HUMAN, EARTH AND FUTURE
Ital Publication
ISSN: 2785-2997

Available online at www.HEFJournal.org

Journal of Human, Earth, and Future

Vol. 3, No. 3, September, 2022

A Crowd-Sourcing Project to Understand, Prevent and Manage Incidences of Injury and Wounding to Astronauts and Off-Earth Colonists

Ben Cahill [1], Martin Braddock [2, 3*]

[1] *Rosliston Astronomy Group, Rosliston Forestry Centre, Burton Road, Rosliston, Swadlincote, DE12 8JX, United Kingdom*

[2] *Sherwood Observatory, Mansfield and Sutton Astronomical Society, Sutton-in-Ashfield, Nottinghamshire, NG17 5LF, United Kingdom*

[3] *Science4U.co.uk, Radcliffe-on-Trent, Nottinghamshire, NG12 2LA, United Kingdom*

Received 16 July 2022; Revised 19 August 2022; Accepted 23 August 2022; Published 01 September 2022

Abstract

Recent technical successes of the unmanned Mars 2020, Tianwen-1 and Hope Mars missions have further increased our hunger for space exploration and the possible colonisation of Mars is now firmly on the mid-term horizon. Furthermore, renewed commitment to settle on the Moon is anticipated within the next three years, led by NASA's Artemis programme utilising the pan-space agency constructed lunar Gateway or Space X's Starship system. These programmes will necessitate a larger number of astronauts spending longer periods in space and despite rigorous risk identification and mitigation procedures, injury is an inevitable consequence and management procedures will demand efficient and effective implementation. We have employed Cognitive Work Analysis to derive an abstraction hierarchy for reducing the potential for physical injury and managing the consequence of injury in space. We have used a crowd-sourcing approach to cluster factors and themes which may emanate from within or without habitat and consider solution management in the light of current and emerging technology. In addition, we also consider mental fitness as a confounder which may emerge during missions and propose methods for both measurement and management.

Keywords: Systems Ergonomics; Human Factors; Cognitive Work Analysis; Wound Prevention; Wound Management; Technology.

1. Introduction

The need to explore is an innate part of being human. In part and as advanced by NASA [1] exploration by humankind is driven by curiosity, drives self- awareness and the need to find and secure resources including shelter, food and water in order to sustain survival. It is more than that. Our desire for human space exploration are rooted in age-old persisting dreams which increase in their intensity as technology advances with a fascination for people seeking adventures on other worlds emanating from ancient myths and fuelled by increasingly life-like immersion experiences where the boundaries between science fact and fiction are blurred [2]. Space exploration represents both a combination of national pride and ideology, which seeks economic application, to develop space sciences and to extend human presence in space [3, 4], and exert influence [5]. Today, it may be argued that space exploration is more important than ever for our species

* Corresponding author: projects@sherwood-observatory.org.uk

http://dx.doi.org/10. 28991/HEF-2022-03-03-04

[6] and that mitigation of existential risk be it imposed by warfare, climate change or a global pandemic has increased our urgency to find alternative places to live [7]; recognizing that there are many socio-economic and ethical considerations to consider (e.g. Levchenko [8]). We have previously explored the rationale and history behind humankind's need to discover and outlined a vision for the colonisation of Mars [9-11], and the requirement for in situ resource utilization (ISRU). When we consider where to place human beings for extended periods of time, there are two options to consider; Mars and the Moon

There are a number of reasons why the colonisation of Mars maybe preferable to the colonisation of the Moon. First, Mars does have an atmosphere [12], and although it is less than 1% that of Earth, it is able to prevent some radiation from reaching the planet's surface. Atmospheric pressure at the planet's surface is <0.7% that of Earth at sea level, however, in theory, this may permit pressurisation of surface-based habitats. In 2021, the Mars Oxygen ISRU Experiment (MOXIE) on the NASA Mars2020 rover Perseverance successfully produced oxygen from carbon dioxide in the Martian atmosphere using solid oxide electrolysis. The technology may have utility to provide breathable oxygen, oxidizer, and propellant and water may also be produced by combining oxygen with hydrogen [13]. In contrast, the lunar atmosphere is regarded as a near vacuum with an atmospheric pressure of almost zero. Secondly, the Martian gravitational field is ~38% that of Earth and greater than that of the Moon being ~ 17 % that of Earth [14]. The effects of reduced gravity on human physiology have been extensively documented [15-18], and although the magnitude of the Martian gravity is somewhat less than that on Earth, it is anticipated that humans will function better than under conditions where it is further reduced.

The third principal reason why Mars may present a better opportunity for settlement, at least in the long term, is the potential for greater resources. This includes the presence of water in greater quantities on Mars compared with the Moon [19], the more favourable potential for plant and crop growth in Martian versus lunar regolith [20-23] and the possible greater efficiency of oxygen-evolving electrolysis under simulated Martian versus lunar gravity [24]. The last advantage for Martian colonisation is that Mars has a similar rotation rate to that of Earth. A day on Mars is ~ 25 hr whereas the moon rotates once every 29.5 Earth days, with night ~14.75 Earth days. Such prolonged time in extreme cold and dark and the energy demand to permit human survival is inferior to the situation on Mars, where solar panels may collect energy and store it for night time use in a manner similar to that on Earth. When illuminated by the sun, the surface of the Moon can reach up to 127 ^{o}C however when the illuminated side moves into darkness, surface temperature can reach as low as -232 ^{o}C. Contrast this with Mars, where surface temperatures may reach a high of ~ 20 °C (293 K; 68 °F) at noon, at the equator, and a low of ~ −153 °C (120 K; −243 °F) at the poles [25].

However, the greatest positive factor for lunar over Martian colonisation is the proximity to Earth. With a typical travel time of ~ 3 days versus ~ 9 months to Mars, the shorter distance offers many advantages. These include reduced comparable cost for off-Earth export of materials, machinery and transportation of astronauts and colonists. Shorter signal latency allowing near real-time communication from the Moon should emergency situations require intervention from mission control and a greater chance for a successful outcome should evacuation back to Earth be required.

Today, the approach adopted by the Space Agencies, private enterprises and academic institutions is to consider colonising both the Moon and Mars, first with the Moon, in order to assess technological feasibility, while maintaining the delivery of scientific objectives and realising opportunities for commercial success. This endeavour necessitates a human presence in both low Earth orbit (LMO) and low Moon orbit (LMO) in addition to travel periods between and residence on the Moon and Mars. Given the predicted rise in the number of human space years, it is essential that mission planners consider the potential for injury and wounding, how it may be reduced and managed and what technological developments could benefit both human beings in space and patients on Earth. Many publications have investigated the effects of reduced gravity on wound and fracture healing (e.g. Kirkpatrick et al. [26], Dadwal et al. [27], Yang et al. [28]) and the risks of anaesthesiology in space [29], effects on the immune system [30, 31] which is required to promote healing. Health risks for a mission to Mars have been recently reviewed [32] and are captured in NASA's Human Research Program (*https://humanresearchroadmap.nasa.gov/*). In this article, we have extended our use of ergonomics systems-based tools to understand, mitigate the effect and provide considerations for the treatment of wounding and injury sustained in space.

We have employed the first phase of Cognitive Work Analysis (CWA) [33, 34], Work Domain Analysis (WDA) [35] to develop an abstraction hierarchy to support a model of understanding the incidence, reducing the potential and management of injury in an off-Earth environment. This includes both the international space station as a representative low Earth orbit environment, habitats on the Moon and Mars. We have collected information on this specialized area on perceived challenges for maintaining both physical and psychological fitness from a targeted group of subject matter experts (SMEs) and clustered their ideas into challenges which we have then tested against our model.

2. Research Methodology

2.1. Construction of Mind Maps

We have adopted a similar approach where we characterised challenges which must be overcome to enable Martian colonisation and societal build [9, 36]. To define boundaries and establish the scope of the CWA, detailed mindmaps were constructed using Mindjet Mindmanager 2012 software for injury prediction, prevention and management within habitat, without habitat or within and without habitat and these were tested and validated with members of the Rosliston Astronomy Group in May 2022 and Mansfield and Sutton Astronomical Society in June 2022.

2.2. Cognitive Work Analysis

The CWA methodology [33] provides a focussed perspective by deploying a framework to guide the design of complex socio-technical systems and has been widely used in many industries for both early phase design, beta testing and implementation of improvement strategies [37-40], including facets of space exporation with human factors analyses [41-45]. WDA is the first phase and used to derive an abstraction hierarchy [35] for both events and actors and is independent of the system or challenge under analysis

2.3. Abstraction Hierarchy Construction

The nine-step methodology for conducting a WDA [35] was used to describe the steps followed during the development of the current WDA.

Step 1: Establish aims and purpose

The purpose of the analysis was to develop a systems model for injury prediction, prevention and management and the 5 hierarchy levels and their principal questions are illustrated in Table 1. Description of aims and purpose consists of consideration of a). environments within the space-craft or habitat, b). without the space-craft or habitat and c). either within or without the space-craft or habitat. Events occuring over both an acute (e.g. physical injury) or chronic time frame (e.g cardiac arrest, decline in mental fitness) are considered. The time frame represents both missions for visitation of overall duration up to 900 days to Mars and the permanent settlement of the Moon or Mars. As previously described [9] the assumption is that astronauts and early stage colonists will be fertile, of child-bearing potential and not greater than 40 yr of age.

Table 1. Abstraction hierarchy descriptors

Level	Abstraction hierarchy	Principle questions
1	Functional purposes	What is the aim of the task?
2	Values and priority	How can mission planners and colonists assess whether the functional purpose is achieved?
3	Purpose-related	What functions must be performed to achieve the purpose of the mission?
4	Object-related processes	What processes and affordances are provided by the environment to mitigate the potential of injury and manage the outcome of its occurrence?
5	Physical objects	What physical objects are required to achieve the mission purpose to reduce/manage injury?

Principle questions are shown for each of the 5 hierarchy levels.

Step 2: Anticipated project constraints

The principle constraint considered was the variation in level of knowledge from participants, the specialist nature of the topic and the demand placed on their time in using a crowd-sourcing approach. To manage this constraint, we utilised multiple SMEs from multiple sources, maximised engagement through publication flyers and social media and reviewed our findings with the lead and corresponding author's astronomical society members in order to provide as much opportunity for participation and concept challenge as possible.

Step 3: Define the system boundary

To develop the WDA, analysis boundaries were confined to consideration of within LEO, LMO, travel to and from and either short term visits or permananet settlement of the Moon or Mars. Unless otherwise indicated, the situation refers to a habitat on Mars and accepts the contraints posed by the inability to mount an emergency evacuation back to Earth.

Step 4: Classify system constraints

For these analyses, the WDA constraints represent the different types of parameters and relationships to be modelled for the different components of maintenance of both physical and mental fitness to enable short term or permanent settlement off-Earth. For example, the logistics associated with equipping and staffing a medical centre to permit treatment, monitoring and convalescence after injury impose both physical constraints on what can and cannot be accommodated off-Earth and demand partnership and understanding of given situations and their outcomes, including acceptance of a less or non-favourable outcome which may result in permanent disability or loss of life. In the event of multiple injuries, colonists may need to adapt to particular stresses on a triage basis to ensure that resources are deployed for the benefit of those likely to make a full recovery.

Step 5: Locate data sources

Existing scientific and philosophical research in peer-reviewed academic literature was considered an appropriate data source for construction of the WDA. In addition, the corresponding author has > 25 years experience of managing and leading international teams of people in complex tasks and the knowledge gained from leading or managing > 40 projects has been used in assessing, improving and driving team performance.

Step 6: Construct the work domain analysis

Initial models of wound causation and management were developed by the research team based on the data collected in step 5. The team lead has internationally reknowned experience in healthcare, ergonomics methodology and human factors, and includes previous work with other reputed researchers with expertise in cognitive and psychological science and philosophy, ethics and social sciences [46-52]. The initial WDA was developed by the lead author and refined in several iterations, which included the input of consultant subject matter experts (SMEs). Data are presented as matrices showing connectivities between descriptors for each of the hierarchy levels.

Steps 7 to 9: Refine, review and validate the work domain analysis using a crowd-sourcing approach

In May 2021, a crowd-sourcing activity was launched through Astronomy Ireland (AI) entitled 'Predicting and Managing Astronaut Injury' (https://astronomy.ie/predicting-and-managing-astronaut-injury/), requesting responses from the Irish Astronomy community. Figures 1-a and 1-b shows the published call for input including an open response to four questions with a defined number of answers requested and Figure 1-c a follow up article informing contributors of the value of their input.

