

A large amount of data on the matter comes from rodent models strongly, suggesting potentially significant consequences of radiation on cognition (Britten et al., 2012; 2016; Rabin et al., 2014; Cacao & Cucinotta, 2019). Furthermore, other researchers recently demonstrated that several alterations in the intrinsic electrophysiological features of CA1 superficial layer pyramidal neurons in the dorsal hippocampus may represent a consequence of the exposure to a prolonged 18 cGy dose of neutron radiation. These changes may persist after six months from the completion of irradiation (Acharya et al., 2019). They also found that chronic (6 months) radiation exposure to low-dose (18 cGy) and dose rate (1 mGy/day) exposures to

a mix of neutrons and photons caused an impairment in cellular signaling both in the prefrontal cortex and the hippocampus. This caused learning and memory impairment, and was linked to the potential increase of anxiety behaviors, thus also indicating damage to the amygdala (Acharya et al., 2019). Some studies pointed out a significant reduction in dendritic complexity and spine density not only in the hippocampal but also in cortical neurons (Parihar et al., 2015; 2016). Moreover, astronauts may undergo deficits in executive functions due to a functional loss in several areas of the brain, such as the medial prefrontal cortex, posterior cingulate, anterior cingulate and basal forebrain (Lonart et al., 2012). Decision-making may also be affected (Acharya et al., 2019). Indeed, it is a common assumption that one out of five astronauts taking part in a long space mission would experience similar behaviors, and out of three would instead face struggles in memory processes (Acharya et al., 2019). Dopamine levels may be another key factor in neurobehavioral response to radiation (Hienz et al., 2010), and also gender, as murine models showed how male mice displayed an increased susceptibility to behavioral decrements secondary to radiation (Krukowski et al., 2018). Different male susceptibility to cognitive processes to irradiation may be due to mechanisms related to memory formation (Greene-Schloesser et al., 2012; Balentova & Adamkov, 2015). Therefore, it is evident that such effects need to be adequately studied in the future planning of interplanetary space fights.

Cognitive issues may also arise due to the effects of microgravity. Indeed, a reduction in different motor functions, such as dual-tasking, motion perception and manual dexterity, following a six-month period spent on ISS was recently demonstrated. However, it should be noted that these cognitive deficits were resolved in four days after landing. In any case, although this research is affected by a major bias that is the small sample size including eight astronauts only (Moore et al., 2019), these effects may be a cue of relevant changes in brain structure (Roberts et al., 2019). On the other hand, it has been suggested that microgravity may actually improve cognitive functions when taken out of a stress context that, instead, may represent the cause itself of cognitive impairment (Wollseiffen et al., 2016).

Sleep disturbances

In the course of space missions, the achievement and maintenance of an adequate sleep quality is far from being an easy goal. Whether due to disturbances or its interruption, sleep alterations may in turn lead to tiredness, difficulties in maintaining the focus and, thus, to errors of different kind, which may result, in the worst case scenarios, to the extreme possibility of loss of life (Buckey, 2006; Pandi-Perumal & Gonfalone, 2016).

Different factors may be involved, either individually or in combination, to sleep alterations, such as the uncomfortableness of sleeping bags, loud noises and different room temperatures (Gundel et al., 1997; Stuster, 2000). The absence of gravity also seems to play an important role, as it may in particular shorten the duration of sleep (Gonfalone, 2016).

In particular, recreational and mission-related activities tend to delay turning off the lights and going to bed, which could explain the delay in the onset of the sleep episode that was noted (Dijk et al., 2001). In addition, a study of a group of astronauts in space over eight days showed an average of 4.6 awakenings per night and an average waking time during sleep of 6.5 minutes. The most frequent cause of these nocturnal

awakenings was muscle stiffness as a result of trying to find a comfortable position in the sleeping bag (Gundel et al., 1993). In parallel, a change in the structure of the cosmonauts' sleep was also observed, with changes in both REM sleep and the amount of slow-wave sleep (Gundel et al., 1993).

In order to study the sleep-wake dynamics in a ground-based simulation of a mission to Mars, six individuals were isolated for 520 days. Most subjects experienced one or more problems, such as recurrent reductions in perceived sleep quality, interrupted sleep-wake periodicity, performance deficits associated with chronic partial sleep deprivation and increased sleep displacement in the daytime period (Basner et al., 2013). These occurred at the start of the experiment and persisted throughout the duration of the simulation (Basner et al., 2013). This reduction in sleep during space missions seems to be present even during a pre-flight training interval of 3 months, as revealed in another study of 64 astronauts (Barger et al., 2014). Although derived from two studies only, these findings further suggest that maintaining good sleep patterns and quality is essential to prevent and/or reduce performance impairments.

