Review Article

Human Factor Studies on a Mars Analogue During Crew 100B International Lunar Exploration Working Group EuroMoonMars Crew: Proposed New Approaches for Future Human Space and Interplanetary Missions

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Abstract

Knowing the risks, costs, and complexities associated with human missions to Mars, analogue research can be a great (low-risk) tool for exploring the challenges associated with the preparation for living, operating, and undertaking research in interplanetary missions. Short-duration analogue studies, such as those being accomplished at the Mars Desert Research Station (MDRS), offer the chance to study mission operations and human factors in a simulated environment, and therefore contribute to exploration of the Moon and Mars in planned future missions. This article is based upon previously published articles, abstracts, and presentations by a series of independent authors, human factor studies performed on mars analogue station by Crew 100B. The MDRS Crew 100B performed studies over 15 days providing a unique insight into human factor issues in simulated short-duration Mars mission. In this study, 15 human factors were evaluated and analyzed by subjective and objective means, and from the summary of results it was concluded that optimum health of an individual and the crew as a whole is a necessity in order to encourage and maintain high performance and the satisfaction of project goals.

Keywords: Countermeasures, Health, Human factors, Mars analogue

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Introduction

From the beginning of the space age, physicians, engineers, and psychologists expressed concerns about an individual's abilities to meet the physical, psychological, and interpersonal demands of working in space. It is widely believed that human factor research is a vital factor in space exploration as it provides an insight into a crew performance, psychology, and interpersonal relationships. Analogous environment offers a low-risk atmosphere permitting the development and testing of countermeasures that can prevent potential hazardous situations and further help to improve mission efficiency and safety of human space missions.[1] Many of the basic human factor issues associated with a voyage to Mars have received attention since Project Mercury and Skylab. Furthermore, it would be received for International Space Station (ISS) as well. Over the years, many prestigious commissions and panels have also made stringent calls for increased research on physiology and psychological factors contributing to performance and what we now call behavioral and physiological health. Limited funds are only one of the factors that have delayed behavioral and physiology research.[2,3] Of course, one of the best analogues for planetary exploration is the ISS, and many valuable human factor studies have

Access this article online	
Quick Response Code:	Website: www.najms.org
	DOI: 10.4103/1947-2714.103313

been conducted there. ISS and the Los Alamos meson beam on cells experiments act as ideal analogues for the study of radiation factors.[4-6] However, ISS studies are expensive and infrequent, small subject based, and can involve privacy issues relative to Earth-based studies. In addition, while the ISS is an ideal analogue, there are no field science experiments focusing specially on geological sampling or equivalent experiments, for instance. NASA's Bioastronautics Roadmap and Human Research Integrated Research Plan has identified a number of barriers to safe human spaceflight and some strategies for overcoming them.[7,8] The long-term environmental effects on health, and many other causative issues such as isolation, international environments, and workload can be successfully studied during analogue missions, which is really difficult studying during ISS mission. Moreover, analogue research is relatively safe and inexpensive and permits an easy approach to study factors including lengthy periods of isolation, communications latency, crowding, bulky life support equipment, small heterogeneous crews, packed schedules, etc., which can be experienced in parallel by the participants. The disadvantage of such multifaceted scenarios is that it is difficult to conduct a traditional human factors study with a control group and minimize other factors, which are in agreement with statistically significant outcomes. However, we hypothesize that human factor analogue studies can provide vital input into the risks of human spaceflight and the value of potential countermeasures; so accordingly, we planned various human factor studies in the Mars Desert Research Station (MDRS). The MDRS is an analogue to a Mars surface habitat, constructed for mission simulations according to Mars Reference Mission guidelines,[9] located in a southwestern desert region of the United States relevant to Mars analogue geological conditions, where human factors and biological research may be carried out. MDRS includes an upper deck with six private staterooms having personal storage and desks, a galley area, workstations, and a meeting/eating area, plus a lower deck with a laboratory, toilet, shower, and extravehicular activity (EVA) preparation rooms. For this reason, it may be of strategic importance to integrate human factor projects into the overall mission science program to enable full participation by the crew. This approach avoids the perception of an additional task being added to the fixed mission timelines. Overall, we studied various human factors in a broad manner, including psychology, physiology, performance, and human–computer interaction. Two weeks participation of 100B International Lunar Exploration Working (ILEWG) in a simulated Mars mission in MDRS, Utah, provides accessible practical mission restrictions and operational scenarios, similar to those on a real Mars. A total of 15 human factor projects were completed during the mission, including a meta-study examining the effects of human factor research on crew schedules.