Figure 1. Crowd-sourcing campaign led by Astronomy Ireland a). Our process for crowd-sourcing presented at UK Space LABS, b). Flyer published with questions and call for responses and c). Follow up article acknowledging responses and commitment to publish: *https://astronomy.ie/predicting-and-managing-astronaut-injury/*.

In order to better understand the perceived major challenges for preventing and manging astronaut injury in space, a crowd-sourcing approach shown in Figure 2 was adopted, and our planning assumed that cost and materials were not limiting factors. Information was requested regarding 4 principal questions relating to injury treatment and management from the Irish Astronomical Science Community comprising members from Shannonside, Galway, Newport and Cork Astronomy Clubs, Friends of Mayo Dark Skies, Blackrock Castle and Kingsland and I-LOFAR Observatories. Information was collected via mailshot, posting via social media and publication in AI. All data was collected by AI and conformed to General Data Protection Regulation (GDPR) where responses were forwarded anonymously to the authors.

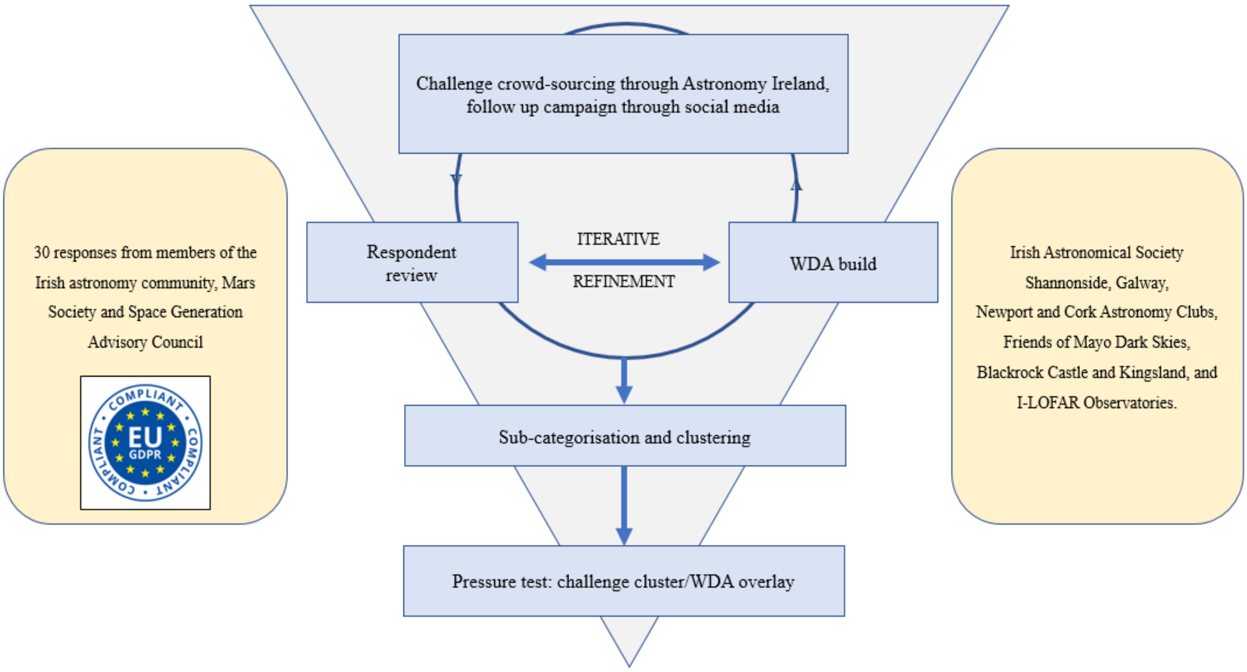
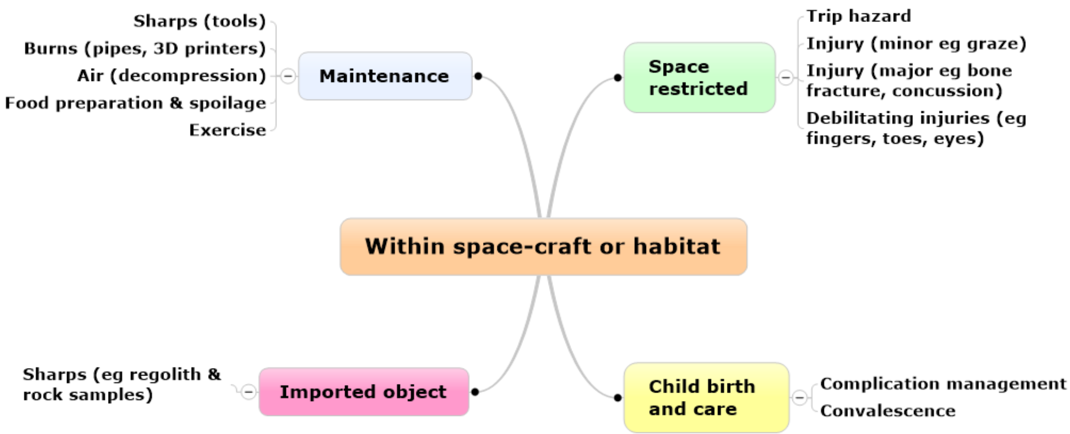
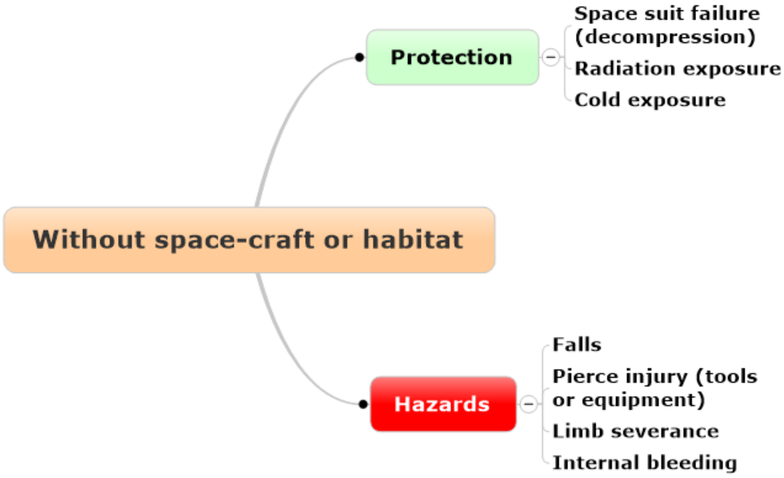


Figure 2. Process funnel for crowd-sourcing and data clustering: Schematic shows the process followed to obtain and cluster data, contributing societies are listed.

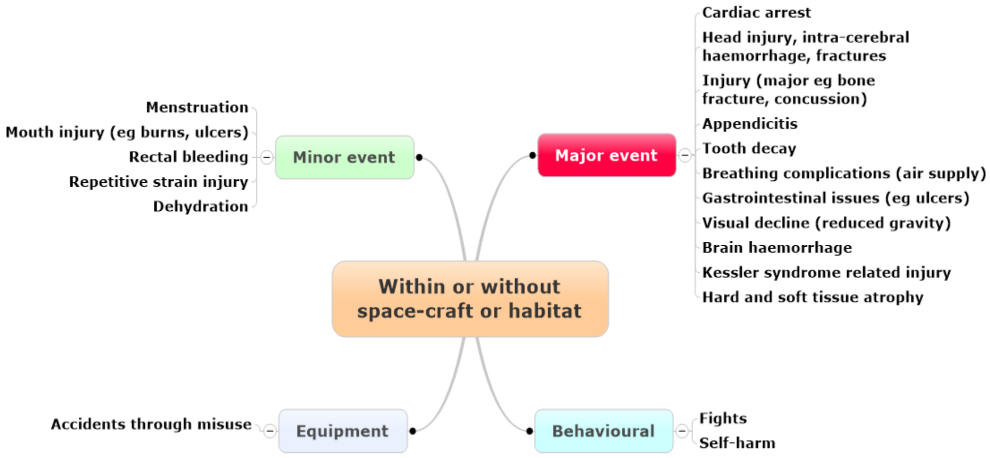
Responses were collated into mindmaps (Figure 3) and clustered into thematic areas and potential confounders identified (Table 2). WDA derived hierarchy level descriptors were assigned (Table 2) and used to develop a key for 3 matrices (Figure 4).



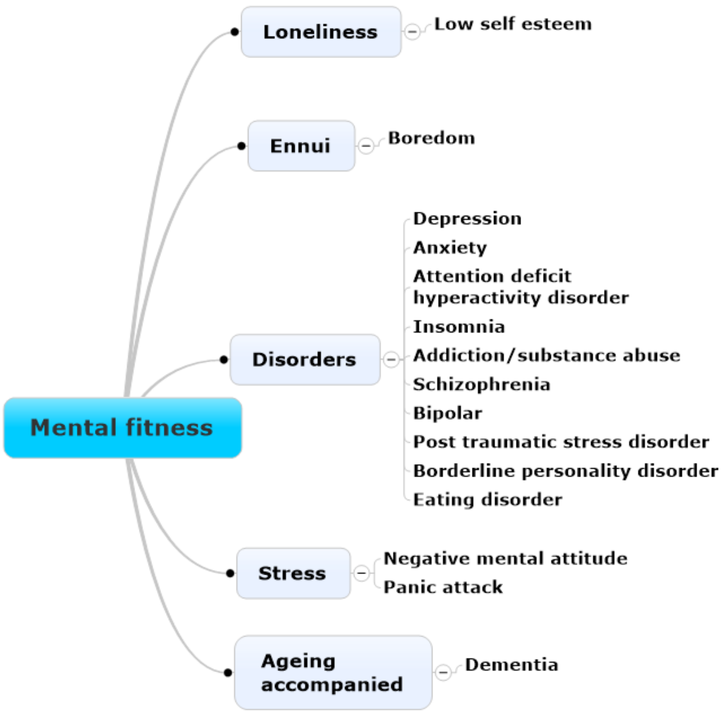
(a)



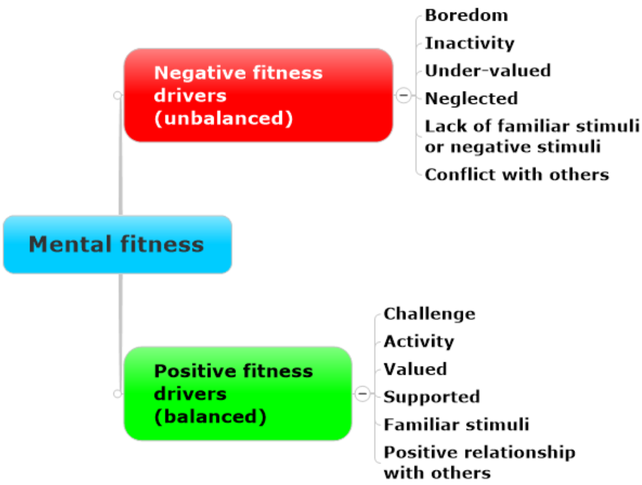
(b)



(c)



(d)



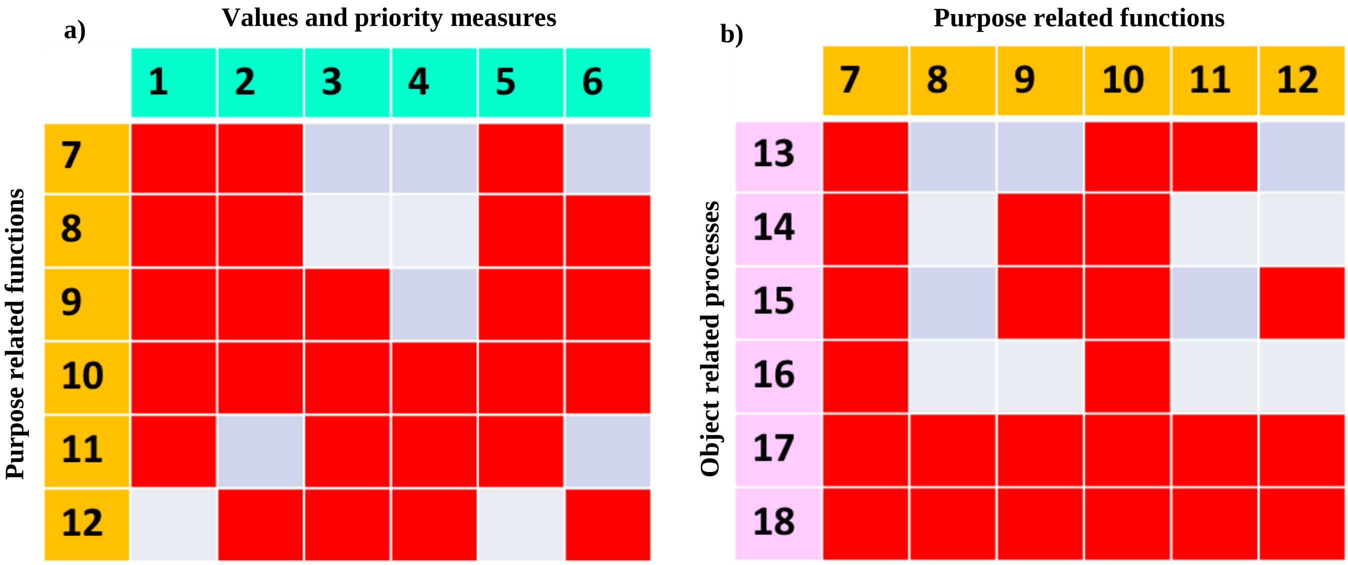
(e)

Figure 3. Mindmaps for injury prediction, prevention and management. Mindmaps were constructed from discussion for a held with members of Rosliston Astronomy Group in March and April 2022: a). Topics relevant within a space-craft or habitat, b). Topics relevant without a space-craft or habitat, c). Topics relevant both within and without a space-craft or habitat, d). Parameters underpinning mental fitness, e). Selected negative and positive drivers of mental fitness.

