IAC-12.A5.1.2

MDRS 2012 ILEWG CAMPAIGN: TESTING HABITABILITY AND PERFORMANCE AT AN ANALOGUE MOON BASE INFRASTRUCTURE OUTPOST ON EARTH

Ms. **Irene Lia Schlacht**
Politecnico di Milano / Technische Universitaet Berlin, Germany, irene.lia.schlacht@gmail.com

Mr. Dipl. Ing. **Jeffey Hendrikse**
Astrium GmbH, Germany, jeffreyhendrikse@yahoo.com
Ms. **Ayako Ono**
Tohoku University Graduate School of Medicine, Japan, a.ono@med.tohoku.ac.jp
Mrs. **Valentina Karga**
University of Arts Berlin, Extreme-Design, Germany, valkarga@gmail.com
Prof. **Jean Hunter**
Cornell University, United States, jbh5@cornell.edu
Mr. **Pieterjan Grandry**
Extreme-Design, Germany, pieterjangrandry@gmail.com
Mr. **Alexandre Mangeot**
University of Orléans, France, alexandre.mangeot@imelavi.fr
Dr. **Balwant Rai**
The Netherlands, drbalwantraissct@rediffmail.com
Mr. **Ivo Ferreira**
Instituto Superior Tecnico, Portugal, ivotomar@gmail.com
Mr. **Romain Benchenafi**
École de l'Air, France, r.benchenafi@hotmail.fr
Prof. **Melchiorre Masali**
Universit_a degli Studi di Torino, Italy, Melchiorre.Masali@gmail.com
Prof. **Bernard Foing**
ILEWG, The Netherlands, Bernard.Foing@esa.int

ABSTRACT

The International Lunar Exploration Working group has been organizing a new campaign to test exploration procedures in Analogue Moon Base Infrastructure. The 2012 campaign called EuroMoonMars/Domus was carried out at the Mars Desert Research Station (MDRS), a space analogue environment in Utah. Inside the station, selected crew members are forced to work and live together in an infrastructure designed on the basis of an early Moon or Mars outpost. The feasibility and limitations of human and robotic planetary exploration were investigated, with prior lessons learned from the ILEWG EuroMoonMars missions since 2008 being taken into account. Two teams were involved, crew 113 and crew 114, each comprised of six members. The focus of this paper will be on presenting the analysis performed by the Extreme-Design Research Group on the living and working conditions, which analyzed and predicted problems related to the habitability of a previous lunar outpost. The living conditions were investigated with the help of a detailed questionnaire and a debriefing workshop, which focused on two points of interest: the social approach of the crew and the relevance of culture/nature/art for increasing the crew's well-being and performance in isolation. The work activities of the crew included human-robotic partnership such as EVA assistance or replacement; extension of the RF robotic remote control network, as well as research in the field of human factors, such as a food study, a sleep study, and other types of habitability research. This paper will review all the results of the studies and compare them with the result from the 2011 campaign.

1. THE PROJECT

The Moon-Mars habitability project by the Extreme-Design Research Group aims to improve habitability and well-being in confined and isolated environments by testing habitability and performance during space mission simulations. Astronauts suffer from insomnia, depression, and stress and these negative effects reduce crew performance. To counter those effects, the Moon-Mars habitability project performed research and worked on a methodology to increase the quality of life. The project was conducted during the International Lunar Exploration Working Group (ILEWG) space mission simulation at the Mars Desert Research Station (MDRS) of the Mars Society during the EuroMoonMars campaign directed by Prof. Bernard Foing. The MDRS is located in the San Rafael Swell, a desert in Utah. It is an analogue Moon-Martian habitat for human exploration, where a crew of six people worked and lived together in a closed-system environment simulating a space mission to carry out specific field research and experiments. During the space mission simulation, they felt exactly the same stressful conditions[1] as during a real mission and had to

[1] Inside the MDRS habitat, life is not easy; space is limited and you need to share it with your crew members while

deal with the stress of a confined and isolated context in extreme environments. The project, which was designed and coordinated by Irene Lia Schlacht, was performed by herself as part of crew 91 in the 2010 mission campaign; then in 2011, it was implemented and performed by Ayako Ono in crew 100a and in 2012 by Valentina Karga in crew 113.