JBR Human Factor Study Overview

The 15 human factor studies (JBR studies) are described in this section. Crew structures and duties are described in Table 1.[11-14] The results of these studies have previously been submitted to journals, which are summarized.[11-13] Our goal in this paper is to provide examples of the kinds of human factor studies that can only be carried out as part of short-term designed analogue missions with integrated operations, and illustrate the value of such studies.

Human interactions in mars analogue environment

Russian and American experience has proven the significance of psychosocial or interpersonal stressors connected to long-duration spaceflights.[10] These factors will become more relevant in the future, particularly in view of the fact that the ISS will in due course be staffed by astronauts from different nations, with different nationalities, religions, social values, and political beliefs. Research in an analogue environment (MDRS) was carried out to investigate these potential issues by subjective (personality, coping, group functioning, and interpersonal climate) and objective standardized (salivary stress marker) methods. Our crew had their saliva samples taken for measurement of stress biomarkers. The method that was used for measuring stress is our standard method, as described in our previous study.[15] Salivary biomarkers such as cortisol and amylase were also measured as described in our previous study.[15] Salivary cortisol (Salimetrics Inc., State College, PA, USA) and alpha-amylase (alpha-amylase assay kit, Salimetrics Inc.) were measured. Data were analyzed using SPSS, version 11 (SPSS, Chicago, IL, USA). Salivary cortisol, alpha-amylase levels, and current stress scores were shown to be significantly higher after the end of mission compared to before the commencement of the mission [Table 2] ($P < 0.05$). We can conclude from this study and the results obtained that strong behavioral health of the individual and the crew as a group is a requisite for the encouragement of high performance and the satisfaction of mastering achievements that bolster behavioral health.[16,17]

Assessing group interactions in a mars simulation

Growing international concerns have been raised regarding psychosocial performance and issues of group and inter-group interactions for space crews, particularly toward human missions to Mars.[16-18] Marsonauts might have valuable attributes including mental toughness, ingenuity, and organizational skills, but other important factors such as danger, frustration, relentless scrutiny, homesickness, and many other external stressors can lead to deteriorating performance, personal unhappiness, and interpersonal conflicts.[19] This project is based on

Table 1: Brief structure of 100B crew international lunar exploration working group EuroMoonMars crew[10]

Variables	Simulating habitat on surface of Mars
Number of crew members	Six
Crew gender and age	3:3; M:F (19–26 years)
Crew structure	Commander (cognitive, biomedical scientist, and emergency physician); health and safety officer; crew biologist (oral and medical physician); rover engineer (engineer); chief scientist (astrophysics); executive officer (engineer); Hab engineer (mechanical engineer)
Duration	Two weeks
Types of accommodations	Staterooms with work areas
International participation	2 Indians, 3 French, and 1 American
Maintenance	Power, electric, human waste, water
Tasking, scheduling, and control	All planning by crew members under the supervision of commander; mission supports logistics assistance; individual tasks, chores, and sleeping time open to individuals
Communications	Daily commander check-in report, commander report, chef report, science report, engineering report, journalist report. Also, posted with photos on public website
Mission timeline	General planning in 2 weeks preceding; crew did not meet prior; crew member replaced in final 2 weeks
Crew safety	Focus on fire and medical emergencies; flight surgeon on call
Habitat construction	Prefab panels assembled on site, ready for crew occupation

the concept that Marsonauts are both individuals and members of a team of individual experts, and they function most cohesively and cooperatively in a group if they understand and adhere to the principles of working as part of a team. All assessments were made on both objective and subjective grounds. The identity and group functioning scale was used for stages of psychometric analysis. Cronbach for each subscale was analyzed by using a minimum criterion of 0.80. All criteria were decreased after mission as compared to before mission [Table 3]. The preliminary results of this study are expected to provide valuable information for the selection of crew members for future missions to Mars.