Table 2. Clustered challenge themes and potential confounders

#	Challenge	Potential space environmental confounders
1	Prevention of incidents and accidents which may lead to injury	• Bulky space suits • Isolation in a confined working and living space • Human desire for open spaces • Shelter from micro-meteorite impact and weather (Moon and Mars)
2	Maintenance of optimal physical and mental health	• Lack of predictive tools • Equipment failure including power outages leading to lost data • Accelerated decline in mental psyche and cognitive function
3	Treatment of serious injury requiring intensive care	• Facilities • Knowledge of injury management and life preservation • Ability to evacuate to Earth • Acceptance and management of negative outcome
4	Dependence upon Earth	• Consumables restocking • knowledge management • Tractability of telemedicine due to signal latency
5	Prototype testing of new technology in-situ and in-life	• Limited opportunity for prototype validation under space environmental conditions • Expectation management
6	Continued sense of purpose and belief	• Reduced capacity and capability to continue mission during convalescence down-time • Increase in stress, home-sickness and depression as a consequence of team member injury

Clustered themes from mind-maps shown in Figure 2 are presented together with potential confounders.



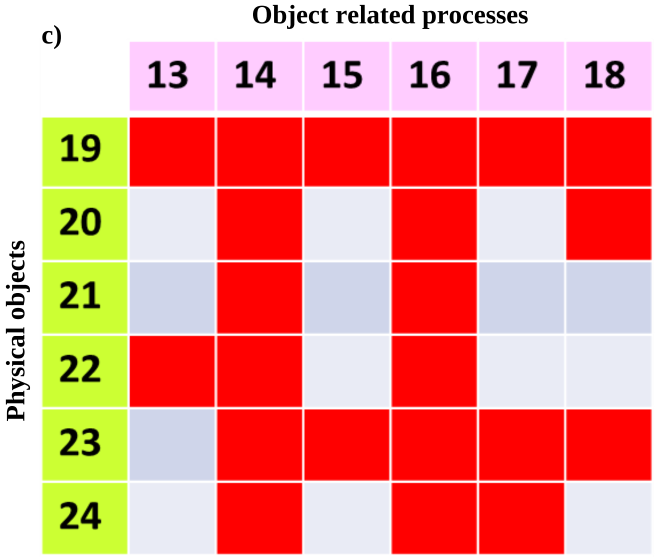


Figure 4. Matrix representation from the WDA; connectivity between constrained abstract hierarchy level descriptors described in Table 1. a). 2 and 3, b). 3 and 4, c). 4 and 5. The WDA for predicting the potential and managing the occurrence of injury in space is constructed from the abstraction hierarchy defined in Table 2 according to standard methodology (Vincente [33], Naikar [35]). Connectivities are shown in filled red boxes: a). connectivities between hierarchy level descriptors for values and priority measures and purpose-related functions, b). purpose-related functions and object related processes and c). object related processes and and physical objects.

3. Results

3.1. Mindmap Construction

The project outline which was used to prime crowd-sourcing of answer to questions in Figure 1 which captured public interest representative of all participating groups is shown in Figure 2. Responses illustrated wide-ranging interest in medical, technical and philosophical categories demonstrating interest in the topical and specialist nature of the subject.

Responses were categorised as being relevant to within the space-craft or habitat (Figure 3-a), without the space-craft or habitat (Figure 3-b) or applicable to both within and without the space-craft of habitat (Figure 3-c). The subject of mental health was addressed with a more positive perspective as mental fitness (Figure 3-d) and considered both negative a positive mental fitness drivers (Figure 3-e).

3.2. Construction of Work Domain Analyses for Mars Colony Build, Maintenance and Expansion

The abstraction hierarchy descriptors shown in Table 1 were used to build WDA plots aimed at reducing and managing the potential for injury and to main physical health and fitness to mitigate the worst case scenario of mission abortion.

Descriptors for each of the abstraction hierarchy levels are shown in Table 2. 6 broad value and priority measure were identified which included cost-effective management of physical and mental fitness, provision of an ergonomically safe environment, clear standard operating procedures (SOPs) and code and consideration of future dependence upon Earth. 6 purpose-related functions were defined which included hands-on management of physical and mental health at an individual level, management of the environment adherence to and enforcement and enactment of SOPs and a code of conduct and communication systems with Earth and on the off-Earth body.

Purpose-related functions were supported by 6 object-related processes which included regular health and fitness check-ups and monitoring, treatment by qualified people, medical care, regular training, communication systems and and emergency evacuation protocol with associated SOPs. Object-related processes were in turn supported by 6 physical objects ranging from monitoring equipment for acute and chronic conditions to medical consummables, facilities for diagnosis, surgery, convalescence, medical procedure knowledge and clinical waste management.

Interconnectivities across the WDA were represented in matrices which illustrate connectivities between individual hierarchy level descriptors. Figures 4-a to 4-c show connectivities between hierarchy level descriptors for values and priority measures and purpose-related functions (Figure 4-a), purpose-related functions and object related processes (Figure 4-b) and finally object related processes and and physical objects (Figure 4-c).

3.3. Crowd-Sourcing, Clustering Metrics and Sub-Categorisation

The process funnel for crowd-sourcing, data clustering and pressure testing against the WDAs is shown in Figure 2. In total 464 responses out of a maximum of 480 were used to generate the mindmaps shown in Figures 3a to 3-e, with the remaining 16 discarded as they did not satisfy the scope of the initial question. We clustered the output into themes and sub-themes, illustrating where available, terrestrial analogues which may inform both mission planners, astronauts and future colonist leadership and management (Table 3). With a lens on current practice and to encourage further discussion with our participants at formal presentation of our findings, we summarise a forward-looking perspective on emerging technologies and how they be leveraged (Table 4). To illustrate the challenge of audio and visual communication from Earth to and from Mars and the dependence upon orbital positioning, we included predictions of one way signal latency as explored by orbital modelling for a mission to and from Mars when Mars is at conjunction and opposition (Figure 5). Finally, taking into account our findings, hypothetical outcome scenarios were summarised in see-saw plots for management of serious injury on Earth, the ISS, Moon or Mars (Figure 6), taking into account distance from Earth and average 2-way signal latency.

Table 3. Themes and sub-themes to assist mission planners and astronauts

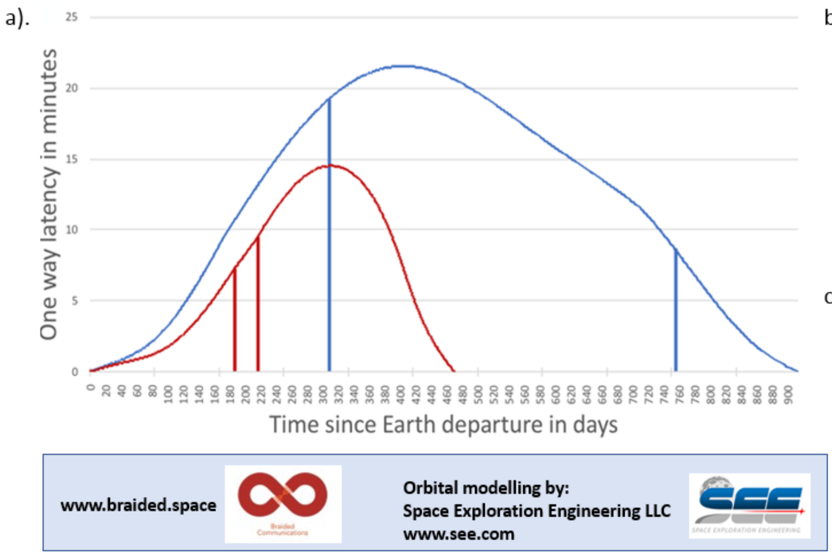
#	Theme	Sub-themes	Product
1	Recreation	• Social activities to build a community • Relaxation and meditation to reduce stress • Physical exercise	Reduce the occurrence of incidents and accidents by maintaining human performance
2	Medical support	• Physical and mental health monitoring • Diagnosis, pharmaceutical and surgical intervention • Maintenance of medical equipment	Provide facilities to treat incidents and accidents, mitigate threat to life and success of colony
3	Communication management	• Reporting to and receiving messages from Earth and on-world mission control • Telemedicine • Equipment servicing and maintenance know how	Infrastructure and operations from Earth
4	Consumables restocking and supply chain	• Equipment and replacement parts • Resupply of medical armamentarium • New technology	Renewed raw materials
5	Water procurement and supply chain	• Maintenance of water production operations • Storage • Disposal of contaminated water	Clean, adequate water supply available on demand
6	Conducting research	• Medicine ADME and PK/PD in reduced gravity • Quantification of healing parameters in reduced gravity • Role of radiation on API shelf-life	Knowledge management

Potential products to address sub-themes challenges as illustrated by terrestrial analogues where available and citation

Table 4.Solution management for clustered challenge themes confounders

	Current and emerging technologies applicable to the space environment		
#	**Current**	**Emerging**	**Reference examples**
1	Best ergonomic practice	Dynamic AI to improve healthcare outcomes	Russo & Lax (2022) and Bohr & Memarzadeh (2020)
2	Prognostic and diagnostic screening using biomarkers	Homeostasis implant monitors	Nsanze (2005) and Ravisetti (2022)
3	On-body digital technology	Vital signs monitoring with smart clothing	Bains (2020) and Ghaffari et al. (2021)
4	Drug-containing implants, 3D printing	Nano-reservoirs for drug delivery 3D bio-printed bandages and organs	Maver et al. (2015), Ballerini et al. (2020), and Kashaninejad et al. (2022)
5	Telemedicine	Robotic and AI-driven remote surgery	Garcia (2022), and Pantalone et al. (2021)
6	Assisted locomotion	Exoskeletons	Rea et al. (2013), Palacios et al. (2021), and Lee et al. (2022)
7	Psychoactive medication	Personalised positive psyche medication	Friedman & Bui (2017)
8	Predictive messaging	Algorithms to manage signal latency	Braided Communications (2022)

Current and potential future solution management options are considered.



b).

Day	Mission at opposition	Latency (min s)
0	Take off from Earth	0
186	Landing on Mars	7' 14"
216	Take off from Mars	9' 28"
311	Maximal distance from Earth	14' 31"
>460	Return landing on Earth	0

c).

Day	Mission at conjunction	Latency (min s)
0	Take off from Earth	0
>310	Landing on Mars	~14'30"
>400	Maximal distance from Earth	>21'
>740	Take off from Mars	>8'
>900	Return landing on Earth	0

Figure 5. Typical one-way signal latency for conjunction (blue) and opposition (red) class Mars missions (Vertical lines show arrival and departure times for each mission): a). Graph of one-way latency (minutes) versus time since Earth departure (days). Vertical lines show arrival and departure times for each mission (credit Space Exploration Engineering LLC). b). and c). Signal latency (minutes) versus time since departure for key event stages; take off from Earth, landing on Mars, take off from Mars and maximal distance from Earth for opposition (red) and conjunction (blue) class missions.