Fig.1: Crew 91 EVA to the MDRS Mount Olympus. © I.L. Schlacht 2010 (MDRS, Utah)

2. THE HABITABILITY EXPERIMENT

The habitability experiment consisted of 3 parts:

1. Sensory Experience: The sensory interaction with color (visual), plants (tactile), fragrances (olfactive), and natural sound (auditive) was investigated. The hypothesis on the basis of the research is that in order for humans to become more efficient and reliable and to feel better, a variability of stimuli comparable to those in the natural environment is needed. To verify this hypothesis, the crew creatively interacted with stimuli such as plants, gradation colors, natural sound, and fragrances. For comparison with these stimuli, the task "Copy & Mirror" was offered.

2. Habitability and Mission Debriefing: This was a small workshop where the crew jointly analyzed the problems of habitability and tried to hypnotize on a solution along the guidelines of six different factors: operational, environmental, physiological, psychological, social, and cultural, while considering at the end of the mission the experiences made both during intra (IVA) and extra (EVA) vehicular activities. The workshop was supported with questionnaires about the mood and the personality experienced at the start, middle, and end of the mission.

3. Creative Performance: This was a free cultural activity. The performance of a creative and artistic activity is needed in order to freely express yourself in relation to the environment and the situation that you are living in.

4. Plants: This research was conducted in 2010 under the supervision of Scott Bates from a psychological perspective and in 2012 by Jean Hunter from a food engineering perspective. The relationship with plants was also investigated as part of the sensory experience on each crew.

Fig.2: Composition made while listening to the natural sound during the sensory experiment of crew 100a during isolation at MDRS.

3. SPACE MISSION 2010

During the 2010 mission, the habitability project was performed by two crews. The results reported here have been published in previous publications (Schlacht, et.al, 2010[1], Schlacht et.al, 2010b[2]). In particular, for comparison we report the results from crew 91, where the investigator was directly present in the crew. The crew was composed of three males and three females, aged between 19 and 33 years, all healthy and students in the space field and space enthusiasts; three were French and three were mixed nationalities.

3.1 Sensory Experience:

The setup of the Sensory Experience was:

Five experimental sessions of 30 minutes each were performed in random order. The results were:

- Color gradation: evoke a visually aesthetic feeling;
- Plants: stimulate the connection with other forms of life;
- Listening to natural sounds: relax and stimulate the imagination;
- Smelling fragrances: evoke past experiences and memories.

As part of the experiment, focused tasks on creative activity and mood analysis were used to measure the sensory stimulation effect on creative performance. The tasks stimulated sensory activity, creativity, and well-being. Those factors were evaluated as being relevant for the success of long duration missions

conducting your crowded schedule of activities, including facility maintenance, experiments, and research. In the desert around the station, the only human presence is the habitat. During EVA (Extra Vehicular Activity), the Hab view gives you a feeling of safety; when you lose visual contact with it, you can lose your orientation in the desert. Going outside the habitat means facing numerous difficulties: you need to wear a helmet and carry 5-6 kg in air circulation backpack, a space suit, and instrumentation; moreover, walking in the sand is tiring. Each day that you spend living in isolation, things that you are missing from your normal daily life became more and more precious. In this context, the level of habitability determines whether you are able to perform your research and carry out experiments.

where an under-stimulating environment can lead to mental drowsiness.[2]

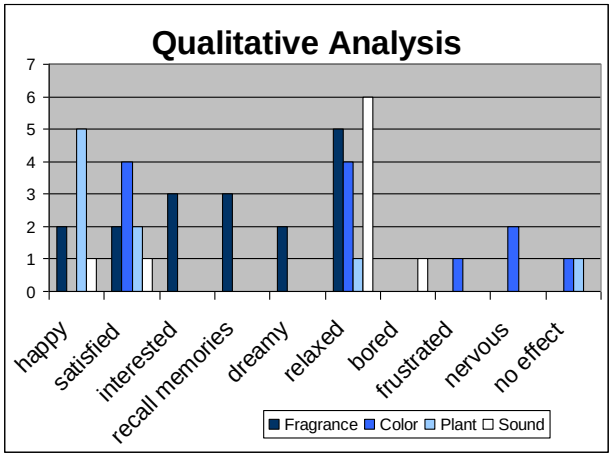

Fig.3: Diagram for the qualitative analysis of the Mars Habitability experiment at the MDRS. (© I.L. Schlacht 2010)

Table 1: Sensory experience mission 2010

Summary
Sound has a relaxing effect with statistically relevant results based on qualitative and quantitative analysis.

