Stress and Human Factors from Antarctica to Mars

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Abstract: In extreme environments, such as Antarctica or Outer Space, stress and performance are key factors for the safety and survival of the team. The Mars Planet Association has been carrying innovative research considering the importance of investigating stress and performance to furthering research and innovation for Space and Earth applications. In particular, focus result investigation will be presented such as the PSI (Performance & Stress in Isolation) experiment leaded by Dr. Alcibiade in different analogue missions.

Keywords: Human Factors · Stress · Extreme environment · Innovation · Mars · Antarctica · Ecological System · VR · Psychology · Co-design.

1 Introduction

Nowadays various governmental and commercial agencies are planning ambitious human space missions to the cis-lunar space, Mars and the asteroid belt. These missions, if realized, will lay the astronauts, among other difficulties, into prolonged isolation and confinement in microgravity condition.

Stress related to a social/environmental confinement is a major obstacle to our capability to undertake long lasting space missions (LLSM) and, thus, selecting and training adequate stress-resilient crews and being able to monitor efficiently their overall performance status, will be a key point for the success of future LLSM. Since it is expected that the aim of these space missions is not the mere survival of individuals, but the execution of mentally challenging and physically demanding tasks, it's easy to understand how the psychological and the physical deconditioning may be a complicating factor in the operating scenario of a space mission.

As the Russian academician I.B. Ushakov, director of IBMP, mentioned, in this endeavour "the human factor becomes the main priority, and humans become the most valuable and vulnerable unit of the mission, to a great extent determining the possibility of realization of the project in general.” [1]

Much of our understanding of human behavior and performance in space has been obtained from the study of analog environments such as Antarctic research stations, nuclear submarines, undersea habitats and small rural communities. Due to the high cost of space operations, analog environments are the best way to study behavioral impacts of isolation, confinement, and stress over long periods of time. [2]

In these extremes environments, such as Antarctica or the International Space Station, crews of scientists and astronauts are actually living in isolation under very difficult conditions, and the stress factor has a very strong impact on overall performance and safety. [3] To create a stable and secure environment, this stress needs to be approached from both a psychological, social and a biological perspective: prior to the mission with a specific environmental design and appropriate crew selection and training; and during the mission through constant monitoring and adoption of specific countermeasures.

Knowing the importance of this topic Mars Planet, an association that focuses on spin-in and spin-off for the development of space research and innovation, has directed its resources into the investigation of stress and human factors in extreme conditions. These kinds of studies have recently become interesting also for the increasing number of organizations in the world which carry out analog simulation missions in areas which can show some similarities to extreme space environments (like deserts or volcanic regions). In this manner, it also becomes useful and necessary to move the research target towards an effort to standardize methods, procedures and software tools, in order to complete a consistent set of research tools for the scientific evaluation of the mission results in extreme environments.

Figure 1: A Mars Society "Analogue Astronaut" operating at Mars Desert Research Station (MDRS). Credit: Mars Planet Association.

2 The Investigations

During 2017, a team of researchers from the Mars Planet conducted innovative researches in the field of Human Factors to improve the safety and performance of operators during long-term missions in extreme environments, focusing specifically on the stress factor.

In particular, the following aspects were investigated:

- Analysis of psycho-physiological parameters in extreme mission;
- Human factors investigation of space system usability;
- Virtual space mission simulation and training system application;
- Space community social and environmental design.

2.1 Analysis of Psycho-Physiological Parameters in Extreme Mission

The PSI (Performance & Stress in Isolation) project aims to quantify the correlation between alterations into the product of a human mental activity, such as written natural language, and the psychological and physiological stress levels in the subject-writer when exposed to isolation and confinement conditions.

The exact definition of this pattern of correlation could lead to the development of an algorithm useful for the creation of a software for the early detection and remote monitoring of stress levels in people operating in extreme contexts.

The idea for the PSI experiment comes from a multitude of studies in scientific literature [4 - 6] which suggest the existence of a strong correlation between the amplitude and frequency variation of the word spectrum used in the everyday vocabulary of an individual in a given period, and the variation in his level of physiological and psychological stress. These studies agreed with saying that "under stress, the subjects tend to write less, using a tighter vocabulary and shorter words."