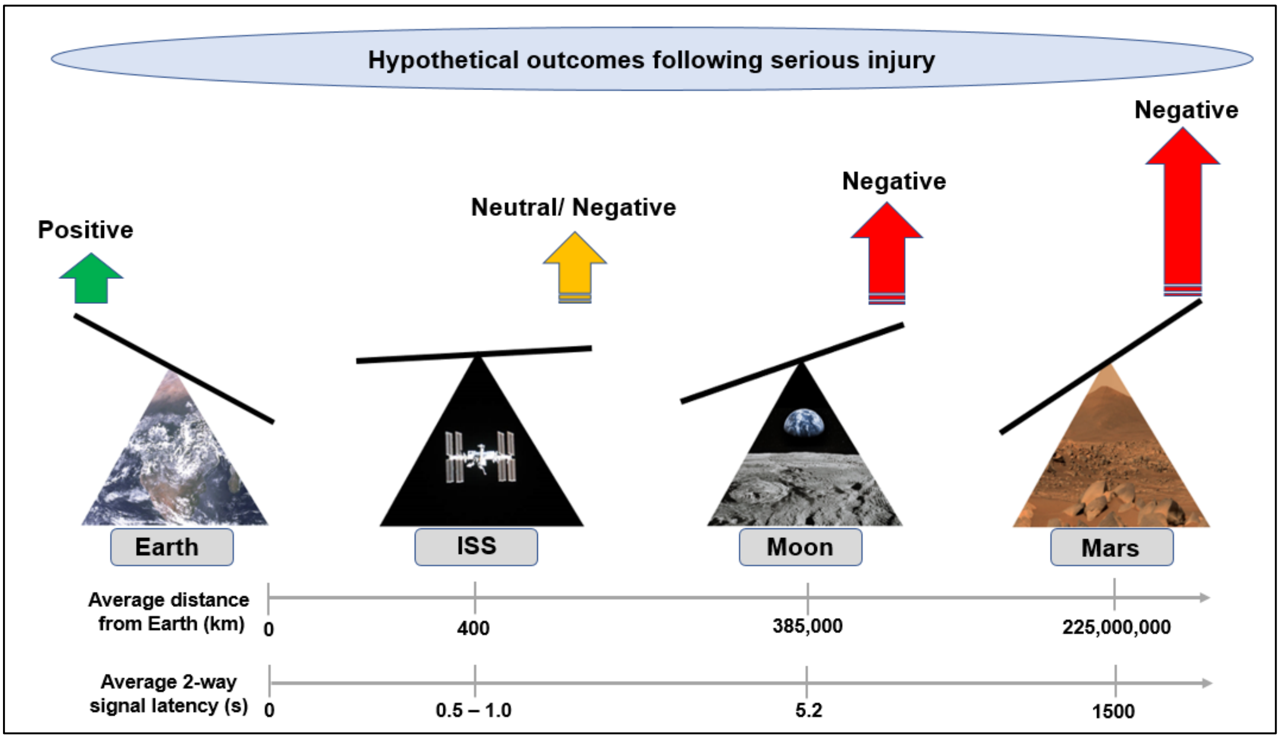


Figure 6. See-saw plots illustrating hypothetical impact scenarios for injury management in space by location: Scenarios are represented for probabilities of successful outcome on the ISS, Moon and Mars relative to that on Earth. Average distance form Earth (km) and average signal latency (s) is indicated.

4. Discussion

In this study, we have again illustrated the power of crowd-sourcing to generate and test ideas, to stimulate public interest and to help form a foundation for further studies which will serve to inspire new thinking and the two way application of technology for both off and on Earth inhabitants. In general our approach was succesful and greatly assisted by engagement with and support by the popular science magazine *Astronomy Ireland* who publicised the call for input widely within the Irish Astronomical community. Our findings further support the use of the abstraction hierarchy methodology from WDA to develop a systems model for managing and treating injury and in understanding the drivers for the maintenance of positive mental fitness. This second study emphasises the important role that ergonomics has to play in modelling systems of such complexity and in previous studies conducted in other extreme environments and non-traditional workplaces [53-57] which should serve to inform both mission planners and amateur astronomers who want to understand, challenge and support the concept vision. The presentation of our findings at two Astronomy Society meetings acted as a route for critique and provided valuable input, particularly concerning our consideration of conditions presented in alternate extreme environments. Construction of mind maps from contributor responses is an effective tool providing structure and focus and enabled us to segment areas related to physical and psychological fitness under the proviso that the two topics are inextricably linked. The challenges and confounders listed in Table 2 were used to generate the WDA-derived abstraction hierarchy level descriptors shown in Table 5 which span the wound management life-cycle through to clinical waste management. Our matrix representation of hierarchy level descriptors described previously [9] and shown in Figure 4 shows a predictable set of interdependencies which drive a focus on solution, using either existing technology or by placing a demand on areas for refinement, scaling, commercialisation or innovation.

Table 5. WDA derived abstraction hierarchy level descriptors and key to matrices for injury management

Functional purpose	Value and priority measures	Purpose-related functions	Object-related processes	Physical objects
	1-6	**7-12**	**13-18**	**19-24**
➢ **Reduce potential for injury in space to maintain astronaut physical health and mental fitness.** ➢ **Manage the occurrence if injury in space to mitigate the potential for mission abortion.**	Cost-effective management of physical and mental fitness	Manage individual physical and mental health	Regular check-ups and monitoring	Monitoring equipment (acute and chronic use)
	Provide an ergonomically safe environment	Manage environmental use	Treatment by qualified person	Medicines, blood, plasma, anaesthetic, water, oxygen, other consumables
	Provide clear standard operating procedures	Adhere to and enforce standard operating procedures	Regular training	Facilities for surgery, convalescence, life support
	Provide code of conduct	Enact code of conduct	Medical care	X-ray, MRI, CT scanning
	Dependence upon Earth	Communication (new world – Earth)	Communication systems including signal latency management	Medical procedure knowledge
	Independence from Earth	Communication (within new world)	Emergency evacuation protocol and processes	Clinical waste management

Colour coded descriptors aligned with matrices in Figure 4.

As shown in Table 3, the importance of recreation and social space was identified as playing a preventative role for the incidents and accidents and not surprisingly plays a role in maintaining positive physical and mental well-being [58]. The need to consider ergonmic design in space analogs [59] and space missions has been previously reported [40, 60-62]. Future designs, potentially using AI as on Earth warrant discussion and inclusion with inhabitants as is illustrated by the role of AI in terrestrial office design [63]. Management of consumables and conducting research to improve healthcare, as on Earth are essential for the well-being of colonists but also for the public-facing image of the mission's success and continued reliance on financial support. It is particularly relevant to consider our current limited understanding in predicting radiation-induced pharmaceutical instability during long-duration spaceflight [64, 65]. which may place extra demand on the supply chain of consumable products**.**

Some of the many current and emerging technologies to assist space travelers and colonists shown in Table 4 include the consideration of ergonomic design and how AI may play a role [66, 67] based on the momentum for AI in terrestrial healthcare management (e.g., Bohr & Memarzadeh 2020 [68]). Delivery of drugs via impregnated bandages (e.g., Maver et al. [69]) or nano-fluidics where a tunable supply of the beta-agonist formoterol from a nano-reservoir has been demonstrated to reduce muscle atrophy in mice [70] and may form the start of a promising modality which was recently been reviewed [71]. An exciting development in 3D bioprinting [72] is the first protype device, called BioPrint FirstAid which is currently under evaluation on the ISS. The current testing procedure does not involve cells at present [73]. In future, however, the device will utilise formerly prepared bio-inks, containing the recipient's own cells, conjugated with a bio-polymer and cross linker to form a band-aid patch over an injury. The concept of powered or semi-powered exoskeletons has received great attention (e.g. [74-80]) in medical applications for patients who have lost use of limbs through acute trauma or paralysis and may undergo robot-assisted rehabilitation [81, 82], and in military applications such as the development of exosuits to make traversing tough terrain more feasible and industrial applications to reduce the risk of upper body injury sustained through extension movements or lifting heavy objects [83]. This field is a further illustration of where terrestrial-driven progression of technology, primarily to assist patients with disabilities may have applications for space exploration and colonisation and NASA has described the application of X1 [84], originally developed for patients with paraplegia. Recently the BIOX-GLOVE a soft robotic hand exoskeleton has been developed intended for use on rover rescue missions on Mars [85]. As will be discussed in more detail shortly, there is a burden of space exploration on the mental well-being of astronauts [86], which to an extent may be accounted for by inclusion of medications in the pharmacy available for use in space [87]. However, it is not believed to be the case that psychoactive drugs are regularly used as mood elevators in space, due to their potential for having unpredictable and addictive effects.

The field of telemedicine, which is now becoming mainstream on Earth [88], has recently been taken to a new level with the application of holoportation in space [89]. First developed in 2016 for use on Earth, holoportation allows high-quality 3D models of people to be reconstructed, compressed and transmitted live anywhere in real time. When combined with augmented reality displays, it allows users to see, hear, and interact with remote participants in 3D as if they are actually present in the same physical space. This allows trained medical staff to interact directly with their subjects in a virtual manner, closely, if not exactly replicating an appointment with a physician. What for telerobotic surgery in space? Clearly, the issue of signal latency illustrated in Figure 5, would seem to preclude procedures led from Earth, even for astronauts in the ISS where the signal latency is minimal. It would appear that the need for greater crew autonomy and the likely increasing severity of medical and surgical interventions that could occur in off-Earth colonisation activities would require the presence of a highly trained surgeon it situ. A surgical robot may assist, though will need to be provided with the capability to perform certain procedures autonomously, have the capacity to use artificial intelligence [90] but permit human intervention if required. Advances in terrestrial development in this technology have been made particularly as a consequence of the Covid-19 pandemic [91].

How can an astronaut, colonist or anybody working in a stressful situation have an early indicator of situations where help may be needed if self-management is unachievable? Technology is already helping us from a diverse range of fields. For example, Epicore Biosystems, in partnership with PepsiCo and Gatorade, has developed a first-of-its-kind personalized performance tracking sweat patch known as the Gx Sweat Patch. The Gx Sweat Patch is a skin-like, wearable patch that pairs with an app to provide real time personalized recommendations for athletes to optimally hydrate and refuel after exercise [92]. This device may highlight the utility of biochemical sensing platforms for personalized assessment of performance, wellness, and health across a broad range of applications, including being in stressful situations. Many wearable devices are already available, particularly in the fitness industry for health monitoring (e.g. Lou et al. [93]). Smart clothing utilises nanotechnology within textiles creating garments which respond to stimuli such as pressure and temperature [94, 95]. Recent advances for monitoring basic signals, such as electrocardiogram (ECG), body temperature, and movement with the aim of understanding the technological requirements for body area network, node design, energy consumption optimization mode, and network architecture to permit physiological monitoring. For example, Hexoskin smart garments allows the continuous monitoring of sleep & heart rate variability for first responder and defence personnel, and for investigators to conduct longitudinal studies on mental health and stress monitoring, operational stress injuries, and post-traumatic stress disorder assessments. The scientific literature is very-fast growing in this field and includes the biometric monitoring of heart rate in different climate conditions under exercise [96], monitoring the impact of particulate matter and noise exposure on cardiac function [97] and the early detection of prediabetes and type 2 diabetes mellitus using wearable sensors and internet-of-things-based monitoring applications [98]. Smart clothing has been developed for use in Space [99], for example Astroskin, an ambulatory vital signs monitoring platform for medical research used for continuous real-time monitoring of blood pressure, pulse oximetry, 3-lead ECG, respiration, skin temperature, and physical activity which was tested on board the ISS in 2018-2019 [100]. One example of how wearable technology may provide assistance to a caregiver, which in the context of space exploration may be a fellow astronaut, is provided the measurement of heart, respiratory and skin parameters for emotional monitoring for people with autism [101]. From these few examples, it is clear that the technology is readily available to monitor one’s personal state of physical health and parameters which may drive negative indicators of mental health.

Futuristically, an extension of biometric measurement technology is the real-time recording of parameters of physiological and psychological mental fitness using homeostasis implant monitors. Implantable sensors have been available for many years, principally to monitor and maintain cardiac function. Already popular in Sweden, A human microchip implant is a personalised radio-frequency IDentification (RFID) transponder encased in silicate glass and implanted subdermally [102]. The device may contain a unique ID number that can be linked to information contained in any external database, such as personal identification, law enforcement, medical history, physical performance, medication and compliance with useage, allergies, and contact information. Although to date, human micro-chipping in the United States has low adoption due to concerns regarding data protection and use of knowledge, health risks, ease of use, negative social impact technical advances, human enhancement, regulations, and affordability which has prompted proposals to explore and modify where needed the technology acceptance model in the public sector [103]. However, this is a rapidly growing field and a detailed discussion is beyond the scope of this paper, however, it is conceivable, plausible and realistic to imagine a future in which space colonists are not only able to self-monitor their health, but monitor the health of their team members which would in turn be monitored by mission planners, allowing for corrective measures, for example, reduction in working hours to be implemented. In April 2022, a helmet was used by crew members onboard Axiom-1 mission’s SpaceX Crew Dragon capsule to monitor brain activity data in near real time for 10 days while on board the ISS [104], specifically to determine whether the brain adapts to a new homeostasis in space while performing cognitive tests. The notion of real-time monitoring of biometrics, telemedicine let alone robotic surgery conducted from Earth is challenged by the inescapable laws of physics which impose a signal latency on astronauts and colonists to and from their position in space. This is clearly illustrated in Figure 5 and may become a significant threat to Mars colonists requiring emergency communication where one way signal latency could exceed 21 min. A communication facilitation tool is being developed by Braided Communications [105] who offer seamless and meaningful communication in contexts where there are large signal latencies. This system may optimise communication supporting operational effectiveness for safety, medical and social exchanges with mission control, friends and family by phasing questions and answers to minimise the perception of time delay. It is under development with several partners including ESA.