3.2 Habitability Analysis and Debriefing.

From the questionnaires, interviews, observations, and collective debriefings of *crew 91*, sensory experiences and creative performances were initially felt as an unclear goal, but were expected to become relevant for increasing habitability during long-term missions.

From the habitability debriefing at the MDRS, the following points emerged as the needs identified by *crew 91*:

- System automation and interface to manage system work maintenance.
- Storage system improvement (difficulties in finding the objects were a problem shared with the ISS station)
- EVA helmet visibility improvement (which could decrease frustration and increase orientation and confidence).
- From a social perspective, the crew felt the need for familiarity, friendship, and cohesion between the members. They concluded that knowing each other before the mission may be relevant. Some problems were due to language and cultural differences; however, these problems led to a discussion that increased crew familiarity and cohesion. For comparison, the Mars Habitability Experiment was also performed by a crew composed of friends from the same country and university: *crew 94*.

Crew 91 experienced a positive mood and cohesion in particular following daily sugar consumption and sports activities; in particular, eating Nutella® and performing push-up exercises with background music became a new social ritual. As one of the goal achieved, the Mars Habitability Project increased the consciousness and knowledge of *crew 91* regarding habitability factors.

Table 2: Habitability debriefing mission 2010

Crew 91	Problem	Solution
Operational IVA	System management (e.g., potable tank water level, diesel and propane tank level, grey water level	Better interface layout
	System maintenance (e.g., toilet and green house system)	Automation
Operational IVA	Object finding	Improvement of the storage system with inventory documentation check list to be performed by each crew
Operational EVA	EVA visibility	Helmet improvement
Physical	Missing of meat	Increasing of meat
Social	Lack of cohesion between the crew	ex. Life voice chatting ½ h once a week one month before the mission; eating Nutella and doing push-ups (gymnastics) together with background music
Debriefing	Increase awareness of mission problem and solutions.	

3.3 Creative Performance

The creative performance was done as a personal experience by Schlacht, who wrote in her report: "With an EVA I collected different kinds of sand that I found around the station. At the Hab I analyzed the different colors' properties and after some time, I decided to express myself creatively by making a color composition with them. Outside the habitat, in the simulated pressurized tunnel I just spontaneously began to create shapes with the different sands. The result was a kind of mandala, with local colored sand.

[2] The result analysis is based on the comparison between the questionnaire on the subjective rate feeling filled in before the sensory experience and the same questionnaire filled in after the sensory experience.
The resulting quantitative value from numerical questionnaires does not express a relevant effect on the overall subjective mood. In fact, the Wilcox test for non-parametrical samples gives resulting values higher than 0.05. The qualitative data from open question questionnaires show how the effects of the stimuli were perceived. The most evident effect is related to natural sound interaction for its relaxing effect; also evident are the memory and relaxation effect from the interaction with fragrances, the positive effect from plants, and the feeling of satisfaction from the colors (Schlacht et.al, 2010b).

The mandala shape was a spiral like a galaxy configuration; I called it Gaia. As a matter of fact, I could feel that putting my inner emotions into the external artistic "vase" helped to release tensions and implement the feeling of satisfaction. In the crew, no interest was shown for the mandala and it did not prompt any discussions." (Schlacht, et al. 2012)[3].

3.4 Growing Plants: Sprout Study

Research was done on growing sprouts and on taking care of an ivy plant. One batch of sprouts was cultivated for two weeks. The batches were not considered edible by the crew, but the personal feeling of growing and sharing a plant was satisfying. Also, the crew was interested in the sprouting process of the seeds.

The ivy plant was used both for the sensory experience research and for the investigation on how to increase the psychological well-being done by Scott Bates. The results indicate that different forms of life may help to increase the quality of life in isolation; for example, older people in nursing homes who need to take care of plants live longer. The results were used as a basis of comparison for the Mars 500 mission as the effect is supposed to increase with mission duration.

4. SPACE MISSION 2011

During the 2011 space mission, the experiment was performed by three crews and implemented by Ayako Ono under the coordination of Irene Lia Schlacht. In particular, for comparison we report the results from crew 100A, where the investigator was directly present in the crew. The crew was composed of four males, two females, aged between 20 and 37 years, all healthy and students in the space field; three were French and three were mixed nationalities.