In spite of chronic sleep deprivation, astronauts may frequently resort to the use of hypno-inducing drugs. In a report study of Barger et al. (2014), about 75% of the crew members had taken a hypno-inducer, with drug take being reported on 52% of nights and the use of two doses of such drugs in around 17% of cases. The most frequently used medications were zolpidem and controlled-release zolpidem; others were temazepam, eszopiclone, melatonin and quetiapine fumarate. Furthermore, different drug combinations were reported, the most common being zolpidem and zaleplon and zolpidem and melatonin (Barger et al., 2014). Another study looked at medication used during flight and found that 94% of astronauts were taking some medication, 45% for sleep disorders. In this case, the most frequently used sleep medications were temazepam (67%), triazolam (10%), flurazepam (7.5%), and zolpidem (10%) (Putchá et al., 1999). In another research, the use of sleep medications was found to be about 10 times higher during spaceflight missions, 71% of the crew members in one study reported using medications to induce or maintain sleep and the most commonly were zolpidem, zaleplon, or both (Wotring, 2015).

However, hypnic dysregulation should not be considered separately from other medical issues that may arise in the course of space missions. Indeed, it may be subsequential to anxiety, depression and personality changes, interpersonal problems (i.e. intra-crew conflicts), and physiological reactions to a new environment, such as muscle atrophy, a reduced immune response and changes in regards to cardiovascular system. All those factors may indeed alter the sleep pattern, which may in turn aggravate psychological and physical stress in a vicious cycle (Kanas & Manzey, 2008).

Visual phenomena

Visual disturbances may also represent a critical issue to space flights, and radiation exposure plays a key role in their genesis, likely along with the effects of intracerebral pressure changes. This is critical since visual impairment may compromise the fulfillment of the space missions goals and potentially lead to long-term consequences on the cosmonauts' life quality upon their return to home. Despite playing a key role in the functioning of vision, the retina and the retinal vasculature have not been considerably studied in regards to radiation exposure during space travel. A recent paper would indicate

that different types of examined radiation might cause significant differences in the responses of endothelial cells to such harmful factors. Indeed, low doses of 160 enhanced apoptosis in the endothelial cells of the retina, with the most significant changes observed following 0.1 Gy irradiation, whilst 160-induced apoptosis was found to be more frequent than apoptosis caused by protons (Mao et al., 2018).

Moreover, during the Apollo, Skylab and MIR missions, astronauts observed flashes of light, of different shapes, moving across the visual field (Sannita et al., 2006). Such flashes are more often present before sleep, predominantly white, with elongated shapes and often accompanied by a sense of movement perceived as lateral, diagonal or in-out (Fuglesang et al., 2006). It has been suggested how these phosphenes can be a consequence of an alteration in perception caused by ionizing radiation on the eye (Narici, 2008). In particular, temporarily increased biophoton emission has been proposed as a key process which may give an accurate description of the matter (Bókkon, 2008). Indeed, the ionizing radiation impacting in the eye generates radicals, some of these generated in rod lipids undergo lipid peroxidation that leads to chemiluminescence and photon emission. At this point, the photon bleaches a nearby rhodopsin and the phototransduction cascade is initiated, which can lead then to the perception of flashes of light (Bókkon, 2008; Narici et al., 2009), giving the impression that light is visible where it is not present and thus posing as a new potential hazard tied to space radiation. Nevertheless, whether this represents a reversible or persistent phenomenon is still an unsolved question, requiring future research. However, it should be mentioned that the effects of radiation exposure on sight are well documented, as they may even lead to impairing medical conditions such as posterior subcapsular cataract (Khan et al., 2017).

Regardless, illusions and hallucinations also frequently appeared in some reports of space missions, possibly as a result of isolation or sensory deprivation (Gushin et al., 1993).

Anorexia in space

Caloric intake may be lower than recommended in the course of space flights, thus leading to the so-called anorexia in space. Caloric deficits up to 1330 kcal per 70 kg astronaut per day may follow, with potential drops in the performances of the astronauts (Da Silva et al., 2002). The causes of this phenomenon are likely related to the continuous light environment of space missions rather than to issues linked to the availability of food or energy expenditure (Varma et al., 2000), with several neurochemical mediators (i.e. hormones and cytokines) involved (Da Silva et al., 2002). The food intake of mice exposed to 24 hours of continuous light for 7 days was assessed and a significant reduction in meal numbers was found, resulting in increased concentrations of dopamine and serotonin in the ventromedial nucleus and lateral hypothalamic area, plasma cortisone and leptin, and decreased levels of insulin, tumour necrosis factor (TNF), oestradiol and testosterone. The results of this study make it possible to hypothesise an action of continuous light on the suprachiasmatic nucleus and ventromedial nucleus, resulting in endocrine and neurochemical changes (Varma et al., 2000). Ionizing radiation may also play an important role in spatial anorexia by causing taste aversion and vomiting. Similarly, microgravity may be involved (Da Silva et al., 2002).