Table 2: Scores of CST and salivary biomarkers levels from six healthy subjects during 2 weeks simulated Mars analogue mission

Parameters	Before mission	After 1 week	After 2 weeks (end of mission)
CST	2.2 (0.13)	2.8 (0.24)	3.2 (0.27)
Salivary alpha-amylase (U/ml)	58.7 (23.1)	62.1 (22.2)	74.7 (22.6)
Salivary cortisol (µg/dl)	0.2 (0.1)	0.3 (0.2)	0.4 (0.2)

Human factors in a mars analogue

Since the beginning of the space age, physicians, engineers, psychologists, and other scientific staff have been anxious to work on the capability of space travelers to meet the physical, psychological, and interpersonal demands of working in space.[18-25] Physiological parameters have recently been examined in relation to the emotional or behavioral state of the subject. Establishing this psychological and physiological connection is important to understand fully the adaptation of humans to the stresses of extreme environments like extended space missions. This particular study investigated the simultaneous collection of physiological, psychological, and behavioral data from six crew members in order to model how the exact relationship between physiological and psychological adaptation to isolated and extreme environments could be evaluated. The data collected reflects changes in salivary cortisol level and salivary amylase activity as well as psychological function,[10,12] as supported by previous studies carried out during the Skylab I–III missions.[26] The investigation of human exertion in space exploration analogue environments permits the advancement and testing of countermeasures and reactions to potential harmful situations, and can thus assist in development of new measures to improve mission efficiency and safety. Short-duration analogue studies, such as those being accomplished at the MDRS, Utah, USA, offer an opportunity to study mission operations and human factors in a simulated environment and contribute to planned missions to explore the Moon and Mars (MDRS Crew 100B ILEWG EuroMoonMars). The MDRS Crew 100B ILEWG EuroMoonMars performed 15 days of studies and experiments in intravehicular activity (IVA) and EVA, each of which provided a unique insight into human factors issues for space exploration.[21,22] In this study, nine human factors were taken into account and analyzed by subjective and objective means during 100B ILEWG EuroMoonMars, and all the results were summarized. From the results of this study, we concluded that strong behavioral health of the individual and the crew as a whole is mandatory in order to foster high performance and the feeling of satisfaction for mastering the tasks at hand, as well as the achievement of bolstering behavioral health. On the other hand, poor behavioral health or dwindling performance could initiate a vicious downward spiral, which should be avoided at all costs. Also, we observed a strong positive correlation between behavioral health and performance.

The dentist on mars (Aeronautic Dentistry)

Current projected missions to Mars will require 18–24 months of exposure to microgravity conditions, which could have potentially deleterious effects on human physiology, including oral health.[13] Very few studies have been published on the effect of microgravity on the oral cavity, although it has been reported that microgravity increases the prevalence of periodontitis, dental caries, bone loss, fracture in the jaw bone, pain, numbness in teeth, oral cavity tissue, salivary duct stones, and oral cancer.[11-13,20,21,27,28] During our mission, dental examination of all crew members was performed. During this process, we found that plaque levels and bleeding from gums were increased during the mission. It is postulated that this might be due to a combination of stress and improper oral hygiene. It was also found that the temporomandibular joint (TMJ) opening was reduced for most crew members as a result of increased stress.

Human dimension and factors

The optimization of various human aspects is imperative for the successful operation of any manned space mission.[23-25] Simulation of the habitability of a given environment was evaluated by the MDRS Crew 100B ILEWG EuroMoonMars crew using a standardized (JBR) questionnaire, with information received from all crew members on the design of the physical living environment, whether the environment fulfilled the primary necessities for human beings and also has the capability to deliver a certain quality of life within a specific space analogous environment as on Mars.[29-32] This study took into account the simulation of requirements for the usability of space (living, working, and movement), the support requirements (medical, food, and life support), as well as characterizing fundamental quantities and qualities and definitions of the requirements. Communal eating seems to be a noteworthy occurrence for the crew as they typically established common mealtimes in order to collectively socialize as a means of reducing collective tensions. We suggest that this routine should be considered as part of future missions to bring positive results during future exploration. Listening to music and watching movies together was also a tool to build motivated teams. According to our survey, the division of living and working areas also provided more comfortable results. The crew quarters were accepted by the crew members with minor modifications. One of our crew members had problems sleeping because of the cold environment, which may have been due to the lack of an adequate sleeping bag, but also could be due to certain air passage connections.