The PSI experiment received the approval of the Ethics Committee of the Pope Giovanni XXIII Hospital in Bergamo on 11 August 2017 and since then it has been conducted during five Space simulation missions involving a total of 27 subjects experiencing voluntary isolation, as follow:

- Poland Mars Analogue Simulation (PMAS) , involving three females and three males crew members, between August 1-13th 2017, organized by the Space Generation Advisory Council at Lunares Habitat, Poland;
- Lunar Expedition I (LunEx I), involving two females and four males crew members, between August 15-31st 2017, organized by the Space Generation Advisory Council at Lunares Habitat, Poland;
- ILMAH Mission IV, involving a three males crew between October 10-24th 2017, organized by the University of North Dakota, USA;
- MDRS Crew 185, involving a female and five males crew members between December 16-31st 2017, at Mars Desert Research Station, Utah, USA;
- D-MARS01 Experiment, involving two females and four males crew members, between February 14-18th 2018, organized by the Israeli Mars Society at Ramon Desert Research Station, Israel.

The experiment consisted of three tasks repeated five times and always at the same time of the day indicatively after hours 4 P.M.:

- The first task was to write in a maximum of 30 minutes a text with a maximum of 500 words in the subject’s mother tongue. The task should be performed at approximately the same time of day;
- The second task was a short questionnaire on how the person feel on the level of stress, well being and comfort;
- The third task consisted in the blood pressure and heart rate monitoring with the given device. The subjects had to fill out this data on the proper form of the software.

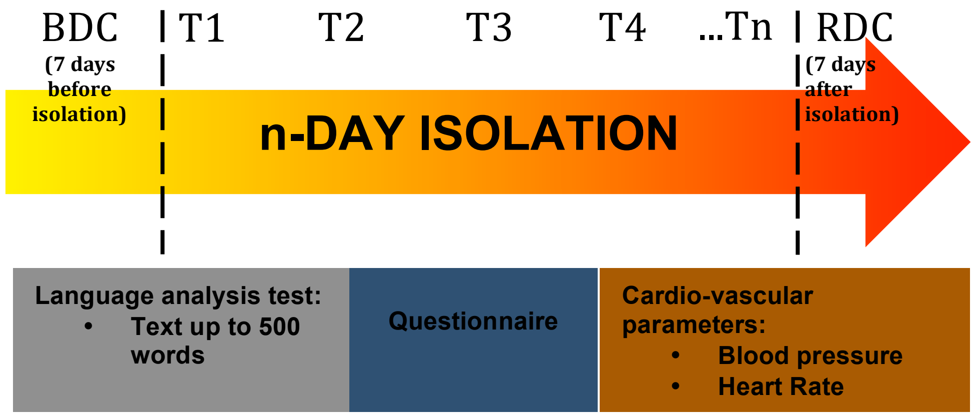

Figure 2: PSI Experimental Timeline.

To run the experiment, the participants were provided with an appropriate software and an individual ID to access the program. At the first log-in to each participant, in addition to receiving the ID, were asked to fill out a personal questionnaire.

A preliminary data analysis was done on the results of the PSI experiment conducted at the PMAS Mission, by searching for Pearson correlations between five language parameters and four cardiovascular parameters. These results were presented to the 68th International Astronautical Congress (IAC) [7].

Since all six participants in the mission were homogeneous for age and linguistic group, comparisons have been made on the averages of the values corresponding to the parameters of all six subjects, and then on the averages of the corresponding values of the parameters of the subjects grouped by gender in order to look for any effect of gender on the results of the correlations.

The preliminary results were substantially consistent with those which were the experimental hypotheses:

- To higher values of blood pressure corresponds a greater aptitude to the production of written language. The higher production of written language also tends to lower values of heart rate;
- Subjects tend to write for more time when they feel less stressed. Subjects also tend to write longer words when they feel stressed and less performing;
- When the individuals feel more performant, they tend to write with a more complex language;
- When the subjects feel more stressed they tend to have higher values of systolic blood pressure;
- When subjects the feel more performing and more comfortable, they tend to have lower systolic blood pressure values and lower medium arterial pressure values;
- Significant gender differences were found only in the scores of the answers to the human factor questionnaire, where women refer to be more stressed, less

functional and less comfortable in the central isolation stages, while men seem to suffer most in the periods immediately preceding and subsequent to insulation.