Nevertheless, it should be noted that current evidence suggests that anorexia in space is a reversible

phenomenon, as cosmonauts' body mass and caloric intake were comparable to those before the missions upon their return on Earth (Da Silva et al., 2002).

Neuroanatomical correlates

Data gathered from studies using different neuroimaging techniques seem to suggest that different areas of the CNS and the peripheral nervous system (PNS) may be affected by the consequences of space

of ventricular CSF volume in the ISS group (Alperin et al., 2017). More recently, an increase was found in summated brain and CSF volumes, a considerable deformation of the pituitary gland and an enhancement of aqueductal CSF hydrodynamics following long-term spaceflight (Kramer et al., 2020). The cerebellum, along with cortical sensorimotor and somatosensory areas, as well as pathways related to the vestibular system, may also be subjected to significant changes in both their structural and functional component, mainly under the

Table 2. Neuroanatomical consequences of space travel

Authors	Year	Neuroimaging	Findings
Demertzi et al.	2016	fMRI	Changes in vestibular and motor-related regions
Alperin et al.	2017	MRI	Enhanced periventricular white matter hyperintensity
Roberts et al.	2017	MRI	Narrowing of the central sulcus Upward shift of the brain Narrowing of CSF spaces Optic-disk edema
Riascos et al.	2019	Quantitative MRI	Thinning of cortical right occipital lobe and of bilateral fusiform gyri Decrease in left thalamus size Expansion of lateral ventricle
Kramer et al.	2020	Longitudinal MRI	Increased summated brain and CSF volumes Deformation of the pituitary gland Enhanced CSF aqueductal hydrodynamics
Buoite Stella et al.	2021	fMRI	Structural and functional changes of: cerebellum, cortical sensorimotor and somatosensory areas, pathways linked to the vestibular system

travel (table 2).

Some studies with magnetic resonance imaging (MRI) revealed some significant changes in the neuroanatomical configuration of the brain and cerebrospinal fluid (CSF) provoked by space flight. A narrowing of the central sulcus, an upward shift of the brain, narrowing of CSF spaces and optic-disk edema were found in post-flight scans of a small sample of astronauts (Roberts et al., 2017). Further evidence derives from a functional MRI (fMRI) research involving a single cosmonaut over a period of 6 months subsequently to microgravity exposure. The authors reported significant changes in both vestibular and motor-related regions that, according to them, might underlie the alteration of the vestibular function and of the motor control skills after return on Earth (Demertzi et al., 2016). Instead, a study employing quantitative MRI detected multiple grey and white matter alterations in a sample of 19 astronauts, such as thinning of the cerebral cortex of the right occipital lobe and of bilateral fusiform gyri, a decreased left thalamus size and an expansion of lateral ventricle (Riascos et al., 2019). An increase in periventricular white matter hyperintensity was found in another research performed in a sample of 17 astronauts who had either taken part to a long-duration mission on ISS or a short-duration mission on the Space Shuttle (Alperin et al., 2017). This finding was further linked to an expansion

influence of microgravity, as proved in a recent research performed with the use of fMRI (Buoite Stella et al., 2021).

Therefore, further studies with MRI or other imaging techniques carried out with larger samples are necessary to deepen these preliminary data that pose the crucial questions of the reversibility or not of the reported changes.

Conclusions

Space exploration was born as one of the most ground-breaking events that mark the history of the human species, that continues to this day to be a primary interest of the scientific community and beyond. Since the success of the launch of the first artificial object, the notorious V2 rocket, to reach outer space, the objectives of space missions have gradually begun to extend, asking the question of how far man is able to go. However, the development of increasingly refined technologies has revealed the risks that space travelers are forced to face and which, for a long time, have not received the right attention. Anecdotes, reports and scientific research have brought to light the dramatic burden on the mental well-being of space travellers, thus leading to a massive effort put in the selection and preparation of both astronauts and space missions

and with the choice of specific countermeasures of psychological and/or psychiatric support. Nevertheless, attention should not be limited to the problems that have arisen during space missions, as the resumption of life on Earth may prove to be an equally arduous task. Over the years, it is likely that new aspects of medical interest on the matter will arise, a challenge that the scientific community must be ready to accept, for the success and safety of space travel.

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