Table 3: Identity and group functioning Cronbach for subscales

Subscales	Before mission	After mission
Identity	0.89	0.78
Goals	0.86	0.76
Culture	0.82	0.76
Stress	0.82	0.56
Motivation	0.84	0.64
Recognition	0.84	0.61
Organization behavior	0.85	0.80

Biomedical experimental results

The resilience of humans in exploring hostile environments has been demonstrated during missions to and around the Moon.[17-20] Space missions such as those to Mars require that humans adapt to a series of extrinsic factors and also adapt to systemic and complex environments which are beyond normal human capacity and tolerance.[17-19] Short-duration analogue studies, such as those being accomplished at MDRS, Utah, USA, offer opportunities to study mission operations and human factors in a simulated environment and further contribute to planned missions to explore the Moon and Mars (MDRS Crew 100B ILEWG EuroMoonMars). The MDRS Crew 100B ILEWG EuroMoonMars performed 15 days of studies and experiments in IVA and EVA, which again provided a unique insight into the physiological issues for space exploration. These studies included EVA activities, with the crew members equipped with space suit including taking surface and subsurface soil and rock samples, handling medical emergencies such as bone fractures, burning, etc., power system failure, and combination of rover–human EVA for taking photographs of soil sampling sites. So, a number of simulated surface activities were carried out. In certain studies, salivary biomarkers were measured (bone loss and formation stress, immunological, and inflammatory markers). Saliva samples were collected using the devices as described in our previous studies.[21-24] Stress and sleep questionnaires were obtained, cognitive activity was checked (CogState Research software), and vital parameters were monitored (by Zephyr BioHarness) and heart rate variability was measured (using NERV Express 4.2 software).[25-27] Each of these factors was taken into account and analyzed by subjective and objective means during 100B ILEWG EuroMoonMars analogue mission, and the results of all these were summarized.[20-27] We concluded from our study results that the cumulative, long-duration burdens associated with an astronaut's health capacity and their ability and tolerance to adjust to all mission conditions imposes considerable concerns that have to be further investigated before human Mars exploration advances. To ensure that crew members have the physical endurance, strength, and sensorimotor capacity needed during missions, it is important that the physiological effects of space travel are thoroughly understood and that effective countermeasures are in place. Further, in order to avoid increased risk of bone fractures during missions, there is a need to develop more effective countermeasures for bone loss than those currently being used on ISS.

Autonomic nervous system variables of EVA participants of mars analogue mission

Astronauts who have been exposed to microgravity during EVA have some degree of orthostatic hypotension during a post-flight stand test, with a reduced mean arterial pressure and excessive cardio-acceleration, which indicates a disturbed autonomic nervous system.[28-30] It is of critical importance that any crew of a Mars landing craft should be physically fit in order to handle work tasks and to be prepared for possible emergency situations during their journey to Mars, which can take months to complete. Accordingly, an appropriate exercise regime must be in place to ensure the safety and satisfactory productivity of the crew. To the best of our knowledge, no evaluation has been made on the autonomic nervous system involved in Mars analogue EVA activity that simulates surface activities during Mars missions, specifically taking soil and rock samples. Hence, this study was planned to study the effects of EVA on the autonomic nervous system particularly. Autonomic regulation of the cardiovascular system was assessed by measuring the heart rate variability by Zephyr BioHarness using NERV Express 4.2 software and by spontaneous baroreflex measurements. All members were selected carefully for this study. The results significantly showed a decrease in the activity of the sympathetic nervous system after EVA. For this reason, stimulation of the sympathetic nervous system should be facilitated via participation in physical activities, by Mars explorers.

Cognitive performance

Crew cognitive performance is another critical factor in manned space missions. Crew performance continues to be dependent on a number of inter-related factors such as cognitive health, physical health, and presence in a healthy external environment.[15,16,20,23,29,32-38] Knowing that there are extremely demanding scientific and engineering responsibilities placed on exploration crews, one of the leading indicators of overall crew performance must be cognitive performance. A sustained effort to track a given crew's cognitive performance along with potential factors of influence, both during actual space missions and as part of precursor activities on the ground, is therefore needed to expand our knowledge of human performance optimization in space. To the best of our knowledge; no previous work has been done on cognitive performance associated with Mars analogue EVA activity. With this knowledge, we planned our study to evaluate the effects of EVA on cognitive performance. Cognitive performance was measured by CogState. Once again, all members were pre-selected for this study. Speed of processing [Detection Task (DET)] was not significantly affected during seven EVAs between six crew members [Figure 1]. Spatial working memory [Continuous Paired Association Learning Task (CPAL)] was significantly decreased during seven EVAs between six crew members [Figure 2]. The results significantly confirmed a decrease in cognitive performance after EVA. Again, our conclusion is that Marsonauts should participate in physical activities in order to experience better performance results.