On the base of the lesson learned from these first results, future study will be performed.

2.2 Human Factors Investigations of Space System Usability

To identify the psycho-physiological stress environment faced by crews during extreme missions, PSI was applied together with the Human Factors debriefing, a collective and anonymous guided discussion that investigates the psycho-physiological problems encountered by the crew. The investigation was tested and finalized in 14 mission simulations of six crew members from 2010 to 2018 [8, 11].

The human factors debriefing is a guided team discussion that is performed at the end of the mission to approach from a holistic perspective all possible positive and negative factors that the user experience during the interaction with the system.
In particular the human factors elements that need to be discussed need to cover all the following aspects:

- Operational & technical factors
- physiological factors
- psychological factors
- sociocultural factors
- environmental factors

and in case of mission plan analysis:

- managing factors

The guided discussion mostly investigates the needs of the crew and the lessons learned during a mission. The main weaknesses and strengths of the mission are discussed collectively. As a result, problems and possible solutions to improve safety, performance, and well-being during the mission are identified collectively and anonymously.

The results were consistent in close to all the 13 missions showing how communication is a key element to consider during extreme missions. Moreover the results show how is important to consider not only quantitative factors but also qualitative, such as psychological and socio-cultural factors [8,10].

In conclusion, the lesson learned by this investigation shows how the user played a vital role regarding overall safety, in particularly considering exploration of extreme and unknown places we still need to deal with "unpredictable" circumstances.
To support the safety on those circumstance we need to prevent stress factors:

- Training the user with a simulation that need to be as close as possible to the reality to simulate the complete interaction experience with the system with a holistic perspective;

- Give the user instrument to prevent, monitor and countermeasure stress factors as much as possible autonomously and holistically;
- Consider the interaction between the user and the system as well as the group of users and the systems.

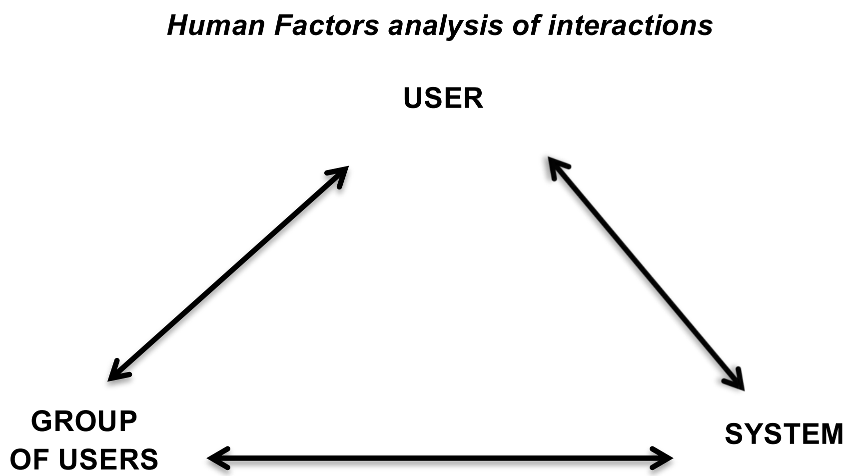

Figure 3: Human Factors Analysis of Interactions.

2.3 Virtual Space Mission Simulation and Training System

Specific training and crew selection can serve as stress prevention system. The Motigravity Training System (MTS) is a virtual reality (VR) treadmill developed by Mars Planet that can simulate stressful activities in extreme environments, including operations in low gravity and medical monitoring.

This tool enables to simulate space operation with an affordable budget. Motigravity is composed of different subsystem that can be used to simulate interaction between human operators and artificial devices, and to analyze external data in VR. It is completed with a set of optional devices that enable the simulation of medical conditions and health monitoring. The MTS has been tested during three space analogue missions involving 20 subjects, but also under non-extreme conditions with 150 users.