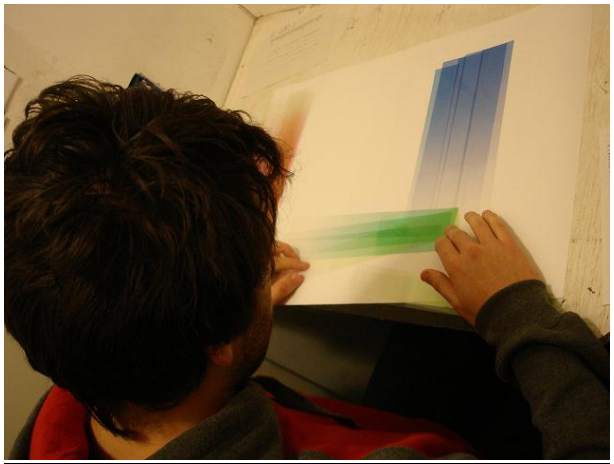

Fig.4: Crew member creating a color composition with color gradation strips during the two weeks of space mission simulation at MDRS 2011 (© A. Ono 2011)

4.1 Sensory Experience against Isolation

During the 2011 space mission, the methodology was based on the psycho-physiological interrelationships with the measurements of saliva amylase, blood pressure, pulse, heart rate, and electrocardiogram, and on questionnaires to measure mood states (POMS, Profile of Mood States; STAI, State-Trait Anxiety Inventory; and original questionnaires), in addition to a collective crew debriefing on the habitability experience.

The subjects were five people from the ILEWG EuroMoonMars *crew 100A* (four more people were added from *crew 100B* for the natural sounds test).

High-quality headphones (ATH-AD2000; Audio-Technica, Tokyo, Japan) were used to listen to nature sounds played from a player (iPod Shuffle; Apple Inc.). A handmade coupler and a sound calibrator (NC-74; RION, Tokyo, Japan) were attached to the headphones and the sound from the headphones was recorded by a digital audio tape recorder (TCD-D100; Sony, Tokyo, Japan). Several types of environmental noise were also recorded by the recorder via the sound calibrator.

Although further analysis is necessary, a primary screening of the results indicated that many people reduced saliva amylase and pulse during the stimuli, except for color gradation and Copy & Mirror[3]. Also, there were some changes on the Profile of Mood States before and after the natural sounds (which included a comfortable stream sound with an occasional bird call), even if the participant said "I didn't feel any changes."

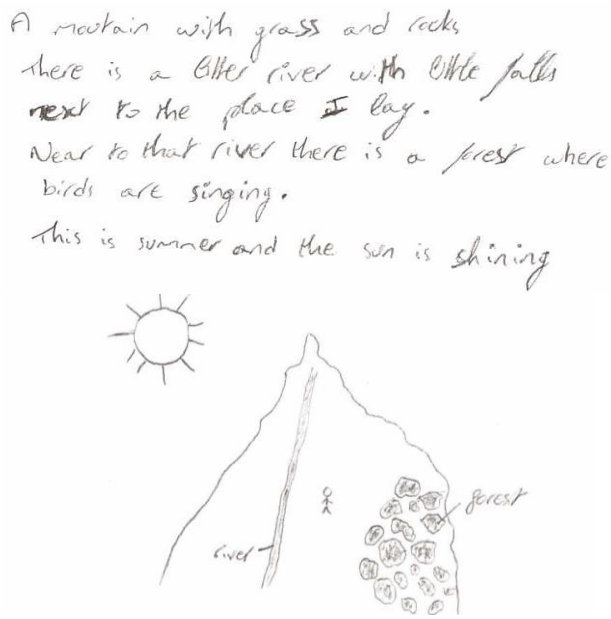

Fig.5: Composition made listening the natural sound (sensory experiment 2011 MDRS).

[3] Example of Tasks:
P) PLANT (ivy plant /lierre plante)
Interact with the plant, make sketches and free notes on A4 white paper. Please hold it, smell it, touch it. Investigate consistency, colors, shape, personal feelings, textures.
P.1) Were there any changes when touching and interacting with the plants? X Yes / □ No
If yes, how does this stimulus make you feel? More relaxed, cozy.
S) NATURAL SOUND (CD – Music player): Start time 11:30+ 10 mins = 11:45. End time
Close your eyes, relax your body, and imagine a beautiful natural environment during the sound. Listen to it for 10 minutes. And interact taking notes of or drawing what you perceive on a sheet of A5 paper while continuing to listen to the sound.