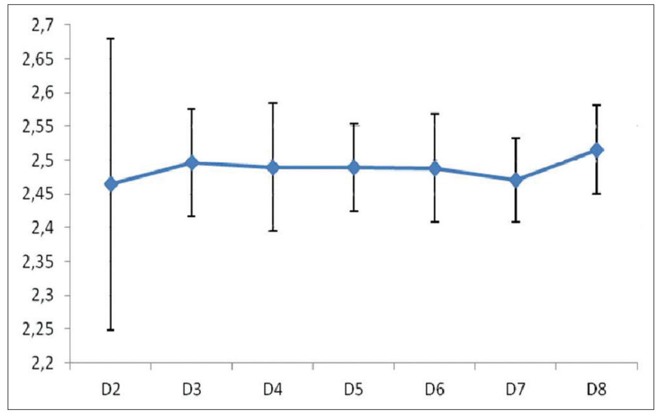

Figure 1: DET means (SD) in six crew members during seven extravehicular activities

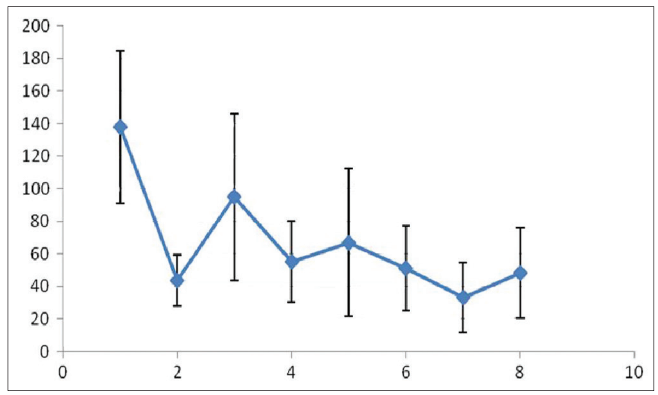

Figure 2: CPAL means (SE) in six crew members during seven extravehicular activities

Effects of mental stress on autonomic cardiac modulation during EVA in mars analogue environments

Space missions like voyages to Mars necessitate that

Table 4: Values of RR, heart rate variability parameters, and blood pressure before, during, and after EVAs

Parameters	Before	During	After
RR	879 (34)	865 (23)	873 (45)
LF/HF	2.3 (0.5)	3.2 (0.3)	3.1 (0.7)
Arterial pressure (mmHg) systolic	117 (6)	119 (8)	117 (7)
Arterial pressure (mmHg) diastolic	64 (7)	69 (6)	65 (6)

humans have to adapt their bodies to handle a variety of extrinsic factors. In addition, humans are required to adapt to systemic and complex environments, which may be beyond human capacity and acceptance.[34-37] This hypothesis is tested again here in our Mars analogue simulated environment by studying alterations in the effects of cardiovascular neural response to standardize cognitive activity. All crew members were again selected for this study. Heart variability was measured before and after EVA by Zephyr BioHarness (using NERV Express 4.2 software), and cognitive status was detected using CogState Research software. The R-R interval (heart rate) (RR), Low frequency (LF)/High frequency (HF), and arterial pressure (systolic and diastolic) levels were increased during EVAs as compared to before and after EVAs [Table 4]. So, LF/HF power ratio acts as an index of sympathetic activity. From the results we conclude that "Test Score" is a valid mental stress tool for Marsonauts in MDRS and other Mars analogous environments.

Heart rate and arterial pressure in EVA participants as part of mars analogue missions

Spaceflight causes adaptive changes in cardiovascular physiology, such as post-flight orthostatic intolerance, that can have deleterious effects on astronauts.[16,17,22-25,37] In-flight cardiovascular data are often difficult to obtain, and results reported so far have been inconsistent. A journey to Mars will take months to complete, and as such, an appropriate exercise regime must be in place to ensure the safety and productivity of the crew. To the best of our knowledge, no evaluation has previously been made on the effect of simulated environments on heart rate and arterial pressure, particularly during Mars analogue EVA activity. To close this gap, our study was planned to study the effects of EVA on heart rate and arterial pressure. All crew members were selected for this study. Heart rate and arterial pressure were measured before and after EVA by Zephyr BioHarness. It was found that heart rate, diastolic pressure, and variability of heart rate and diastolic pressure levels were significantly increased [Table 4].[32,35] A logical conclusion from this work is that astronauts should be required to participate in physical activity to minimize these adverse effects on the human body.