In addition to the feedback received on physical wound injury, its prevention and management, responses received from our contributors have clearly highlighted the need to consider mental health and psychological well-being. The Department of Health and Human Services in the USA (mentalhealth.gov) definition of mental health is that it includes our emotional, psychological and social well-being. It affects how we think, feel and act. It also helps determine how we handle stress, relate to others and make choices. Mental health is a complex and multi-factorial topic influenced by genetics and diagnosis of family history of mental health conditions, brain biochemistry, life experiences such as trauma, physical or mental abuse, environmental and occupational stress, biological factors, such as genes or brain chemistry [106, 107]. It is a wide and general misconception, particularly in people who have no known challenges to their ability to cope and manage situations that mental health is simply defined about the presence and severity of mental disorders. Indeed, it may be more appropriate to rephrase mental health as mental fitness where the capacity of an individual to adapt and cope with challenge is determined by both innate and trained resilience and both negative and positive trigger points are defined and managed [108, 109]. For the context of this paper, we will make the assumption that mental fitness is supported by an environment that maximises mental health and minimizes negative stress drivers while keeping a balance with positive stress drivers which are necessary to challenge human beings, drive ingenuity and realise full potential.

Mental fitness can be affected both positively and negatively as there are many different stimuli in the environment including social interaction which can affect mental fitness [110, 111]. Some examples of stimuli include visual (images, landscapes, animations), audible (music, bird song, alarms), olfactory (scented products, food, body odour) and physical (exertion exercise, hobbies, contact with others). It is generally acknowledged that good mental state relates to a feeling of calmness, safety and positive occupational load. Importantly, a good mental state requires a stable emotional state which enables productivity, clear communication with others which encourages and drives collaboration while recognizing individual contribution [106].

As shown in Figures 3-d and 3-e, it is appropriate to consider factors driving mental fitness in the space environment and how we may best optimise positive drivers, minimise and counter-act negative drivers. Whether on a space ship or in a habitat on the Moon or Mars, there are ergonomic constraints that may impose immense mental pressure on mission members. The first is having to adapt to living and working in a confined space which may have a negative effect by inducing claustrophobia and feeling of being trapped which may progress to anxiety and panic attacks leading to a downwards spiral of personal and team demoralization and for a person to become withdrawn, intensifying the feeling of isolation. This would likely make communication with fellow inhabitants difficult and possibly even make inhabitants prone to aggression which when contained in such a confined space would be a challenge to resolve. The second is the consequence of aggression or simply of non-physical conflict which could have catastrophic repercussions on both the mission and health of all people involved. This is mainly due to the fact that conflict usually leads to a lack of communication, and can create a hostile environment which encourages irrational thinking. Under extreme conditions such conflict may lead to physical aggression which could ultimately lead to loss of life, mission failure and irreparable damage to the concept credibility of an off-Earth settlement.

We can learn from terrestrial analogues potential sources for sub-optimal mental fitness [112]. One clear outcome from lunar and Martian isolation studies is the need for personal space. As on the ISS, in an off-Earth habitat, each colonist is to be provided with an autonomous environment recognizing the importance of personal space. This has long been recognized in human beings and primates as an innate requirement and has been termed the ‘invisible second skin’. The need for personal space and the tensions it may cause if not provided has been demonstrated on board the ISS [113-116] and in submarines [117] where the confinement, isolation and stress that is characteristic of the environment provides an analog for space missions [118] and creates a psychological need for more room and a sense of privacy and this need becomes more important for longer missions. Three general reasons why humans need their own personal space relate to reducing the potential for sensory overload, protection from potential aggression, and, ultimately, stress and lastly with non-verbal behaviours such as eye contact and body orientation which we use to control the type of message we want to communicate with others. This design feature for colony architecture is prerequisite for building a team environment which will survive by collaboration, recognition and acknowledgement of individual contribution while providing necessary moments for isolation and self-reflection [119-121]. In 2021 the requirement for maintenance of personal space of both humans and human-like avatars has been modelled [122] and reported that discomfort-by-distance functions for both humans and avatars were closely aligned in a power relationship. This reinforces the notion that humans need personal space not just from other humans, but may also need space from human-like objects which could become important for future design of humanoid robots [123-126].

It is important to recognize that mental fitness is important at every stage of life, from childhood and adolescence through to adulthood. With the long-term aim of establishing human colonies on Mars where inhabitants are to be born and grow up on the planet, this is an essential concept to accommodate within mission planning. All high pressure environments generally function well when there is a clear sense of purpose, protocols and system with a very high level of adherence [127-130], together with a strong sense of team identity and cohesion as described in a Company environment [131, 132]. One of the main ways in which mental fitness is usually maintained in normal conditions is through activities that humans find pleasurable for example music, art, entertainment, hobbies, socializing and forming relationships which include sexual activity. Maintenance of mental fitness could be maintained by all or part of the habitat being adaptable as a sensory stimulant chamber mimicking environments found on Earth [133, 134] such as freshly cut grass [135]. This could be through the use of sounds, smells, images, and temperature change to accommodate a range of human needs as has been achieved in the maritime environment [136, 137].

In this manner an Earth-like familiar environment could be replicated where a person may feel comfortable and safe and tunable to the demands of the individual. It may also provide a sense of movement by being able to transition between environments and reduce the mental fatigue associated with a confined space. It may add value as a source of entertainment making it more multi-purpose and demonstrate better return on investment for budget planning purposes. Any environmental design will require establishment, updating and maintenance of a data storage system. This is of paramount importance as important information would need to be recorded, kept private and be retrievable for example colonist health records. Such a data management system has a secondary purpose as a provider of forms of entertainment such as music, film, TV shows and other forms of media, as on Earth, requested on demand to be streamed over a period of time. Maintenance of physical health through the use of sports equipment adapted for reduced gravity [60, 138] is one activity that positively may impact mental fitness, keeping colonists active and providing challenge through personal or team competition.

Our summary of hypothetical outcomes following serious injury by location in Figure 6 are based, we believe, on reasonable conjecture. In essence, the outcome is largely driven by the ability of the patient to receive the best standard of care regardless of location and, therefore dependent upon the ability of transportation to facilities either off-Earth or in evacuation back to Earth. There are limitations for our overall assessment. The reality of basic transport to and delivery of intact and undamaged materials via a supply chain that maintains shelf-life of active products in the case of many medical consumables must be taken into account, particularly during the early stages of colonisation. As previously discussed, [139] and even with potential threats to the human population on Earth illustrated by the Covid-19 pandemic and climate change, continued human exploration of space and off-Earth colonisation must have a very clear value proposition beyond that of romantic heroism. It is essential to understand the underlying theory and application of return on investment measurement, assessment and where there may be added scope for incremental increase [8, 140, 141]. The colonisation of the Moon is in essence the first stage of our species migration and should be acknowledged [142, 143] and the positive effects that NASA brings to the American economy [144].

The possibility of longer-term financial return on investment gained by mining the Martian sub-surface and returning valuable minerals to Earth may be one such incentive. Boron has been found by the Curiosity rover [145] and rare siderophiles such as Re, Os, Ir, Ru, Pt, Rh, Pd, and Au) in the mantles of Earth, Moon, and Mars [146]. Recently a biomining experiment onboard the ISS has demonstrated the feasibility of rare earth element extraction in microgravity and in Mars gravity [147], laying the foundation for what may become an added source of rare metals.

5. Conclusion

In this paper we have further illustrated the utility of sociotechnical tools to understand and model the management and treatment of injuries in space. We have used a crowd-sourcing approach collecting over 400 responses from members of the Irish Astronomy community who represent a cross-section of the general public with an interest in astronomy. Our findings illustrate continued high public awareness and curiosity enabled by extensive media presentation of recent Mars landings together with well publicised descriptions of the return to the Moon. We maintain our belief that this inclusive approach of seeking public opinion may assist mission planners for future endeavours by helping to nuture positive public opinion by outreach to the general public and to support further exploration of space and off-Earth colonization by a consideration of all facets of human behaviour and requirements.

Said Hubertus Strughold, a German physiologist and medical researcher dubbed the father of space medicine in 1959, 'Space is an environment of emptiness. It offers no possibility for natural adaptation to any living organism – and particularly not to the highly sophisticated creature, man. Yet man has the ability to resolve this paradox through his intellectual power and creative faculties'.

6. Declarations

6.1. Author Contributions

Conceptualization, B.C. and M.B.; methodology, M.B.; software, B.C. and M.B.; validation, B.C. and M.B.; formal analysis, B.C. and M.B.; investigation, B.C. and M.B.; resources, B.C. and M.B.; data curation, M.B.; writing—original draft preparation, B.C. and M.B.; writing—review and editing, B.C. and M.B.; visualization, B.C.; supervision, M.B.; project administration, B.C. and M.B. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

Data sharing is not applicable to this article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Acknowledgements

The authors are indebted to participants from the Irish Astronomical community and to Tom Finnegan, Ann Dunne at Astronomy Ireland for managing the crowd-sourcing activity. The authors thank Dr. Rob Brougham at Braided Communications and Space Exploration Engineering LLC. Martin Braddock also acknowledges the UK Space Life and Sciences Biomedical Science Association for their inclusion of the crowd-sourcing concept in the 2021 white paper. Mansfield and Sutton Astronomical Society (MSAS) and Rosliston Astronomy Group are registered charities, numbers 51813 and 1175118 respectively. MSAS was founded in 1970 to foster interest in astronomy in Ashfield, Nottinghamshire and surrounding district. RAG was founded in 1999 to foster interest in astronomy in south Derbyshire and South-East Staffordshire and surrounding districts.

6.5. Institutional Review Board Statement

Not applicable.

6.6. Informed Consent Statement

Not applicable.

6.7. Declaration of Competing Interest

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

7. References

[1] Granath, B. (2015). The human desire for exploration leads to discovery. National Aeronautics and Space Administration (NASA). Available online: https://www.nasa.gov/feature/the-human-desire-for-exploration-leads-to-discovery (accessed on August 2022).

[2] Vernikos, J. (2008). Human exploration of space: why, where, what for?. Hippokratia, 12(Suppl 1), 6-9.

[3] O'Keefe, S. (2004). The vision for space exploration. National Aeronautics and Space Administration (NASA). Available online: https://history.nasa.gov/SP-4701/session%20intro.pdf (accessed on May 2022).

[4] Obama, B. (2010). Remarks by the president on space exploration in the 21st century. John F. Kennedy Space Center Merritt Island, Florida, United States. Available online: https://obamawhitehouse.archives.gov/the-press-office/remarks-president-space-exploration-21st-century (accessed on August 2022).

[5] Moltz, J. C. (2019). The changing dynamics of twenty-first- century space power. Journal of Strategic Security, 12(1), 15–43. doi:10.5038/1944-0472.12.1.1729.

[6] Whitwam, R. (2021). 5 Reasons space exploration is more important than ever. ExtremeTech https://www.extremetech.com/extreme/268062-5-reasons-space-exploration-is-more-important-than-ever (accessed on August 2022).

[7] World Economic Forum. (2021). Space: Why the human race must become a multiplanetary species. Available online: https://www.weforum.org/agenda/2021/12/humans-multiplanetary-species/ (accessed on August 2022).

[8] Levchenko, I., Xu, S., Mazouffre, S., Keidar, M., & Bazaka, K. (2021). Mars Colonization: Beyond Getting There. Terraforming Mars, 3(1800062), 73–98. doi:10.1002/9781119761990.ch5.

[9] Braddock, M., Wilhelm, C. P., Romain, A., Bale, L., & Szocik, K. (2020). Application of socio-technical systems models to Martian colonisation and society build. Theoretical Issues in Ergonomics Science, 21(2), 131–152. doi:10.1080/1463922X.2019.1658242.

[10] Szocik, K., Wójtowicz, T., & Braddock, M. (2020). The Martian: Possible Scenarios for a Future Human Society on Mars. Space Policy, 54, 101388. doi:10.1016/j.spacepol.2020.101388.