Table 3: Sensory experience mission 2011

Summary
Plants, smells and sounds had a relaxing effect, reducing saliva amylase and pulse.

4.2 Mission Debriefing

Through the debriefing workshop, we could learn about the constraints imposed by space environments. We found some problems such as environmental noise, too many tasks, low-quality radio, uncomfortable bathroom, and so on. We then focused on the possible solutions, including improvement of communication systems, quality of the food and cooking, and how jokes, hobbies, and sports can be helpful to uplift your mood state. During free time, there were also cultural activities. Crew members were listening to music during meal times; watching movies after the sorrow of watching one of the members leave, cooking. Some of the crew members liked to sing, and there were some artistic activities.

Table 4: Habitability debriefing mission 2011

Crew 100A	Problem	Solution
Operational, physical and environmental	Environmental noise, overloading of tasks, low-quality radio, uncomfortable bathroom…	Improvement of communication systems, quality of the food and cooking
Psychological	Mood state	Jokes, hobbies (music, singing, movies), and sports

4.1 Creative Performance

As a creative performance, Ayako Ono took pictures and wrote a poem:

Complete Darkness

After everybody went to bed, I went outside of MDRS.
It was cloudy that day.
I started out being scared without any stars above nor the Moon.
After a little while, I felt the Moon through the clouds.
Soon afterwards, I also felt the existence of the bright stars through the clouds.
Then, darkness was not darkness anymore.
Darkness need not be scary.
Darkness is just the opposite side of the lighting.
Our body is always adjustable and flexible.
We can feel more and more.

She reported "Before the creative performances, I was excited, and after that, I had fun and satisfaction, but felt I had to have more time to do them again. Such preferences and hobbies could combine people who have similar interests. Also, the poem and photos could be shared by all crew members. I think that the creative activities and positive feelings are important for quality of life and well-being in isolation and during space missions, because the missions could be stressful with isolation and many other stresses" (Schlacht, et al. 2012)[3].

4.2 Growing Plants

The research with plants was performed as part of the sensory experience. The drawings composed during a timeframe of ten minutes given to interact with the plants tactilely show great creative performance; the crew members drew and wrote about nature and relaxing surroundings, escaping from the MDRS reality of isolation in the desert.

5. SPACE MISSION 2012

During the 2012 space mission, the habitability research was performed by Valentina Karga under the coordination of Irene Lia Schlacht. She added to the research the sprout study as well as sustainability research, performed the debriefing and did the creative performance. The sensory experience was not scheduled anymore as sufficient data had been collected during the previous mission and the conclusion was that the experiment needed to be performed in a long duration mission (more than two weeks) for data comparison. The research was performed on crew 113 with one female and five males, aged between 19 and 26 years; four were French and two were mixed nationalities.

5.1 Debriefing

As reported by Karga, during the debriefing a clear problem emerged: an inhomogeneity of the crew member variety: four of the crew members, including the commander, were all French and colleagues from the École de l'Air, with an average age of 21 years (19, 20, 21, 26), while the other two crew members were Belgian and Greek, respectively, both 26 years old and not French speakers. As a consequence of the strong internal connection among the French group, which composed the majority of the persons, this group led the result of the debriefing, which is summarized below with the problems followed by proposed solutions:

Problem 1: Private space (no storage place for the baggage, more flexibility and space needed in the quarters)
Solution 1: Better cabins, more ergonomic, more storage space

Problem 2: Bad space management (partly because of the dust, and unnecessary things left from previous groups)
Solution 2:
- Remove unnecessary stuff from the laboratory,
- Increase the heat in the Hab (to work on PCs)
- Insulate the floor in the lab
- Put collapsible furniture and desks everywhere, in particular into lab, bedroom, and on the work floor

Problem 2: Language and personal habits (majority of one language group created communication barriers to the rest of the crew)
Solution 2:
- Acceptance of communication barriers and understanding

- More mixed teams, mix nationalities and genders

Problem 3: Bed air quality, dusty (you breathe the dust, no aeration system)

Solution 3:

- Periodic cleaning service to maintain and wash the Hab (too much dust)
- Integrate plants to produce oxygen