Simulated microgravity biomedical experiments

Marsonauts will be subjected to physiological and psychological extremes during the journey to Mars, while on the Mars terrain, and on the journey back to Earth.[16,17,23,25,37] To evaluate certain biomedical factors, short-duration analogue studies, such as those carried out at the MDRS, Utah, USA, offer an opportunity to study mission operations, human factors, and biomarker measurements in a simulated environment, and therefore contribute to planned exploration missions to the Moon and Mars (MDRS Crew 100B ILEWG EuroMoonMars).

For this particular series of studies, the MDRS Crew (100B ILEWG EuroMoonMars) underwent a 6-h HDT program (simulated microgravity conditions)[27,28] that provided a unique insight into physiology issues for space exploration. In this study, salivary biomarkers were measured (bone loss and formation, stress, immunological and inflammatory markers), saliva samples were taken using the Versi•SAL® Saliva Collection Device from Oasis Diagnostics® (according to the manufacturer's instructions), questionnaires were obtained, cognitive activity was tested (CogState Research software), vital parameters were monitored (by the Zephyr BioHarness), and heart rate variability was also measured (using NERV Express 4.2 software).[12,18,19,29-35,39] Salivary bone markers (calcium and osteocalcin), salivary stress biomarkers (amylase and cortisol), and inflammatory [C-reactive protein, interleukin (IL)-6 and IL-8] biomarkers were unchanged after simulated microgravity compared to levels of each of these markers tested before simulated microgravity.[19] One of the reasons for this could be the short duration of the study. These factors were taken into account and analyzed by subjective and objective means during 100B ILEWG EuroMoonMars, and the preliminary results of each experiment were summarized. We concluded from this study that cumulative, long-duration burdens associated with an astronaut's health capacity and their ability and tolerance to adjust to all mission conditions impose considerable concerns that require further investigations before human Mars exploration advances.

Odorant identification based on solid phase in EVA participants during mars analogue missions

As previously mentioned, spaceflight causes adaptive changes in physiology that can have deleterious effects on astronauts.[16,17,22-25] Journeys to Mars can take months to complete and, in order to maintain a fit and healthy crew, an appropriate exercise regime must be in place to ensure the crew safety and productivity. To our knowledge, no evaluation has been made on the effect of simulated environments on retronasal gustatory (sense of taste) of human during in Mars analogue mission EVA activity. Six crew members were selected and seven herbal Indian spices were used in this experiment. Based on partial analysis data obtained from only two crew members, it was determined that crew members could not identify these spices after EVA. We feel that the reason for this could be stress, which is known to affect trigeminal sensations.[14]

Sleep disturbance, heart rate variability, energy consumption, salivary stress biomarkers in participants on mars analogue missions