To investigate human behavior in hypogravity conditions, a pilot experiment called the Moon Gait has been performed at the German Aerospace Center (DLR) under the guidance of Prof. Jörn Rittweger (Head of the "Space Physiology" division at the DLR), Dr. Irene Lia Schlacht and different international field specialists.

A methodology has been investigated for the analysis of the gait posture in hypogravity conditions, to be applied in architecture design in space. This investigation was run in cooperation with the Karlsruhe Institute of Technology and the DLR. The statistical analysis has been done on 5 tests and 36 videos collected on a total of 6 participants heterogeneous by age, gender and body mass. The analysis of the videos has been performed using the software "Tracker". The gait's vertical oscillation (the variation in height given by the oscillation of the top of the head) and the gait's variation of OAE angle (the variation of subject's point of view towards the camera) were both measured, but only the gait's vertical oscillation values showed significant changes. [11]

Figure 4: Mukadam self-experimenting Vertical Treadmill, © Mukadam 2017

The significant result of the Moon Gait pilot experiment was the evidence that, on Earth, the vertical oscillation variates in accordance to the speed of running, as well known to the experts [12], while on Mars or in any other hypogravity environment, like the Moon, this behavior acts in a completely different way, as the vertical oscillation during the gait has no major changes at both a slow and a fast speed. We aim to further investigate this phenomenon running the following protocol on a coorte of at least 30 subjects:

- "Step by step" data analysis, considering the left step as independent from the right one,
- Application of a "Linear Mixed Effects Model" statistical test,
- The vertical run on the treadmill will be performed also by subjects kept on a bed rest condition,
- Execution of the protocol in a variety of different analogue environments, such as Moon/Mars gravity parabolic flights or the neutral buoyancy facility.

Upon further investigation and confirmation of the preliminary results, the data acquired after the Moon Gait Experiment can be implemented into the VR simulation to enhance immersion and realism prospect of the setup.

The best application of MTS will be on Moon/Mars hypogravity parabolic flights, even if current advances to MTS for its improvement are also being made, with the addition of a lifting mechanism to simulate hypogravity, including a safer body attached harness allowing the participant to walk, rotate, jump and crouch safely all in connection with VR. The MTS allows also testing the walk and the interaction of a group of people whose members are located in different regions of the Earth. This will enable us to run a behavioral analysis on people of different cultures, backgrounds and age while working together in the same VR environment.
The final aim of these studies is to create an instrument to help astronauts to train for outer-space activities in order to decrease their stress levels and enhancing their mental and physical safety and performances, in a very cost-effective way.

2.4 Space Community Social and Environmental Design

Another relevant matter deals with the design and selection of environments that facilitate psychophysiological conditions and survival. Design strategies to figure out the best prototypes of environments capable of preventing social and environmental stress factors in isolation have been built upon real scenarios of missions in terms of simulations and analogs. Simulations of extreme conditions experienced by communities are a way to research human factors, collect data and train humans in the field. Simulation sets considered in the study were:
MDRS run by the Mars Society in Utah (USA), the Mars 500 habitat at the IBMP in Moscow, the ESA Caves project and the Italo – French "Concordia" Antarctic Station.
In addition to specialized research via simulation, it is worthwhile to learn from the experience accumulated in relevant environments that already exist on earth. In 2017, analog environments such as Muruntau gold mine (Uzbekistan), the Kupol Mine in Russia (600 workers) and kibbutz communities in Israel (200-1000 inhabitants), but also oil rig and Antarctic bases were analyzed from a social, technical, and management perspective in order to start the collection of a database for the purpose of future Antarctica and Mars settlement co-design.