Problem 4: The food is according to American standards

Solution 4:

- Adapt the food to the crew, considering differences between Europeans and Americans
- Integrate different meals from European and American cuisines, and study the habits of the people better
- More nutritional food (increase the quantity of European Nutella, as it is more nutritious in comparison to American peanut butter)
- Powder is better (food for mountain climbers in powder form is better than the precooked food offered at the MDRS)

Extra consideration:

- Integrate a drinking system into the suit (have drinking bottle for use in EVA)

These considerations have a cultural background that may be easily associated with a group of French males about 21 years old. Considering that the MDRS facility is made to support also this kind of target group, the debriefing is a good start point to understand this target group's needs to increase the habitability level during a mission.

Fig.6: Habitability debriefing at MDRS 2012 (© V. Karga 2012)

Table 5: Habitability debriefing mission 2011

Crew 113	Problem	Solution
Operational IVA	Space design, e.g. small quarters, cold environment, low air quality	Better layout, e.g. increase private storage area, insulation, plants to produce oxygen
Social	Communication barrier caused by dominance of French language group	Avoid cultural dominance with mixed crew
Cultural and physical	Food according to American culture	Increase variability of food and nutritional level, e.g. with more Nutella

5.2 Sustainability Research

After brainstorming with the crew, we developed plans about how to improve the MDRS simulation by implementing more low-cost custom-made systems that are already being used on Earth. Sufficient photovoltaic panels could cover the needs of the Hab and the ATVs, which should then become electric. A solar cooker could save electric energy in this sunny climate. Rainwater could be collected from the roof and, if combined with a sand-algae filter, could become drinkable. The crew uses a dry toilet. Both liquid and solid waste are fermented anaerobically separately and become compost to be used in the green Hab to grow edible plants. All organic waste becomes compost as well. In a next step, the urine could be treated in order to become potable water again. Water, which is used in the kitchen and the shower, could be purified in order to be used again (Karga, 2012)[4].

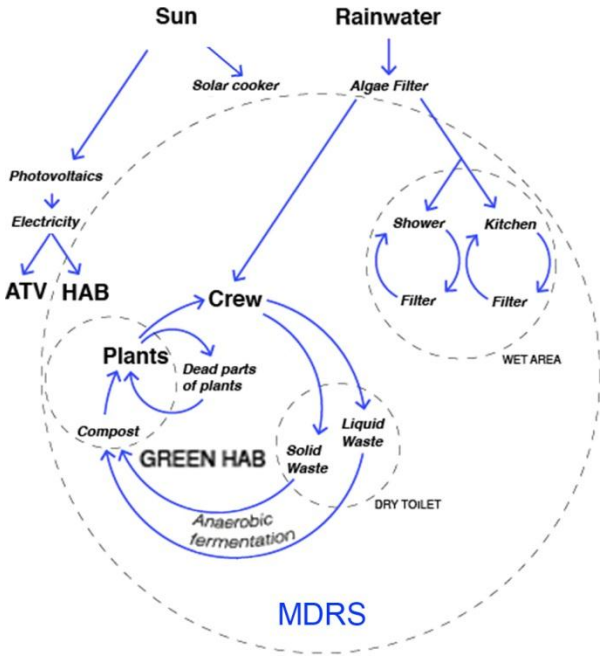

Fig.7: Brainstorming on sustainability at MDRS in 2012

5.1 Growing Plants: Sprout Study

Under the coordination of Jean Hunter, research was done on growing sprouts. Two batches of sprouts were cultivated, one during each week. The time spent on the process and the water required were both monitored. The crew evaluated the sprouts according to smell, appearance, and taste. Both batches were considered edible, but the results of the second batch were more satisfactory. Also, less water and time was

spent the second time. The crew noticed that it was nice to eat something fresh.

5.1 Creative Expression

Creative expression was performed by two crew members, the experiment referent Valentina Karga and the crew artist, Pieterjan Grandry. Here we report a summary of the performance as described in the paper "A field study on the role of art in space exploration" (Schlacht, et al. 2012)[5].