Sleep problems, such as poor quality of sleep, insomniam, and hypersomnolence, have been a frequent observation during space flights.[16,17,38] Stress can elicit profound and lasting effects on sleep. It is intuitively appealing to hypothesize that worry and intrusive thoughts delay the onset of sleep and studies have supported this hypothesis. Similarly, stress-related intrusive thoughts and negative suggestions may color one's subjective perceptions about the quality of one's sleep. Extreme environments allow us to examine various aspects of sleep physiology, heart rate variability, and the relationship between the two that is essential to a broader understanding of the adaptation of humans to stresses imposed by these environments. When teams or individuals operate in extreme environments, their responses are products of either situational drivers or internal personal characteristics. MDRS (Utah, USA) provides a unique opportunity to examine the interaction of salient individual factors such as gender and personality factors with social relationships and group identity. The MDRS is an analogue to a Mars surface habitat, constructed for mission simulations according to Mars Reference Mission guidelines, and located in a US southwest desert region relevant to Mars analogue geology and biology research. MDRS includes an upper deck with six private staterooms having personal storage and desks, a galley area, workstations, and meeting/eating area, plus a lower deck with a laboratory, toilet, shower, and EVA preparation rooms. For this study, six crew members were selected. Sleep questionnaires and saliva samples were taken pre-sleep and post-sleep. Saliva was collected using the Versi•SAL® Saliva Collection Device from Oasis Diagnostics and preserved at −20°C pending further analysis. Heart rate variability was measured by the Zephyr BioHarness and analyzed by the NERV Express 4.2 software. Sleep duration was measured by SenseWear Pro Armband™ (SWA, BodyMedia, Pittsburgh, PA, USA). Circadian pattern of sleep, energy expenditure, and skin temperature were measured on the first day and at the end of the mission by SenseWear Pro3 armband (BodyMedia) worn on the right upper arm (on the triceps). Salivary stress biomarkers including salivary amylase, melatonin, and cortisol were measured according to the reported methods.[31,33,34] Correlation between sleep questionnaires, salivary stress biomarkers, and HF/LF1, HF/LF2, and HF/LF were observed.[10,31,33,34] Total sleep time, nighttime sleep duration, (NAP) duration, skin temperature, near body temperature, energy expenditure, and metabolic equivalents of task levels were not significantly changed from the first day compared to at the end of the mission [Table 5]. Results of this study conclude that changes in heart rate variability associated with acute stress may represent one pathway to disturbed sleep.

Rescue techniques during mars analogue missions

During long-duration space flights such as Mars missions, astronauts are prone to many physiological changes such as loss of bone mass, muscle strength, and cardiovascular fitness[16,17] Maintenance of these factors and keeping them under control is an important requisite; so, accordingly we planned an EVA activity devoted to medical rescue. This work provided definitive information on which injuries future astronauts may have to cope with, which rescue techniques might be suitable for recovery of survivors, and the limited possibilities for treating injured astronauts.

Facial action coding system analysis of crew behavior

The Facial Action Coding System (FACS) is based on facial activity and may roughly be interpreted as the smallest visible units of muscular activity in the face, which produce changes in facial appearance.[40] By concentrating completely on muscular activity and eliminating subjective interpretation, the FACS produces a purely descriptive account of facial expressions. For this reason, the FACS is one of the most widely used and comprehensive coding systems for facial expression analysis. Extensive research shows that certain combinations of action units are linked to the six "universal" facial patterns of the emotions, such as anger, disgust, fear, sadness, surprise, and happiness. Interpretation of these reported activated units, however, is not covered in the FACS, but in separate systems. These are methods for objectively scoring and interpreting

Table 5: Comparison between sleep characteristics and energy expenditure during first day and end of mission in six crew members

Variables	First day	End of mission	*P* value
Total sleep time (hours)	6.7–8.8	5.7–8.9	NS
Nighttime sleep duration (hours)	5.6–7.2	5.1–7.4	NS
NAP duration (hours)	1.3–1.6	1.2–1.7	NS
Skin temperature (°C)	32–36	33–36	NS
Near body temperature (°C)	32–37	33–38	NS
Energy expenditure (kcal/min)	119–123	118–1134	NS
Metabolic equivalents of task	1.00–2.00	1.00–2.00	NS

emotional or affective expressions. Photographs and videos were taken of six crew members for analysis of FACS by standardized software.[40]

Lessons Learned

Our emphasis is on lessons which are either a) relevant to future human factor research or b) can be applied directly to Moon or Mars exploration missions, rather than those which are specific to the time and place of the mission.

1. No crew can fake motivation or playact over the long term.
2. Crews appreciate the value of human factor research, and are willing to put in important time if the study is perceived to produce meaningful results. The Commander of the crew must give a comprehensive overview of all experiments.
3. Crew members should not be coerced into taking part in an experiment if he/she is not willing to do so.
4. Crew members should not be remotely forced into experiments that they may not want to do.
5. Serious communication problems have the potential to develop between crew members and the Mission Support team.
6. Communication latency is also a significant barrier to remote collaboration.
7. Particular strengths and weaknesses of specific crews may be observed, and countermeasures to improve performance can be proposed and tested.
8. Dining together and listening to music gives strength, motivation, and countermeasures to improve working stress and team work quality.
9. Crew members have only limited medical training and expertise, and for this reason, biomarker analyses should be simple to execute using easy-to-access materials such as salivary biosensors and simple software.
10. Not only medical health, but also oral health should be taken into account.
11. If human factor experiments are planned that necessitate regular crew member participation, a high workload can frequently lead to participants not fulfilling all necessary work, unless the daily schedule is structured accordingly.
12. Crew selection is at the center of attention for achieving a balanced set of skills and experience, with emphasis on practical abilities, strong work ethic, general professional skills, and interpersonal compatibility.