[11] Szocik, K., Abood, S., Impey, C., Shelhamer, M., Haqq-Misra, J., Persson, E., Oviedo, L., Capova, K. A., Braddock, M., Rappaport, M. B., & Corbally, C. (2020). Visions of a Martian future. Futures, 117, 102514. doi:10.1016/j.futures.2020.102514.

[12] European Space Agency (2018). Comparing the Atmospheres of Mars and Earth. Available online: https://www.esa.int/ESA_Multimedia/Images/2018/04/Comparing_the_atmospheres_of_Mars_and_Earth (acessed on May 2022).

[13] Hecht, M., Hoffman, J., Rapp, D., McClean, J., SooHoo, J., Schaefer, R., Aboobaker, A., Mellstrom, J., Hartvigsen, J., Meyen, F., Hinterman, E., Voecks, G., Liu, A., Nasr, M., Lewis, J., Johnson, J., Guernsey, C., Swoboda, J., Eckert, C., … Ponce, A. (2021). Mars Oxygen ISRU Experiment (MOXIE). Space Science Reviews, 217(1). doi:10.1007/s11214-020-00782-8.

[14] National Aeronautics and Space Administration (2021). Planetary Fact Sheet - Ratio to Earth Values. NASA. Available online: https://nssdc.gsfc.nasa.gov/planetary/factsheet/planet_table_ratio.html (accessed on August 2022).

[15] Clement, G., Boyle, R. D., & Gunga, H. C. (2019). Editorial: The Effects of Altered Gravity on Physiology. Frontiers in Physiology, 10. doi:10.3389/fphys.2019.01447.

[16] Iwase, S., Nishimura, N., Tanaka, K., & Mano, T. (2020). Effects of Microgravity on Human Physiology. Beyond LEO - Human Health Issues for Deep Space Exploration. IntechOpen, London, United Kingdom. doi:10.5772/intechopen.90700.

[17] Goswami, N., White, O., Blaber, A., Evans, J., van Loon, J. J. W. A., & Clement, G. (2021). Human physiology adaptation to altered gravity environments. Acta Astronautica, 189, 216–221. doi:10.1016/j.actaastro.2021.08.023.

[18] Adamopoulos, K., Koutsouris, D., Zaravinos, A., & Lambrou, G. I. (2021). Gravitational influence on human living systems and the evolution of species on earth. Molecules, 26(9), 2784. doi:10.3390/molecules26092784.

[19] Liu, L. G. (2022). Water on/in Mars and the Moon. Terrestrial, Atmospheric and Oceanic Sciences, 33(1), 3. doi:10.1007/s44195-022-00001-7.

[20] Wamelink, G. W. W., Frissel, J. Y., Krijnen, W. H. J., Verwoert, M. R., & Goedhart, P. W. (2014). Can plants grow on mars and the moon: A growth experiment on mars and moon soil simulants. PLoS ONE, 9(8), 103138. doi:10.1371/journal.pone.0103138.

[21] Wamelink, G. W. W., Frissel, J. Y., Krijnen, W. H. J., & Verwoert, M. R. (2019). Crop growth and viability of seeds on Mars and Moon soil simulants. Open Agric. 4, 509–516. doi:10.1515/opag-2019-0051.

[22] Harris, F., Dobbs, J., Atkins, D., Ippolito, J. A., & Stewart, J. E. (2021). Soil fertility interactions with Sinorhizobiumlegume symbiosis in a simulated Martian regolith; effects on nitrogen content and plant health. PLoS ONE, 16(9), 257053. doi:10.1371/journal.pone.0257053.

[23] Duri, L. G., Caporale, A. G., Rouphael, Y., Vingiani, S., Palladino, M., De Pascale, S., & Adamo, P. (2022). The Potential for Lunar and Martian Regolith Simulants to Sustain Plant Growth: A Multidisciplinary Overview. Frontiers in Astronomy and Space Sciences, 8. doi:10.3389/fspas.2021.747821.

[24] Lomax, B. A., Just, G. H., McHugh, P. J., Broadley, P. K., Hutchings, G. C., Burke, P. A., Roy, M. J., Smith, K. L., & Symes, M. D. (2022). Predicting the efficiency of oxygen-evolving electrolysis on the Moon and Mars. Nature Communications, 13(1), 583. doi:10.1038/s41467-022-28147-5.

[25] Williams, D.R. (2021). Mars Fact sheet. NASA. Available online: https://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html (accessed on August 2022).

[26] Kirkpatrick, A. W., Ball, C. G., Campbell, M., Williams, D. R., Parazynski, S. E., Mattox, K. L., & Broderick, T. J. (2009). Severe traumatic injury during long duration spaceflight: Light years beyond ATLS. Journal of Trauma Management & Outcomes, 3(1), 4. doi:10.1186/1752-2897-3-4.

[27] Dadwal, U. C., Maupin, K. A., Zamarioli, A., Tucker, A., Harris, J. S., Fischer, J. P., Rytlewski, J. D., Scofield, D. C., Wininger, A. E., Bhatti, F. U. R., Alvarez, M., Childress, P. J., Chakraborty, N., Gautam, A., Hammamieh, R., & Kacena, M. A. (2019). The effects of spaceflight and fracture healing on distant skeletal sites. Scientific Reports, 9(1), 11419. doi:10.1038/s41598-019-47695-3.

[28] Yang, J. Q., Sun, P. M., Jiang, N., Yue, Y., Li, Z. P., Guo, S., Chen, Z. Y., Li, B. Bin, Chai, S. Bin, Lu, S. Y., Yan, H. F., Zhang, T., Sun, H. W., Yang, J. W., Zhou, J. L., Yang, H. M., & Cui, Y. (2021). Impact of Microgravity on the Skin and the Process of Wound Healing. Microgravity Science and Technology, 33(5), 64. doi:10.1007/s12217-021-09907-2.

[29] Komorowski, M., Fleming, S., & Kirkpatrick, A. W. (2016). Fundamentals of Anesthesiology for Spaceflight. Journal of Cardiothoracic and Vascular Anesthesia, 30(3), 781–790. doi:10.1053/j.jvca.2016.01.007.

[30] Akiyama, T., Horie, K., Hinoi, E., Hiraiwa, M., Kato, A., Maekawa, Y., Takahashi, A., & Furukawa, S. (2020). How does spaceflight affect the acquired immune system? Npj Microgravity, 6(1), 14. doi:10.1038/s41526-020-0104-1.

[31] Spatz, J. M., Fulford, M. H., Tsai, A., Gaudilliere, D., Hedou, J., Ganio, E., Angst, M., Aghaeepour, N., & Gaudilliere, B. (2021). Human immune system adaptations to simulated microgravity revealed by single-cell mass cytometry. Scientific Reports, 11(1), 11872. doi:10.1038/s41598-021-90458-2.

[32] Patel, Z. S., Brunstetter, T. J., Tarver, W. J., Whitmire, A. M., Zwart, S. R., Smith, S. M., & Huff, J. L. (2020). Red risks for a journey to the red planet: The highest priority human health risks for a mission to Mars. Npj Microgravity, 6(1), 33. doi:10.1038/S41526-020-00124-6.

[33] Vicente, K. J. (1999). Cognitive work analysis: Toward safe, productive, and healthy computer-based work. CRC press, Boca Raton, United States. doi:10.1201/b12457.

[34] Naikar, N. (2017). Cognitive work analysis: An influential legacy extending beyond human factors and engineering. Applied Ergonomics, 59, 528–540. doi:10.1016/j.apergo.2016.06.001.

[35] Naikar, N. (2013). Work domain analysis: Concepts, guidelines, and cases. CRC press, Boca Raton, United States.

[36] Szocik, K., Wójtowicz, T., & Braddock, M. (2020). The Martian: Possible Scenarios for a Future Human Society on Mars. Space Policy, 54, 101388. doi:10.1016/j.spacepol.2020.101388.

[37] Shorrock, S. T., & Williams, C. A. (2016). Human factors and ergonomics methods in practice: three fundamental constraints. Theoretical Issues in Ergonomics Science, 17(5–6), 468–482. doi:10.1080/1463922X.2016.1155240.

[38] Stanton, N. A., Salmon, P. M., Walker, G. H., & Jenkins, D. P. (2017). Cognitive Work Analysis. CRC Press, Boca Raton, United States. doi:10.1201/9781315572536.

[39] de Vries, L., & Bligård, L. O. (2019). Visualising safety: The potential for using sociotechnical systems models in prospective safety assessment and design. Safety Science, 111, 80–93. doi:10.1016/j.ssci.2018.09.003.

[40] Salmon, P. M., Stanton, N. A., Read, G. J., Walker, G. H., Stevens, N. J., & Hancock, P. A. (2019). From systems ergonomics to global ergonomics: The world as a socio-ecological-technical system. Chartered Institute of Ergonomics and Human Factors Annual Meeting, 28 October-1 November, 2019, Seattle, United States.

[41] Binsted, K., Kobrick, R. L., Griofa, M. Ó., Bishop, S., & Lapierre, J. (2010). Human factors research as part of a Mars exploration analogue mission on Devon Island. Planetary and Space Science, 58(7–8), 994–1006. doi:10.1016/j.pss.2010.03.001.

[42] Neerincx, M. A. (2011). Situated cognitive engineering for crew support in space. Personal and Ubiquitous Computing, 15(5), 445–456. doi:10.1007/s00779-010-0319-3.

[43] Braddock, M., Szocik, K., & Campa, R. (2019). Ergonomic constraints for astronauts: challenges and opportunities today and for the future. CIEHF Meeting on Ergonomics and Human Factors 2019, 29 April-1 May, 2019, Stratford-upon-Avon; United Kingdom.

[44] Shive, J., & Dischinger Jr, H. C. (2019). Cognitive Work Analysis of Space Launch System Manual Steering. Marshall Space Flight Center Faculty Fellowship Program, 98.

[45] Cinelli, I. (2020). Short- and Long-Duration Mission Human Factors Requirements. Handbook of Life Support Systems for Spacecraft and Extraterrestrial Habitats. Springer, Cham, Switzerland. doi:10.1007/978-3-319-09575-2_34-1.

[46] Braddock, M. (2017). Ergonomic Challenges for Astronauts during Space Travel and the Need for Space Medicine. Journal of Ergonomics, 07(06), 1–10. doi:10.4172/2165-7556.1000221.

[47] Braddock, M., Hanania, N. A., Sharafkhaneh, A., Colice, G., & Carlsson, M. (2018). Potential Risks Related to Modulating Interleukin-13 and Interleukin-4 Signalling: A Systematic Review. Drug Safety, 41(5), 489–509. doi:10.1007/s40264-017-0636-9.

[48] Braddock, M. (2019). From Target Identification to Drug Development in Space: Using the Microgravity Assist. Current Drug Discovery Technologies, 17(1), 45–56. doi:10.2174/1570163816666190112150014.

[49] Braddock, M. (2019). Tissue engineering and human regenerative therapies in space: benefits for Earth and opportunities for long term extra-terrestrial exploration. Innovations in tissue engineering and Regenerative medicine, 1(3), 1-5.

[50] Szocik, K. (2019). Human Place in the Outer Space: Skeptical Remarks. An Interdisciplinary Approach, Space and Society, 233–252. doi:10.1007/978-3-030-02059-0_14.

[51] Szocik, K. (2019). Should and could humans go to Mars? Yes, but not now and not in the near future. Futures, 105, 54–66. doi:10.1016/j.futures.2018.08.004.

[52] Sharpe, R., & Braddock, M. (2022). Sustaining Resources for Homo Martis: The Potential Application of Synthetic Biology for the Settlement of Mars. Studia Humana, 11(1), 1–16. doi:10.2478/sh-2022-0001.

[53] Reid, C. R. (2017). Thematic issue: ergonomics in extreme environments and non-traditional workplaces. Theoretical Issues in Ergonomics Science, 18(5), 385–387. doi:10.1080/1463922X.2017.1290159.

[54] Alcibiade, A., Del Mastro, A., Schlacht, I. L., Monaco, F., Finazzi, F., Notea, A., Mukadam, M. M., Masali, M., & Musso, G. (2019). Stress and Human Factors from Antarctica to Mars. Advances in Human Aspects of Transportation, AHFE 2018. Advances in Intelligent Systems and Computing, 786. Springer, Cham, Switzerland. doi:10.1007/978-3-319-93885-1_17.

[55] Smith, N., & Barrett, E. (2020). Coping with life in isolation and confinement during the Covid-19 pandemic. The Psychologist, 2071-1050.

[56] Bhattacharyya, D., Pal, M., Chatterjee, T., & Varshney, R. (2021). Extreme Interaction among Human–Environment–Equipment: A Pilot Study on the Ergonomic Design of Military Snow Boots. Ergonomics in Design: The Quarterly of Human Factors Applications, 106480462110208. doi:10.1177/10648046211020851.