Valentina applied her creative expression to the preparation of food. She sees a social ritual in communal dinners, something that can be important for a Space mission. She felt that she had to develop a new language of cooking with the unusual dehydrated or freeze-dried ingredients. As her creative performance, she filmed a series of cooking shows for Mars and experimented with cooking both inside and outside the Hab. Outside the Hab, she cooked during EVA with a solar cooker that made use of the site with available materials. By being playful and creating something from the given restrictive parameters (in this case the food), she tried to open a window through the rules and create a personal language inside the impersonal system of the habitat. The prepared meals were shared with the other crewmembers. The crew seemed to appreciate the effort but was not so intrigued as to also be creative with food.

*Fig. **8**: Solar Cooking in Mars EVA, creative performance task (© Valentina Karga, 2012).*

The result of Pieterjan creative performance is reported by him in the following. He wrote: "If you are for 2 weeks in a closed space where everything is controlled and organized around you I think one starts to feel the need to create something where one has total control over. It is more a manifestation of creativity than a work of art. The act of creating (like God) distracts us from our daily routines and (like a dream) we can create a micro world of our own. During my time at MDRS I did not schedule a specific time for artistic expression. Creativity gets evoked in a moment, by objects, persons, smells, tastes or touch. A found object on one of the EVA's drew my attention and a few meters further I found another (it is very unlikely to find 2 non-native objects in an empty desert-like environment in such close distance). Combining both they form a flag, which holds historical connotations with conquering and marking land, such as planting a flag as symbol of achievement or landmark (ex. planting a flag on the moon). The act of creating in a non-forced, spontaneous way relieves one, in this scenario, from a certain pressure. When failing is not an option and working pressure is high this could be a way to ventilate and stimulate one's mind".

6. CONCLUSION

Astronauts are required to approach problems creatively and adaptively in space exploration, because space explorers face the unknown. However, in long duration missions, in isolation and confinement in a completely artificial, controlled and monotonous place, psychological and physical stressors, like boredom, depression, and insomnia (Kanas & Manzey, 2010)[6], can negatively affect the performance of cognitive and creative tasks. Those stressors are those that are related to the level of habitability during a space mission.

In 2010, 2011, and 2012, the Extreme-Design Research Group performed the Moon-Mars Habitability project during the EuroMoonMars mission campaign simulation of ILEWG at MDRS to analyze and improve the level of habitability. The project verified that a space habitat system with varied sensory and creative stimulation may result in giving "a break on the routine" (observation by crew 91 member) improving the quality of life and, as a consequence, sustained performance, well-being, and reliability. This would increase overall habitability and further facilitate and maintain the mental activity necessary for the performance of research and for exploration duties. Moreover, in order to improve habitability, the needs of the crew need to be investigated from a operational, psychological, socio-cultural, physiological, environmental perspectives.

Table 6: Habitability debriefing mission 2010-1-2

Crew 91, Crew 100a, Crew 123	Common key words used during debriefing regarding problem and solutions
Operational, psychological, socio-cultural, physiological, environmental, factors	Food (Nutella) 91 100 113 Communication 100 113 Storage 91 113 Layout 91 113 Toilet 91 100 Music 91 100 Gymnastics 91 100

These parameters were discussed by each crew analyzing the problem and possible solutions. The debriefing discussions were performed at the end of each mission. Food was mentioned as a key word by each crew, in particular Nutella was mentioned by two crews.

Another result was that the MoonMars Habitability Project also increased the crew's awareness and knowledge regarding habitability factors and their relevance.

Considering that habitability will become even more important in long duration missions, this research provided some baseline data and a methodology for further investigation in long duration missions.

ACKNOWLEDGMENTS

The EuroMoonMars 2010-2012 campaigns were organized and supported by the International Lunar Exploration Working Group (ILEWG), NASA Ames Research Centre, Vrije Universiteit Amsterdam, and École de l'Air. We acknowledge the contribution of the EuroMoonMars campaign crew and the mission support team.
Funding and support were provided by: The Mars Society, ILEWG (sci.esa.int/ilewg), ESA ESTEC, NASA Ames, École de l'Air, SKOR, Extreme-Design (www.extreme-design.eu), Università di Torino (www.unito.it), MMS Berlin Technische Universität (www.mms.tu-berlin.de), DAAD, Space Florida, University of Utrecht.
We would like to also thank all the other people and institutions involved.

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Contact Details of IAC Presenter

- Irene Lia Schlacht: irene.lia.schlacht@gmail.com
IT: +39 320 3168 723 DE: +49 0176 3588 2695

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