Proposed Approach for Future Human Space and Interplanetary Missions

We are proposing a concept of a combination approach involving ISS, ground-based simulation (bed rest condition), and analogue stations to fill the gap of space and interplanetary missions. Typically, an ISS crew acts more as an autonomous group. We believe this could result in further failure in experiments and studies due to a combination of high workload, and physiological and psychological effects. Life support systems, countermeasures for improvement in health, radiation risks (animal studies only), intracranial pressure, visual effects, physiology, sleep, circadian rhythm, and landing approach areas are important facets to study on board the ISS. Countermeasures for improvement in health and physiological changes, especially cardiac physiology areas, are important to study using ground-based bed rest conditions.

Surface activities are very significant part of space and interplanetary missions, and these activities can be studied at ground-based analogue stations such as the MDRS facility in Utah, USA. Work operations, physiology during surface investigations (EVA), and other geological activities including psychological activities are studied on board MDRS, which functions as a ground-based analogue model of space flight. Mars analogue stations similar to MDRS and other ground-based analogues are partially autonomous, so we recommend highly that to the list of problems analogue environments can handle, crew composition, logistics, and others should be added. We believe the maximum quantity of research should be carried out in analogue environments using experience collected from the ISS including crew selection, logistics, and other factors. ISS is the "real world" situation as it involves true space flight and interplanetary missions. We would like to recommend new research approaches for the establishment of guidelines for space and interplanetary missions. According to known procedures, ISS crews perform ground-based surface activities immediately after landing when experimentation is carried out at ground-based analogue environments under medical supervision. The idea behind this concept is to combine true space flight (ISS) and surface activities together as surface activities are not possible on the ISS. Human physiology, psychology, and surface activities must be studied during Earth-to-interplanetary-space and landing back to earth.

Conclusions

The 100B mission was one of the first significant broad-based experiments to study integrated expeditions under simulated Martian conditions in order to maximize scientific output, especially medical and human factor research related to surface activities. This mission was for a time period of 2 weeks according to well-designed and planned protocols, simulating the exploration of the Martian surface. Fifteen human factor studies were conducted, from which we were able to derive the results of the specific studies and learn valuable lessons on how to best conduct such studies in the future. It is important to identify organizational and environmental characteristics that contribute to impaired psychological coping and well-being in multinational crews living and working in space together. A major obstacle in evaluating the efficiency of psychological and physiology countermeasures is the identification of valid and reliable performance criteria against which they can be tested. Continuous monitoring of human health status in a cost-effective manner has to be realized for a crew on the way to Mars. Given the likelihood that Mars crews will include members with different health status, both genders, various nationals, and cultural backgrounds, and substantially larger crews than ISS, it will be highly desirable that all partners identify and agree to establish a set of common standards and procedures for the selection, training, support, and evaluation of Mars mission crews. We therefore believe that if different research teams can work together to reach a final goal, Mars Mission, we will create a new worldwide drive and standard for mankind, which will create benefits for all Earth inhabitants. In summary, long-term designed analogue missions can advance our understanding of human factors in space exploration. The JBR studies described here demonstrated this potential.

Acknowledgments

We would like to express our gratitude toward the Mars Society, ILEWG, ESA/ESTEC, l'Ecole de l'Air, VU Amsterdam, Dr. Guy Pignolet from the SALM institute, Mr. Akos Kerezturi, Dr. Tamarack Czarnik, Dr Carol Stoker (NASA Ames), Mission Support, Mr. Don Lusko, and all other related people for their daily assistance, and our remote supporters from America, Europe, Canada, and India. We are very thankful to our crew members such as Quentin Bourges (Bob), Matthieu Ansart, Crystal Latham, and Rachel Dompnier for taking part in this project, without which this project would have not possible.

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How to cite this article: Rai B, Kaur J. Human factor studies on a mars analogue during crew 100B international lunar exploration working group euromoonmars crew: Proposed new approaches for future human space and interplanetary missions. North Am J Med Sci 2012;4:548-57.

Source of Support: Nil. **Conflict of Interest:** None declared.