[57] Harrison, D., Sarkar, M., Saward, C., & Sunderland, C. (2021). Exploration of psychological resilience during a 25-day endurance challenge in an extreme environment. International Journal of Environmental Research and Public Health, 18(23), 12707. doi:10.3390/ijerph182312707.

[58] Heinicke, C., & Arnhof, M. (2021). A review of existing analog habitats and lessons for future lunar and Martian habitats. REACH, 21–22, 100038. doi:10.1016/j.reach.2021.100038.

[59] Posselt, B. N., Velho, R., O'Griofa, M., Shepanek, M., Golemis, A., & Gifford, S. E. (2021). "Safety and healthcare provision in space analogs." Acta Astronautica, 186, 164–170. doi:10.1016/j.actaastro.2021.05.033.

[60] Braddock, M. (2018). Exercise and ergonomics on the International Space Station and Orion spacecraft. Journal of ergonomics research, 1(2).

[61] Brandić Lipińska, M., van Ellen, L., & Damann, V. (2021). Senses as Drivers for Space Habitats Design in Microgravity. 50th International Conference on Environmental Systems, 12-15 July, 2021, Corinthia Hotel Lisbon, Portugal.

[62] Jiang, A., Schlacht, I. L., Yao, X., Foing, B., Fang, Z., Westland, S., Hemingray, C., & Yao, W. (2022). Space Habitat Astronautics: Multicolour Lighting Psychology in a 7-Day Simulated Habitat. Space: Science & Technology, 2022, 1–11. doi:10.34133/2022/9782706.

[63] Fukumura, Y. E., Gray, J. M., Lucas, G. M., Becerik-Gerber, B., & Roll, S. C. (2021). Worker perspectives on incorporating artificial intelligence into office workspaces: Implications for the future of office work. International Journal of Environmental Research and Public Health, 18(4), 1–15. doi:10.3390/ijerph18041690.

[64] Blue, R. S., Chancellor, J. C., Antonsen, E. L., Bayuse, T. M., Daniels, V. R., & Wotring, V. E. (2019). Limitations in predicting radiation-induced pharmaceutical instability during long-duration spaceflight. Npj Microgravity, 5(1), 15. doi:10.1038/s41526-019-0076-1.

[65] Ryder, P., Braddock, M. (2022). Harnessing the Space Environment for the Discovery and Development of New Medicines. Handbook of Space Pharmaceuticals. Springer, Cham, Switzerland. doi:10.1007/978-3-030-05526-4_32.

[66] Williams, M., & Braddock, M. (2019). AI Case Studies: Potential for Human Health, Space Exploration and Colonisation and a Proposed Superimposition of the Kubler-Ross Change Curve on the Hype Cycle. Studia Humana, 8(1), 3–18. doi:10.2478/sh-2019-0001.

[67] Russo, A., & Lax, G. (2022). Using Artificial Intelligence for Space Challenges: A Survey. Applied Sciences (Switzerland), 12(10), 5106. doi:10.3390/app12105106.

[68] Bohr, A., & Memarzadeh, K. (2020). The rise of artificial intelligence in healthcare applications. Artificial Intelligence in Healthcare, 25–60, Academic Press, Cambridge, United States. doi:10.1016/b978-0-12-818438-7.00002-2.

[69] Maver, T., Hribernik, S., Mohan, T., Smrke, D. M., Maver, U., & Stana-Kleinschek, K. (2015). Functional wound dressing materials with highly tunable drug release properties. RSC Advances, 5(95), 77873–77884. doi:10.1039/c5ra11972c.

[70] Ballerini, A., Chua, C. Y. X., Rhudy, J., Susnjar, A., Di Trani, N., Jain, P. R., Laue, G., Lubicka, D., Shirazi-Fard, Y., Ferrari, M., Stodieck, L. S., Cadena, S. M., & Grattoni, A. (2020). Counteracting Muscle Atrophy on Earth and in Space via Nanofluidics Delivery of Formoterol. Advanced Therapeutics, 3(7), 2000014. doi:10.1002/adtp.202000014.

[71] Kashaninejad, N., Moradi, E., & Moghadas, H. (2022). Micro/nanofluidic devices for drug delivery. Progress in Molecular Biology and Translational Science, 187(1), 9–39. doi:10.1016/bs.pmbts.2021.07.018.

[72] Cubo-Mateo, N., & Gelinsky, M. (2021). Wound and Skin Healing in Space: The 3D Bioprinting Perspective. Frontiers in Bioengineering and Biotechnology, 9, 720217. doi:10.3389/fbioe.2021.720217.

[73] European Space Agency (2022). BioPrint FirstAid. ESA. Available online: https://www.esa.int/ESA_Multimedia/Images/2022/02/Bioprint_First_Aid (accessed on August 2022).

[74] Ferris, D. P. (2009). The exoskeletons are here. Journal of NeuroEngineering and Rehabilitation, 6(1). doi:10.1186/1743-0003-6-17.

[75] Cortés, C., Unzueta, L., De Los Reyes-Guzmán, A., Ruiz, O. E., & Flórez, J. (2016). Optical enhancement of exoskeleton-based estimation of Glenohumeral angles. Applied Bionics and Biomechanics, 2016. doi:10.1155/2016/5058171.

[76] Awad, L. N., Bae, J., O'Donnell, K., De Rossi, S. M. M., Hendron, K., Sloot, L. H., Kudzia, P., Allen, S., Holt, K. G., Ellis, T. D., & Walsh, C. J. (2017). A soft robotic exosuit improves walking in patients after stroke. Science Translational Medicine, 9(400), 9084. doi:10.1126/scitranslmed.aai9084.

[77] Hill, D., Holloway, C. S., Morgado Ramirez, D. Z., Smitham, P., & Pappas, Y. (2017). What are user perspectives of exoskeleton technology? A literature review. International Journal of Technology Assessment in Health Care, 33(2), 160–167. doi:10.1017/S0266462317000460.

[78] Zhang, J., Fiers, P., Witte, K. A., Jackson, R. W., Poggensee, K. L., Atkeson, C. G., & Collins, S. H. (2017). Human-in-the-loop optimization of exoskeleton assistance during walking. Science, 356(6344), 1280–1283. doi:10.1126/science.aal5054.

[79] Agrawal, A., Dube, A. N., Kansara, D., Shah, S., & Sheth, S. (2016). Exoskeleton: The Friend of Mankind in context of Rehabilitation and Enhancement. Indian Journal of Science and Technology, 9(S1), 1–8. doi:10.17485/ijst/2016/v9is1/100889.

[80] Lee, J., Kwon, K., & Yeo, W. H. (2022). Recent advances in wearable exoskeletons for human strength augmentation. Flexible and Printed Electronics, 7(2). doi:10.1088/2058-8585/ac6a96.

[81] Low, K. H., Liu, X., Goh, C. H., & Yu, H. (2006). Locomotive control of a wearable lower exoskeleton for walking enhancement. JVC/Journal of Vibration and Control, 12(12), 1311–1336. doi:10.1177/1077546306070616.

[82] Lajeunesse, V., Vincent, C., Routhier, F., Careau, E., & Michaud, F. (2016). Exoskeletons' design and usefulness evidence according to a systematic review of lower limb exoskeletons used for functional mobility by people with spinal cord injury. Disability and Rehabilitation: Assistive Technology, 11(7), 535–547. doi:10.3109/17483107.2015.1080766.

[83] Brown, M., Tsagarakis, N., & Caldwell, D. G. (2003). Exoskeletons for human force augmentation. Industrial Robot, 30(6), 592–602. doi:10.1108/01439910310506864.

[84] Rea, R., Beck, C., Rovekamp, R., Diftler, M., & Neuhaus, P. (2013). X1: A robotic exoskeleton for in-space countermeasures and dynamometry. In AIAA SPACE 2013 Conference and Exposition. American Institute of Aeronautics and Astronautics. doi:10.2514/6.2013-5510.

[85] Palacios, P., Cornejo, J., Rivera, M. V., Napan, J. L., Castillo, W., Ticllacuri, V., Reina, A. D., Chaves-Jimenez, A., Jamanca-Lino, G., & Chavez, J. C. (2021). Biomechatronic Embedded System Design of Sensorized Glove with Soft Robotic Hand Exoskeleton Used for Rover Rescue Missions on Mars. 2021 IEEE International IoT, Electronics and Mechatronics Conference (IEMTRONICS). doi:10.1109/iemtronics52119.2021.9422634.

[86] Arone, A., Ivaldi, T., Loganovsky, K., Palermo, S., Parra, E., Flamini, W., & Marazziti, D. (2021). The Burden of Space Exploration on the Mental Health of Astronauts: a Narrative Review. Clinical Neuropsychiatry, 18(5), 237–246. doi:10.36131/cnfioritieditore20210502.

[87] Friedman, E., & Bui, B. (2017). A psychiatric formulary for long-duration spaceflight. Aerospace Medicine and Human Performance, 88(11), 1024–1033. doi:10.3357/AMHP.4901.2017.

[88] Stokel-Walker, C. (2020). Why telemedicine is here to stay. BMJ, m3603. doi:10.1136/bmj.m3603.

[89] Garcia, M. (2022). Innovative 3D telemedicine to help keep astronauts Healthy. NASA: National Aeronautics and Space Administration. Available online: https://www.nasa.gov/feature/innovative-3d-telemedicine-to-help-keep-astronauts-healthy (accessed on August 2022).

[90] Pantalone, D., Faini, G. S., Cialdai, F., Sereni, E., Bacci, S., Bani, D., Bernini, M., Pratesi, C., Stefàno, P. L., Orzalesi, L., Balsamo, M., Zolesi, V., & Monici, M. (2021). Robot-assisted surgery in space: pros and cons. A review from the surgeon's point of view. Npj Microgravity, 7(1), 56. doi:10.1038/s41526-021-00183-3.

[91] Feizi, N., Tavakoli, M., Patel, R. V., & Atashzar, S. F. (2021). Robotics and AI for Teleoperation, Tele-Assessment, and Tele-Training for Surgery in the Era of COVID-19: Existing Challenges, and Future Vision. Frontiers in Robotics and AI, 8. doi:10.3389/frobt.2021.610677.

[92] Ghaffari, R., Yang, D. S., Kim, J., Mansour, A., Wright, J. A., Model, J. B., Wright, D. E., Rogers, J. A., & Ray, T. R. (2021). State of Sweat: Emerging Wearable Systems for Real-Time, Noninvasive Sweat Sensing and Analytics. ACS Sensors, 6(8), 2787–2801. doi:10.1021/acssensors.1c01133.

[93] Lou, Z., Wang, L., Jiang, K., Wei, Z., & Shen, G. (2020). Reviews of wearable healthcare systems: Materials, devices and system integration. Materials Science and Engineering R: Reports, 140, 100523. doi:10.1016/j.mser.2019.100523.

[94] Muhammad Sayem, A. S., Hon Teay, S., Shahariar, H., Luise Fink, P., & Albarbar, A. (2020). Review on Smart Electro-Clothing Systems (SeCSs). Sensors, 20(3), 587. doi:10.3390/s20030587.

[95] Lei, S., Xiangfang, R., Jianbin, W., Han, C., & Jianyong, O. (2022). Study on body area network of smart clothing for physiological monitoring. International Journal of Distributed Sensor Networks, 18(2), 1-14. doi:10.1177/15501477211061251.

[96] Al Sayed, C., Vinches, L., & Hallé, S. (2017). Validation of a Wearable Biometric System's Ability to Monitor Heart Rate in Two Different Climate Conditions under Variable Physical Activities. E-Health Telecommunication Systems and Networks, 06(02), 19–30. doi:10.4236/etsn.2017.62002.

[97] Buregeya, J. M., Apparicio, P., & Gelb, J. (2020). Short-term impact of traffic-related particulate matter and noise exposure on cardiac function. International Journal of Environmental Research and Public Health, 17(4), 1220. doi:10.3390/ijerph17041220.

[98] Baig, M. M., Gholamhosseini, H., Gutierrez, J., Ullah, E., & Lindén, M. (2021). Early Detection of Prediabetes and T2DM Using Wearable Sensors and Internet-of-Things-Based Monitoring Applications. Applied Clinical Informatics, 12(1), 1–9. doi:10.1055/s-0040-1719043.

[99] Kumar, A., Levin, E., Cowings, P., & Toscano, W. B. (2015). Evaluation of the accuracy of Astroskin as a behavioral health self-monitoring system for spaceflight. Annual Summer STEM Internship Symposium, Salinas, United States.

[100] Bains, N. (2020). Canadian Space Agency 2018–19. Departmental Results Report. Available online: https://www.asc-csa.gc.ca/eng/publications/drr-2018-2019.asp (accessed on August 2022).