An emerging field of research within Mars Planet Association is the Co-design of communities in extreme environments. Participants should be involved in the design of solutions and technologies meant to support themselves to face stress and increase as facilitate their performances during the missions. A growing field of study is connecting resilient practices from the bottom with technical design of technology and solutions. Case studies and examples like oil rig teams, kibbutzim, simulations and analogue missions are considered for the construction of a model that sees people involved in the missions, not only as final users of artifacts, environments or means of survival, but as bricoleurs or makers. It is a useful and dynamic perspective about systems that are structured on an ecology of human-technical-nature factors. A much wider and deep understanding of how missions are in real life is needed by including the accountability of the extreme environment and what people do to change and repair stuff for their own daily survival. The way to design survival practices go through the social activities enacted by the

community members that can support the relief of each other's stress and can increase or motivate individual performance.
In the part of the research that replies on historical data and natural experiments, we make use of the accumulated knowledge about Kibbutzim, which were created as small communities in circumstances of extreme uncertainty regarding survival. It is worth noting that the explicit discussion of human factors and stress is relatively new, and when learning from historical events and experiences, we need to reverse engineer those issues from the other evidence: when a group disbands, which means it hasn't survived as a group, it is often due to various types of stress. So even if stress is not discussed directly, it is implicitly present as a consideration when trying to maximize the chances of survival of the group.
Co-design of a society should be considered in the context of initial planning before the a group of people starts working and living together, and should also be considered in the context of ongoing adaptation. It is clear that the planning phase should take advantage of accumulated knowledge, and of experts in relevant fields. A less intuitive necessity that is acknowledged by Kibbutzim researchers is that in the planning phase it's important to have the people building the Kibbutz sit together before starting, and figure out their values and plans as a group. The social structure and rules need to be co-designed by the prospective members of the social group themselves. Trying to work according to a "manual" created by others tends to lead to the failure of the group.
Beyond the initial planning, one way to look at how flexibility enhances survival of the group, is to look at that flexibility as continuous co-design of the social structure, allowing and expecting the members of the group to adapt the rules to the circumstances - both internal and external - that are bound to change in ways that could not be foreseen by the original designers. Again, there is historical evidence of how continuous adaptation of the social rules, done by the members of the social group, enhanced the group's resilience and long-term success.

A somewhat grim distinction is worth making: It is easy for us to think about a scenario where the individuals survive, while the group doesn't. It is more difficult for most of us in the relatively safe 1st world to think about situations where the group survives while individuals perish, and especially situations where we need to plan for such situations. This is likely to be the case in high-risk activities such as building a settlement outside of Earth.

One example of co-design both in the planning phase and the adaptation phase, is the economic basis for Kibbutzim. In the beginning of the 20th century, Kibbutzim were created as agricultural groups. In many cases the individuals had no background in agriculture, and certainly had no experience in agriculture in the arid environment of Palestine/Israel. They had to import knowledge from the experts, and create their own knowledge by training - as a group - in existing agricultural settlements. So the planning and initialization of the agricultural entity were a product of co-design.
Decades later, many of the Kibbutzim decided to move from reliance on agriculture to various industries. Again they had to make the decisions, train themselves and import knowledge from the outside. So the adaptation phase was also a manifestation of co-design.

3 Conclusions

Considering that the aim of future LLSM will not be the mere survival of individuals, but the execution of mentally challenging and physically demanding tasks, stress related to the social/environmental confinement will be a major obstacle to our capability to undertake LLSM.
"Mars Planet" research team, with the aim of furthering research and innovation for Space and Earth applications, has been carrying out researches on stress countermeasures, to be applied from the preliminary stages of a mission to its end. Specifically the following research topics have been approached:

- Analysis of psycho-physiological parameters in extreme mission
- Human factors investigation of space system usability
- Virtual space mission simulation and training system application
- Space community social and environmental design

The results show how in counter measuring stress psychological support, social planning and psycho-physiological training and deconditioning need to be considered as preliminary factors in the operating scenario of a space mission. In particular new methodologies that support the "autonomy" of the user in long duration mission in the extremes have been investigated.

In conclusion, to ensure the safety and to expand and maintain a human presence in extreme environments, from the future mission to Mars to the present missions to Antarctica, further researches need to be conducted in the field of Human Factors, which then need to be applied during all stages of a mission, from design, via training to the conduct of the mission itself. In particular stress counter measuring was presented here as a key human factor element for the success of a mission in the extremes.

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