[101] Taj-Eldin, M., Ryan, C., O'Flynn, B., & Galvin, P. (2018). A Review of Wearable Solutions for Physiological and Emotional Monitoring for Use by People with Autism Spectrum Disorder and Their Caregivers. Sensors, 18(12), 4271. doi:10.3390/s18124271.

[102] Nsanze, F. (2005). ICT implants in the human body-A review. The European Group on Ethics in Science and New Technologies to the European Commission 2005, Luxembourg.

[103] Shafeie, S., Chaudhry, B. M., & Mohamed, M. (2022). Modeling Subcutaneous Microchip Implant Acceptance in the General Population: A Cross-Sectional Survey about Concerns and Expectations. Informatics, 9(1), 24. doi:10.3390/informatics9010024.

[104] Ravisetti, M. (2022). Ax-1 Astronauts Headed to ISS Will Soon Wear Microgravity Brain-Tracking Helmets. CNET Your guide to a better future. Available online: https://www.cnet.com/science/space/ax-1-astronauts-headed-to-iss-will-soon-wear-microgravity-brain-tracking-helmets/ (accessed on August 2022).

[105] Braided Communications. (2022). The future of deep space communication. Available online: https://braided.space/space-braiding/ (accessed on August 2022).

[106] Fusar-Poli, P., Salazar de Pablo, G., De Micheli, A., Nieman, D. H., Correll, C. U., Kessing, L. V., Pfennig, A., Bechdolf, A., Borgwardt, S., Arango, C., & van Amelsvoort, T. (2020). What is good mental health? A scoping review. European Neuropsychopharmacology, 31, 33–46. doi:10.1016/j.euroneuro.2019.12.105.

[107] Solmi, M., Dragioti, E., Arango, C., Radua, J.,…, Shin, J. Il, & Fusar-Poli, P. (2021). Risk and protective factors for mental disorders with onset in childhood/adolescence: An umbrella review of published meta-analyses of observational longitudinal studies. Neuroscience and Biobehavioral Reviews, 120, 565–573. doi:10.1016/j.neubiorev.2020.09.002.

[108] Shucksmith, J., Spratt, J., Philip, K., & McNaughton, R. (2009). A critical review of the literature on children and young people's views of the factors that influence their mental health. NHS Health Scotland, Edinburg, Scotland.

[109] Fritz, J., de Graaff, A. M., Caisley, H., van Harmelen, A. L., & Wilkinson, P. O. (2018). A Systematic Review of Amenable Resilience Factors That Moderate and/or Mediate the Relationship Between Childhood Adversity and Mental Health in Young People. Frontiers in Psychiatry, 9, 230. doi:10.3389/fpsyt.2018.00230.

[110] Alegría, M., NeMoyer, A., Falgàs Bagué, I., Wang, Y., & Alvarez, K. (2018). Social Determinants of Mental Health: Where We Are and Where We Need to Go. Current Psychiatry Reports, 20(11), 95. doi:10.1007/s11920-018-0969-9.

[111] Bernardi, L. (2021). Mental Health and Political Representation: A Roadmap. Frontiers in Political Science, 2, 2020 587588. doi:10.3389/fpos.2020.587588.

[112] Cromwell, R. L., Huff, J. L., Simonsen, L. C., & Patel, Z. S. (2021). Earth-Based Research Analogs to Investigate Space-Based Health Risks. New Space, 9(4), 204–216. doi:10.1089/space.2020.0048.

[113] Farand, A. (2001). The code of conduct for international space station crews. ESA bulletin, 105, 64-68.

[114] Kanas, N., Salnitskiy, V., Weiss, D. S., Grund, E. M., Gushin, V., Kozerenko, O., Sled, A., Bostrom, A., & Marmar, C. R. (2001). Crewmember and ground personnel interactions over time during Shuttle/Mir space missions. Aviation Space and Environmental Medicine, 72(5), 453–461.

[115] Kanas, N. A., Salnitskiy, V. P., Boyd, J. E., Gushin, V. I., Weiss, D. S., Saylor, S. A., Kozerenko, O. P., & Marmar, C. R. (2007). Crewmember and mission control personnel interactions during international space station missions. Aviation Space and Environmental Medicine, 78(6), 601–607.

[116] Boyd, J. E., Kanas, N. A., Salnitskiy, V. P., Gushin, V. I., Saylor, S. A., Weiss, D. S., & Marmar, C. R. (2009). Cultural differences in crewmembers and mission control personnel during two space station programs. Aviation Space and Environmental Medicine, 80(6), 532–540. doi:10.3357/ASEM.2430.2009.

[117] Ponton, K., Parera, D., & Irons, J. (2021). The submarine habitability assessment questionnaire: A survey of RAN submariners. Journal of Marine Science and Engineering, 9(1), 1–31. doi:10.3390/jmse9010054.

[118] Aufauvre-Poupon, C., Martin-Krumm, C., Duffaud, A., Lafontaine, A., Gibert, L., Roynard, F., Rouquet, C., Bouillon-Minois, J.-B., Dutheil, F., Canini, F., Pontis, J., Leclerq, F., Vannier, A., & Trousselard, M. (2021). Subsurface Confinement: Evidence from Submariners of the Benefits of Mindfulness. Mindfulness, 12(9), 2218–2228. doi:10.1007/s12671-021-01677-7.

[119] Mohanty, S., Jørgensen, J., & Nyström, M. (2006). Psychological Factors Associated with Habitat Design for Planetary Mission Simulators. Space 2006. doi:10.2514/6.2006-7345.

[120] Landon, L. B., Slack, K. J., & Barrett, J. D. (2018). Teamwork and collaboration in long-duration space missions: Going to extremes. American Psychologist, 73(4), 563–575. doi:10.1037/amp0000260.

[121] Flinders, L., Grainger, J., Rich, B.J, Clark, H., Braddock, M. (2022). Design architecture for 3D printing a Lunar habitat. ROOM Space Journal of Asgardia, 1(31), 90-97.

[122] Tootell, R. B. H., Zapetis, S. L., Babadi, B., Nasiriavanaki, Z., Hughes, D. E., Mueser, K., Otto, M., Pace-Schott, E., & Holt, D. J. (2021). Psychological and physiological evidence for an initial 'Rough Sketch' calculation of personal space. Scientific Reports, 11(1), 20960. doi:10.1038/s41598-021-99578-1.

[123] Hambuchen, K., Marquez, J., & Fong, T. (2021). A Review of NASA Human-Robot Interaction in Space. Current Robotics Reports, 2(3), 265–272. doi:10.1007/s43154-021-00062-5.

[124] Chen, H., & Breazeal, C. (2021). Toward Designing Social Human-Robot Interactions for Deep Space Exploration. arXiv preprint arXiv:2105.08631. doi:10.48550/arXiv.2105.08631.

[125] Jiang, Z., Cao, X., Huang, X., Li, H., & Ceccarelli, M. (2022). Progress and Development Trend of Space Intelligent Robot Technology. Space: Science & Technology, 2022, 1–11. doi:10.34133/2022/9832053.

[126] Orzech, G. (2022). Intelligent systems division. National Aeronautics and Space Administration, NASA. Available online: https://www.nasa.gov/intelligent-systems-division (accessed on May 2022).

[127] Manca, D., Nazir, S., Komulainen, T., & Øvergård, K. I. (2016). How extreme environments can impact the training of industrial operators. Chemical Engineering Transactions, 53, 193–198. doi:10.3303/CET1653033.

[128] Xi, Z., Li, C., Zhou, L., Yang, H., & Burghardt, R. (2022). Built environment influences on urban climate resilience: Evidence from extreme heat events in Macau. Science of The Total Environment, 160270. doi:10.1016/j.scitotenv.2022.160270.

[129] Waring, S. (2019). Using live disaster exercises to study large multiteam systems in extreme environments: Methodological and measurement fit. Organizational Psychology Review, 9(4), 219–244. doi:10.1177/2041386619892262.

[130] Prysyazhnyuk, A., McGregor AM, C. (2022). Space as an Extreme Environment—Galactic Adventures: Exploring the Limits of Human Mind and Body, One Planet at a Time. Engineering and Medicine in Extreme Environments, Springer, Cham, Switzerland. doi:10.1007/978-3-030-96921-9_7.

[131] Markopoulos, E., & Vanharanta, H. (2018). Project teaming in a democratic company context. Theoretical Issues in Ergonomics Science, 19(6), 673–691. doi:10.1080/1463922X.2018.1439543.

[132] Vanharanta, H., & Markopoulos, E. (2019). The applied philosophy concept for management and leadership objects through the Company Democracy Model. Theoretical Issues in Ergonomics Science, 20(2), 178–195. doi:10.1080/1463922X.2018.1510060.

[133] Luca, P., Valter, B., Lorenzo, R., Mauro, P., Christian, B., Manuela, M., Carlo, V., Maurizio, L., Michela, B., Filippo, R., Massimo, R., Eleonora, M., & Michele, C. (2012). Virtual Simulation of Hostile Environments for Space Industry: From Space Missions to Territory Monitoring. Virtual Reality - Human Computer Interaction, Intechopen, London, United Kingdom. doi:10.5772/51121.

[134] Stepanova, E. R., Quesnel, D., & Riecke, B. E. (2019). Space—A Virtual Frontier: How to Design and Evaluate a Virtual Reality Experience of the Overview Effect. Frontiers in Digital Humanities, 6, 2019 00007. doi:10.3389/fdigh.2019.00007.

[135] Wenz, J. (2018). Making outer space smell like fresh cut grass. DISCOVER. Available online https://www.discovermagazine.com/the-sciences/making-outer-space-smell-like-fresh-cut-grass (accessed on August 2022).

[136] Di Bucchianico, G. (2015). Design for human diversity in the maritime design domain. Theoretical Issues in Ergonomics Science, 16(4), 388–398. doi:10.1080/1463922X.2015.1014070.

[137] Di Nicolantonio, M., Di Bucchianico, G., Camplone, S., & Vallicelli, A. (2015). The visual pleasantness in yacht design: natural lighting, views and interior colours. Theoretical Issues in Ergonomics Science, 16(4), 399–411. doi:10.1080/1463922X.2014.1003992.

[138] Tanaka, K., Nishimura, N., & Kawai, Y. (2017). Adaptation to microgravity, deconditioning, and countermeasures. Journal of Physiological Sciences, 67(2), 271–281. doi:10.1007/s12576-016-0514-8.

[139] Cahill, B., & Braddock, M. (2022). Back to the Future: The Rise of Human Enhancement and Potential Applications for Space Missions. Studia Humana, 11(1), 17–21. doi:10.2478/sh-2022-0002.

[140] Zubrin, R. (2018). The Economic Viability of Mars Colonization. Deep Space Commodities, Palgrave Macmillan, Cham, Switzerland. doi:10.1007/978-3-319-90303-3_12.

[141] Cohn, J. V., & Mutai, J. C. (2019). Introduction to the thematic issue on valuing research: theory, research, policy and practice of return on investment. Theoretical Issues in Ergonomics Science, 20(1), 1–3. doi:10.1080/1463922X.2018.1526350.

[142] Dastagiri, M.B., (2017). The Theory and Economics of MARS and MOON Colonization: Steps and Policy Advocacy. European Scientific Journal, ESJ, 13(28), 239. doi:10.19044/esj.2017.v13n28p239.

[143] National Aeronautics and Space Administration (2019). How Investing in the Moon Prepares NASA for First Human Mission to Mars, NASA. Available online: https://www.nasa.gov/sites/default/files/atoms/files/moon-investments-prepare-us-for-mars.pdf (accessed on August 2022).

[144] NASA. (2019). NASA Economic Impact Report—FY19. National Aeronautics and Space Administration, NASA. Available online: https://www.nasa.gov/sites/default/files/atoms/files/2020_nasa_eir_brochure_for_fy19.pdf (accessed on June 2022).

[145] Gasda, P. J., Haldeman, E. B., Wiens, R. C., Rapin, W., Bristow, T. F., … , Bodine, M. R., & McInroy, R. (2017). In situ detection of boron by ChemCam on Mars. Geophysical Research Letters, 44(17), 8739–8748. doi:10.1002/2017GL074480.

[146] Brasser, R., & Mojzsis, S. J. (2017). A colossal impact enriched Mars' mantle with noble metals. Geophysical Research Letters, 44(12), 5978–5985. doi:10.1002/2017GL074002.

[147] Cockell, C. S., Santomartino, R., Finster, K., Waajen, A. C., … Demets, R. (2020). Space station biomining experiment demonstrates rare earth element extraction in microgravity and Mars gravity. Nature Communications, 11(1). doi:10.1038/s41467-020-19276-w.